Study on
Identification of the best Biodigester Model for Lao PDR

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1. INTRODUCTION AND BACKGROUND

In the framework of the Asia Biogas Programme (ABP) co-financed by the Directorate-General for International Cooperation (DGIS) of the Dutch Ministry of Foreign Affairs, the Netherlands Development Organization (SNV) aims to facilitate the setting-up and the implementation of pilot project on domestic biogas in Lao PDR. As the most appropriate partner for this, the Lao Ministry of Agriculture & Forestry (MAF) has been identified, more in particular the Department of Livestock & Forestry (DLF) and/or the National Agricultural & Forestry Extension Services (NAFES).

The overall objective of proposed Biogas Pilot Project (BPP) is to properly introduce domestic biogas in the rural areas of Lao PDR resulting in a significant improvement of the quality of life of the families and their environment concerned.

The tentative specific objectives contributing to its overall objectives are:

- To construct 6,600 family sized quality biogas plants in selected provinces during the period 2006 through 2009;
- To ensure the continued operation of all biogas plants installed under the BPP;
- To maximize the benefits of the operated biogas plants, in particular the optimum use of digester effluent;
- To develop in-country capacities for further wide-scale deployment of biogas digester technology in Lao PDR.

To successfully achieve the objectives, it is imperative that the best suited model/design of biodigester is selected for the wide-scale dissemination. Varieties of models/designs of biodigesters are being used in different countries in the world with successful track records. Even in Lao PDR, models like Plastic Tunnel, Lao-GTZ and Chinese fixed-dome, are in use. SNV Lao PDR envisages selecting the best model for the wide-scale dissemination of the biodigester technology in the country and proposed a study to come into a conclusion.

2. OBJECTIVE OF THE ASSIGNMENT

The main objective of this assignment is to select the most suitable and appropriate digester type for the proposed Biogas Pilot Project in Lao PDR, prepare quantity and cost estimation of the selected model, develop training materials and formulate training programme.

3. EXPECTED OUTPUT

The following outputs were expected by the end of the assignment:

- A digester design has been selected,
- BoQ (quantity and cost estimation) for different sizes of digesters (4, 6 and 8 Cubic meters) is prepared,
- Training materials (Mason's manual, Supervisor's Manual, Training Curricula and Guidelines to Trainers to conduct Mason's and Supervisor's Training, and Presentation slides for the training) are available, and
- A training program is designed.

4. METHODOLOGY

The following activities were carried out during the course of the assignment:

- Review and study various secondary data and information (reports and documents) related to domestic biogas in Lao PDR and other countries;
- Review/observation of existing biogas plants constructed in Lao PDR so far (Ban Nong Phouwiang and Ban Xok – Chinese design and Thai/German design in Vientiane and the north of Lao PDR) and assess the general physical status and functioning of these plants
- Propose an appropriate design of biogas plant for the BPP based upon the observation of existing digesters as well as review of secondary data and information including the "Evaluation Study for Biogas Plant Design" prepared for Cambodia" and "Identification of Appropriate Design of Biogas Plant" prepared for Bangladesh.
- Consider installation and operation and maintenance costs, structural durability, easy to construct using local labour, availability of construction materials at the local level, easy to operate and maintain, existing physical status and functioning, user's level of satisfaction as main criteria for the selection of the best design;
- Based upon the design chosen, prepare a "Bill of Quantities" for different sizes of the digester chosen.
- Prepare training materials and develop a training program to train digester constructors (masons, supervisors, etc.)

5. LIMITATIONS

The study has used the existing data and information related to design and installation of domestic biodigesters – 'the desk study' as the main tool. Observation of some biodigesters installed in various parts of the country has been made to collect primary data and validate the existing information. Various data and information are borrowed from the experience of other countries with similar socio-economic and geographical conditions.

6. MODELS SELECTED FOR ANALYSIS

The following factors have been considered to select the type of biodigester for detailed analysis:

- Models presently in use at the local level
- Models not in use at the local level but are being widely used in other countries with similar socio-economic and climatic conditions
- Models with proven track records of successful operation

Based upon the above mentioned criteria, the following models have been selected for in-depth analysis:

a. Chinese fix-dome model being installed in Laos under Chinese grant aid
b. Vietnam Model (KT2A) being disseminated by Biogas Programme supported by SNV
c. Cambodian Farmer's Friend Model (Modification of Indian Farmer's Friend Model) being disseminated by National Biodigester Programme, Cambodia supported by SNV
d. Nepalese GGC Model being installed under the framework of BSP-Nepal supported by SNV

e. Model constructed in Laos under the framework of Canada-Thailand Trilateral Environment Sub-project popularly known as Lao-GTZ model

While selecting these models it is assumed that the biodigesters are intended for domestic use, mostly in rural and semi-urban areas with families having at least 2 or more cows/buffalo or 10 or more pigs.

7. CRITERIA FOR EVALUATION

The following factors have been considered to evaluate the biodigesters under the study assuming that the suitability of any biodigester in a given context depends mainly upon these factors.

a. Climatic and geo-physical parameters

- Ambient temperature
- Geo-physical conditions of the soil
- Condition of ground water-table

b. Technological Parameters

- Structural strength against different load conditions (structural durability)
- Methods of construction
- Methods of operation and maintenance
- Applicability/adoptability of the design in different geographical context for mass dissemination
- Prospects for sharing of technical information and know-how

c. Affordability of potential farmers to install biodigester

- Availability of construction materials
- Availability of human resources (skilled and unskilled) at the local level
- Cost of installation, operation and maintenance
- Transportation facilities

d. Purpose of the use of the biodigester products

- Use of gas for cooking, lighting and/or operating a duel-fuel engine
- Use of slurry as organic fertiliser

e. Performance of existing models, if any, in the local and/or regional conditions

- Existing physical status and functioning
- User's level of satisfaction

f. Quality and quantity of available feeding materials

- Type of feeding materials (cattle dung, pig manure, human excreta etc.)
- Availability of water for mixing
- No. of cattle/pig per household

8. EVALUATION OF SELECTED MODELS

8.1. Climatic and Geophysical Conditions

8.1.1. Ambient Temperature

About 70% of the total area in Lao PDR falls under hilly and mountainous terrain with a maximum elevation of 2,820 m from the mean sea level. Lao PDR enjoys a tropical climate with two distinct seasons – the rainy season from May to September and the dry season from October through April. The annual average temperature is about 28° C, rising to a maximum of 38° C and a minimum average of 14° C. However, temperature may drop to the freezing points to some areas in the mountainous regions in the north during cold nights.

It has been experienced that quantity of gas production decreases during the cold months. The major cause of declination of gas production has been the higher differences of minimum and maximum temperatures inside the digester during the day and night times; but not solely the lower ambient temperature. Therefore while selecting biodigester for Laos, care should be given to select those model which does not allow much fluctuation of temperature inside the digester during day and night times. Top filling over the gas-holder is important consideration in this case. The more the depth of top-filling over the gasholder, the less fluctuation of temperature inside the digester. The ratings of biodigesters based upon the depth of top-filling over dome are somewhat similar to Farmer's Friend, Chinese and GGC designs but less for Lao-GTZ and KT2A models. The top of gas holder are back-filled with a soil layers 50 cm in GGC model, 40 cm in Farmer's Friend Model, 37 cm in Chinese model, and 12 cm in KT2A model, however, the top of dome is exposed to the ground level in the case of the Lao-GTZ model. Moreover, not the whole area above the dome is covered in Lao-GTZ, Chinese and KT2A model as the manhole has to be kept visible to check the water seal. Therefore, the temperature fluctuation is expected to be less in GGC model followed by Farmer's Friend Model. Lao-GTZ and KT2A models may experience higher temperature fluctuations due to absence of insulation above the dome.

8.1.2. Geo-physical Condition of the Soil

The review of available secondary data and information reveal that the soil types in Laos in general is poor with most of the northern part consisting of shallow lateritic soils. Areas along the bank of Mekong River, which constitutes a large portion of the human settlements, consist of alluvial, silt, sandy and conglomerate soils. All of these types of soils have sufficiently enough bearing capacity to withstand the pressure exerted from biodigesters. However, the alluvial and conglomerate soil is not suitable for Chinese model biodigester which demands a vertical cutting of soil while digging the pit for digester construction. Because of the less cohesive nature of these types of soil, the sides of the soil-cutting have to be angled to some extent. This results in added concrete to fill the extra portion of the excavation. Lateritic soil is best suited for the Chinese Model plant.

8.1.3. Condition of Ground Water Table

Various literatures suggest that the ground water table in Laos fluctuates seasonally from 1.7 m to 5.0 m depending upon the flood level in Mekong River. Most of the hilly and mountainous regions have very low water table. Besides the few locations along the bank of the Mekong,

ground water is not a problem in Laos and therefore there is not much a need for structural modifications to safeguard the structure from the pressure of buoyancy. Therefore, whether the base of biodigester is flat or spherical or conical, it does not matter much. However, in flood prone areas along the Mekong, Cambodian Farmer's Friend and Vietnamese KT2A models have added advantages over Chinese, GGC and Lao-GTZ models.

8.2. Technological Parameters

8.2.1. Structural strength (structural durability)[1]

a. Inlet Chamber and Inlet Pipe

The outcome of a study carried out by ILI Consulting Engineers Mekong Ltd. suggested the fact that the structural design of inlet-pit and pipe is very good in KT2A model as the inlet tank is flat bottomed and the pipe is raised slightly above the flat base allowing the grits and soil particles to settle just below the intake. The Farmer's friend model has also the same provision. The use of plug at the entrance to the pipe adds safety against anything falling inside the digester. However, the inlet in KT2A model is designed to be constructed on the back-filled surface to gain the slope for inlet pipe. This adds the risk of cracks in the floor of inlet if the soil is not properly rammed before the construction. The inlet of Chinese design is prone to flood water entering into it as it is kept exactly at the ground level. Moreover, mixing of dung and water is rather difficult. The circular inlet channel passes through the concrete dome, weakening the structure of the dome and increasing the potential of gas leakage. The inlet tank of Lao-GTZ model is very small and congested. The inlet pit of Nepalese GGC model is enhanced with the provision of a mixing device to facilitate the through mixing of dung and water. Provisions of two inlet pipes in Farmer's Friend and GGC models are useful to attach toilet or convey feeding from pig-sty to the digester. However, this could be done in other designs with a small modification.

b. Digester, Gas holder and Manhole

As far as the structural design of digester and gas holder is concerned, Farmer's Friend models is better than KT2A, Chinese, GGC and Lao-GTZ models as it has a spherical structure that forms both the digester and gas-holder. Though the bottom is not spherical, KT2A, Chinese and Lao-GTZ Models have spherical digester and gas holders. There is no joint in between the digester and gas holder in the case of Farmer's Friend, KT2A, Chinese and Lao-GTZ Models. In the case of GGC and Chinese model; the gas holder is spherical and the digester is cylindrical. The digester and gas holder walls remain under compression in KT2A, Farmer's Friend and Lao-GTZ models and hence are less likely to suffer from cracks. If constructed properly, when the gas space of the fixed dome is under pressure, the forces will be evenly distributed at every point and therefore, will less likely to crack. However, the exposed gas holder as in Lao-GTZ model increases the risks of cracks in it due to temperature fluctuations and vandalisms.

A curved base as used in Farmer's friend model provides the best load bearing capacity owing to its shape. The conical shaped base, as used in KT2A and Chinese models can withstand higher

[1] This section of the analysis is based upon the outcome of the study carried out by ILI Consulting Engineers Mekong Ltd. for National Biodigester Programme in Cambodia.

loads than flat bottomed base as in the GGC and Lao-GTZ models. The bottom ring provided in the Lao-GTZ model provides better structural stability.

Both the Farmer's Friend and GGC plants are designed so the digester can be accessed through the outlet tank. However, the outlet tank needs to be emptied, for both models, in order to gain access to the digester. GGC model provides easier access to the digester from the outlet tank for removing grit. It is possible to stand at the outlet tank and 'rake out' the grit as the base of the digester is almost at the same level as that of the outlet tank. The actual opening for the Farmer's Friend is smaller than that of the GGC. The Farmer's Friend has an arched frame opening, providing support to the rest of the dome above it – it is more structurally stable than the opening created in the GGC, which is rectangular. Entry inside the digester to monitor the quality of construction especially the dome-plastering is very easy in the case of GGC. Though it is not very difficult in the case of farmer's friend model, person with added weight finds it difficult to enter into the digester because of smaller dimensions of the opening.

The Chinese, KT2A and Lao-GTZ models have manholes at the top of the digester, which are sealed to prevent gas leaks. However, they affect the strength of the dome structure, as the openings create inherent weaknesses and a latent risk of gas leakage. The Chinese Dome model has two access points – through the outlet and through the manhole on the dome – both of which are similar in size and smaller than the access points for the KT2A, Farmer's Friend and GGC models. A single opening through the outlet pit is sufficient access to the digester and additional large opening increases the probability for gas leakages, structural failure, and complicates construction.

c. Outlet Tank

The digested slurry is displaced to the outlet tank, also known as displacement/hydraulic/ compensation chamber, by virtue of the pressure of biogas produced in the digester and stored in the gas holder. KT2A and Lao-GTZ models have an outlet pipe that connects the digester and outlet tank, however, GGC, Chinese and Farmer's Friend models have no pipes and the outlet tank is directly attached to the digester with a provision of manhole. Lao-GTZ model has provisions of two outlet pipes. A pipe is more advantageous when trying to conserve heat within digester especially in cold areas in Laos. The outlet tank is circular in the case of Chinese, Lao-GTZ and KT2A models and rectangular in GGC and Farmer's Friend models. Circular structure is structurally sounder than the rectangular structure as the loads are evenly distributed in the surface. If proper back-filling is not provided, cracks may appear near the corners of the rectangular tank.

The outlet tank of KT2A and Chinese models are just below the ground level making it prone to flood water entering into it during the rainy season. It affects the water content of the slurry inside the digester which ultimately alters the Hydraulic Retention Time (HRT).

8.2.2. Methods of construction

a. Digging of Pit and Construction of Base

All the five models require considerable quantity of excavation. Excavation in Chinese, Farmer's Friend and KT2A are more complicated as these design requires spherical and conical base. Moreover, in the case of Chinese model, the walls of cutting should be vertical strictly

complying with the dimensions in the drawing – non-compliance to this will lead to more concrete to be poured to compensate the additional cutting. Non-cohesive soils like conglomerate, silt and sandy-silt need some angle of repose to withstand the cutting and hence Chinese model is not suitable in these types of soils. Likewise, the excavation work for Lao-GTZ biodigester also needs skills. In contrary, excavation in GGC model, which has a flat bottom, is simple and easy.

The base of Farmer's Friend model, although superior in its load bearing capacity is the most difficult to construct. The concrete base consumes more construction materials especially cement, sand and aggregates. The cone shaped base of KT2A, collar and ring base of Lao-GTZ and sloped bottom of Chinese models are also made from concrete and requires more skilled construction. The base of GGC is made from bricks bats or stone with a tick layer of plaster in the top. It is economical and easy in construction. This is likely to be more prone to cracks under uplift pressure in the case of higher water table.

b. Digester, Gas Holder and Manhole

The construction works do not consume much time to install Chinese model biodigester. However, the construction of digester wall and gas storage tank is relatively cumbersome. A heavy mould made up of pieces of the segments of a cylinder and sphere is used to facilitate the concreting work. The natural soil acts as a framework in the outer side of the wall. If excavation is done even slightly more than the necessary volume, it consumes more concrete. Moreover, erection of the framework needs skilled manpower. Transportation of framework is a very difficult task in areas without good road networks.

Likewise, construction of the digester wall necessitates input of a very skilled manpower in the case of Farmer's Friend, KT2A and Lao-GTZ models, however, it rather easy and simple in the case of GGC model. GGC model has the benefit of being suitable both for brick and stone masonry walls depending upon the availability of those construction materials. Farmer's friend, Lao-GTZ and KT2A models could not be constructed with stone masonry which is a serious drawback in the context of Laos where stone is easily available and widely used for construction. Use of hooks and counter-weight to prevent the freshly laid brick from falling down is a cumbersome task in the case of Farmer's Friend, KT2A and Lao-GTZ models. There is also a limitation on the number of layers of bricks to be laid in one day. Once cracks appear in the fresh masonry, the construction work has to be stopped to allow the fresh laid brick and mortar to set. It prolongs construction period. However, in the case of Chinese and GGC models, there is no such limitation.

The KT2A, Lao-GTZ and Chinese Dome models have a manhole on top of the dome and the curved top of the dome does not have to be constructed. However, the Farmer's Friend has a full dome, and scaffolding has to be erected within the dome to allow the top to be finished. The scaffolding is later removed through the outlet tank, but this adds to the difficulty in constructing the dome even though it will be more structurally stable.

The construction of dome-shaped gas holder is a cumbersome task for GGC plants. The dome for the GGC is made from concrete. The walls for the digester are constructed and filled with soil. The soil is compacted and shaped using a template with the correct radius. The concrete is then cast over the filling and the fill material (soil) is removed via the outlet pit once the concrete is set. This method requires more labour and less skill compared to the other fixed-dome models. The dome has a concrete collar – where the concrete is thicker at the point where it meets the

cylindrical walls. This requires more attention, similar to constructing the base for the Farmer's Friend, and if not constructed properly, the dome could be left susceptible to cracking and leakages. Templates have to be used to shape the soil mould; carrying of such moulds though not very difficult is an added job.

Similarly, the Chinese Dome model is more complex to construct as it has more openings in the digester than other models. It is assumed the chute for the inlet is constructed from bricks and formwork would have to be constructed within the dome to support it while it sets. Sets of reinforced covers would have to be constructed - for the slurry inlet, slurry outlet and gas outlet. In addition to this, it has a reinforced concrete ring around the digester, similar to the collar for the GGC, would require more attention.

All designs refer to different wall thickness and this variation can be attributed to the fact that each country or even region manufactures bricks of different sizes. The average size for the bricks made in Cambodia and Vietnam is 8.5cm x 4cm x 18cm (b x h x l) while it is 11.5cm x 7.5cm x 25cm in Nepal and . The sizes of brick widely available in Laos have the size of 8cm x 3.5cm x 17cm.

The Farmer's Friend, GGC, Lao-GTZ, Chinese Dome and KT2A are plastered properly from inside. The Farmer's Friend model also specifies plastering the dome on the outside. This increases the comparative cost minimally, but the benefits of having a 'leak-proof' digester which resists plant-roots from penetrating outweigh this cost. All the fixed-dome models require applying gastight paint.

Lao-GTZ, Chinese Dome and KT2A models have more than one joint in the gas conveyance pipe in between main gas valve and dome gas pipe which makes plant more vulnerable to leakage. It is very difficult to maintain leakage through the joints in this length of the pipe system. GGC and Farmer's Friend models have only one joint in between the dome gas pipe and main gas valve.

Once the digester has been constructed, the area around it needs to be back-filled. The pit, excavated to construct the digester, requires backfilling and compaction in order to counter the hydrostatic pressures from within the digester. Since the GGC has vertical walls, the trench dug to construct it requires a smaller amount of backfilling. Chinese model do not need backfilling against the digester walls as the digester wall is supported with the undisturbed soil and all the excavated portion is filled with concrete. All the models require a soil cover because of the gas pressure inside the dome. The design for the GGC and Farmer's Friend models recommends placing compacted earth on top of the dome, the ceiling of which is at ground level, as seen in the picture in Appendix 1. This reduces the depth to which the pit has to be excavated, as the counter weight is added above ground level. The same principal can be applied to the other models. However, the Chinese Dome model has both inlet and outlet below the ground, which can pose a problem in flood prone areas, as discussed above.

c. Inlet and Outlet Tanks

It is recommended that the inlet tank be constructed on 'undisturbed soil' to prevent settlement from unconsolidated soil. This is not an issue with the Chinese Dome model, but poses a problem with the KT2A model where the inlet tank is constructed on backfilled soil in order to gain a steep angle on the inlet pipe entering the digester. The circular inlet fitted with a mixing devise in the case of Farmer's Friend and GGC models has an advantage for easy operation and

quality mixing. The inlet of Chinese model is prone to flood water entering into it. The inlet tank of Lao-GTZ model is very small posing a problem to mix dung and water effectively.

The outlet tank also known as displacement/hydraulic/compensation chamber is circular in the case of Chinese model. For KT2A and Lao-GTZ models, it is a dome shape and is more complex to construct when compared to the other models. The outlet tank is rectangular for GGC and Farmer's Friend models. Circular chamber consumes slightly less construction materials, covers less area and risk of dead volume at the corners are minimised, however, the difficulty in construction is often complained by the masons as its drawback. The circular tank is slightly difficult to build in comparison to the rectangular one.

The overflow opening in the outlet of Lao-GTZ, Chinese and KT2A models is either on the ground level or below it posing serious problem of rain water entering into the outlet tank. Moreover, natural flow of slurry from outlet to compost pit or the disposal area through gravitational force is difficult. A drain or channel has to be constructed. However, in the case of GGC and Farmer's Friend model, the over-flow opening is slightly above the natural ground level to facilitate the slurry flow by gravity. The raised wall of outlet tank to facilitate the flow of slurry necessitates proper backfilling in the outer surrounding of walls to counteract the pressure exerted by the slurry in the tank.

8.2.3. Operation and Maintenance

a. Operational Activities

Operation activities in all the designs under study are quite similar. In the case of plants that supply the feeding material direct to the digester such as Chinese and Lao-GTZ models, care has to be provided not to add more water to flush the cattle dung/pig manure from stable to the digester. There is also likely that grits and other foreign material may enter into the digester which may cause scum layer in the top or dead volume in the bottom. Such risks are minimised in Farmer's Friend, KT2A and GGC models constructed with a mixing tanks (inlet tanks) as those materials could be sorted out during mixing. However, it adds more labours as the dung has to be collected and deposited into the inlet tank prior to mixing.

Digested slurry flows out of the displacement chamber (outlet tank) through overflow opening located at opposite side of the dome in the shorter wall of the outlet tank. This opening is prone to clogging due to dried slurry. This dried slurry has to be removed from time to time to facilitate the continuous flow of slurry. If some portion of the opening is blocked with dried slurry, it will increase the volume of the outlet tank. Increase in volume of outlet will pose serious problem in the functioning of biodigester as it will result in serious complications. One of these complications is the problem of slurry in the pipeline. Therefore, the users should maintain the overflow level clean from dried slurry at all time. Regular inspection of this opening is therefore necessary. Cleaning of this overflow opening is easy in the case of GGC and Farmer's Friend models as the opening remains above the ground. However, in the case of Lao-GTZ, KT2A and Chinese models, the opening is designed to be placed below the natural ground level. Regular inspection and cleaning of the clogged opening in these designs needs more care than the other two models.

It is likely that a scum layer is formed in the digester because of the inert materials that float in the surface, like straw, hard or dried dung etc. This layer obstructs the flow of gas from digester

to gas holder. The gas produced in the digester could not penetrate this layer to reach the gas holder and therefore, escapes out of the manhole opening to the outlet and ultimately to the atmosphere. If the quality and quantity of feeding materials are proper, this problem never arises. However, it is likely that a scum layer is formed on the top of the slurry level in the digester. This unwanted layer of scum has to be broken/removed to facilitate the natural flow of gas from digester to the gas holder. This could be done by stirring the slurry inside the digester with the help of a rod or bamboo or pole inserted through the manhole opening. Breaking of scum is difficult for KT2A and Lao-GTZ models as this models have manhole from the top. The entire gas collected in the gas-holder has to be emptied to facilitate the removal of scum layer. The work is easy for GGC model. For Chinese and Farmer's Friend model, the task is easier than KT2A and Lao-GTZ models but more difficult than GGC model.

b. Maintenance Activities

The life-span of the biodigesters under the study is generally 20-30 years depending upon the quality of construction and effectiveness of operation and maintenance activities. Minor maintenance works are similar in all the five models. Depending upon the feeding materials used, the biodigesters need cleaning and over-hauling from inside. Experience in the field has shown that the quantity of gas production decreases over time, typically 10 years after the installation. Digested slurry and other grits and soil accumulate in the bottom of the digester creating 'dead zones'. These dead zones decrease the effective volume of the digester which in turn decreases the retention time. This necessitates the cleaning of digester to eliminate the dead zones which requires the emptying of digester.

As mentioned earlier, access to digester is relatively easy in the case of GGC, Farmer's Friend and Chinese models, as these models have manhole attached with the outlet tank. However in the case of Lao-GTZ and KT2A model or even Chinese model the access to digester is from the top of the gas holder. Breaking of the seal at the manhole is a cumbersome and time consuming task. Once the maintenance work is completed, the manhole needs to be resealed to ensure its gas tightness. The manhole requires regular monitoring to ensure the clay seal is still intact and there is sufficient water to ensure that the seal does not dry and crack.

The whole structure in the case of GGC and Farmer's Friend model could be buried under the ground leaving the surrounding of biodigester clean. However, this is not possible for Lao-GTZ, Chinese and KT2A model as the water seal on the top of the gas holder should be visible always. This also increases the risk of mosquito breeding.

8.2.4. Applicability/adoptability in different geographical context

Applicability/adoptability of any design to different geographical context is important for wide-scale dissemination of biodigester technology in Laos. The geographical condition and there by the availability of construction material, transportation facilities etc. varies considerably in different parts of Laos. Farmer's friend, KT2A and Lao-GTZ models are more suitable in areas where the supply of sand, cement and brick is not a problem. However, Chinese model, which is constructed mostly with concrete, is suitable in all locations where the supply of cement, sand and aggregates is not a problem; however it requires transportation of moulds in a truck or tractor. The GGC model could be constructed both in brick and stone masonry works. This is an added advantage in the context of Laos where stone as construction material is widely used especially in the northern hilly districts because of their abundance and cost effectiveness.

Transportation of bricks in these areas may be a problematic job, which may increase the cost of installation too.

8.2.5. Prospects for sharing of Technical Information and Know-how

The three models being disseminated under the Asia Biogas Program namely KT2A in Vietnam, Farmer's Friend in Cambodia and GGC in Nepal have a long proven track records of success. An ocean of information and know-how exists on R&D of the models which could be transferred in Laos. The Chinese Model though used widely in China, have little information, especially on R&D to share. Lao-GTZ model has been installed in a considerable numbers in Thailand; however, little information is available on its functioning.

8.3. Affordability of potential farmers to install biodigester

8.3.1. Availability of construction materials

The main construction materials needed for the Farmers friend, KT2A and Lao-GTZ models are Brick, sand, cement and aggregates. Sand and aggregates are mostly available in all parts of the country. However, bricks and cement have to be transported in rural areas from farther distances. Chinese model needs cement, sand and aggregates as the main construction materials. It needs slightly more quantity of cement than other models. GGC model could be constructed either with cement, sand, brick and aggregates or stone in place of brick. This model provides better flexibility as bricks and stones can be used supplementary to each other as per their availability in a particular location. Cement, which is the main construction material for GGC plant, has to be transported from the road-head to the construction sites.

8.3.2. Availability of human resources at the local level

Construction of biodigester of any model needs both skilled as well as unskilled labours. However, Farmer's friend, KT2A, Lao-GTZ and Chinese designs needs more skilled persons than GGC and model. There are some skilled labours in the market to install Chinese model and Lao-GTZ model plants. A thorough training is needed to produce skilled masons to construct GGC, KT2A and Farmer's Friend models of biodigester. Farmer's friend model requires more skilled personnel than any other model.

The Farmer's Friend model requires slightly more labours to fix the curvature in the bottom more carefully than other models. GGC plants need more labours to fill the digester with soil to prepare mould for concreting the gas holder and take the soil out once the concrete is set.

8.3.3. Cost of installation, operation and maintenance

Cost of operation and maintenance does not vary much for all the models of biodigesters under study if operational activities are carried out as specified. Hence the cost of installation is the major factor to assess the suitability of biodigester from financial point of view. Therefore the cost of installation plays an important role in selecting biodigester for mass dissemination.

Installation of biogas digester in Lao has been limited to some pilot demonstration plants constructed either in the institutional premise like in Champasak, Huanpan and Xiengkhuang or private households, probably that of village head or government officials, like in Savannakhet. All the investment costs were provided by the project and therefore the owner had nothing to do with the cost of construction. However, the costs of construction of these plants are found to be beyond the capacity or affordability of small and medium farmers in Lao. These so-called demonstration pilot plants could not attract any neighbors to install biogas plants and the main reason for this could be attributed to the higher cost of construction.

A cost comparison has been made for biodigesters that are very similar in size and have a plant volume of 6 cubic metres. However, in the case of Lao-GTZ model, the cost has been calculated for 8 cum size and assumption has been made accordingly for 6 cum plant. For the structural parts made up of brick masonry, dimensions relating to Laotian brick sizes of 17 cm x 3.5 cm x 8 cm have been used.

The following table shows the comparative cost of installation of 6 cum size biodigester.

Table-1: Cost of Installation of Biodigesters

Biodigester Model	Estimated Cost of Installation in USD*	Actual Cost of installation as responded
Chinese fix-dome model	246	400
Vietnam Model (KT2A)	267	
Cambodian Farmer's Friend Model (Modification of Indian Farmer's Friend Model)	293	
Nepalese GGC Model	270	
Model constructed in Laos under the framework of Canadian Project (Lao-GTZ Model)	373	500

** Costs of transporting of construction materials and other tools and equipment such as moulds in the case of Chinese design are not included in the calculations.*

As shown in the table above, Chinese model biodigester is the cheapest in terms of installation costs. Lao-GTZ model is the most expensive. The costs of KT2A, GGC and Farmer's Friend do not differ much. Cost-wise, Chinese model has an advantage over other models.

8.3.4. Transportation Facilities

Modern transportation facilities are lacking in the rural areas of Laos, especially in the northern parts of the country. KT2A, Lao-GTZ and Farmer's Friend models are constructed in brick masonry. It is likely that brick may not be easily available in all the locations and one has to transport it from the nearest kiln. Keeping in view the present situation of transportation networks, Chinese model biodigesters may be less suitable for rural areas as it requires heavy moulds to be transported, though it has good prospects in areas with good transportation facilities – especially along the highway corridors. This model consumes slightly more cement than other

models as the walls are constructed with concrete. Cement should also be transported from the read-head to the construction site and in absence of road facility; manual labour should be used to transport it. GGC model can be constructed both with stone and brick masonry. In areas where brick is not available, stone can be used as construction material. In the rural parts of northern Laos, stone has been the major construction materials used for similar type of works. However, as mentioned earlier, cement which is also an integral part of GGC plant construction has to be transported from the nearest road-head to a remote location.

8.4. Purpose of the use of the biodigester products

The main purpose of the use of biodigester products in Laos is for cooking followed by lighting. The use is diversified with the application of slurry in agricultural lands to supplement or complement the use of chemical fertilisers. In view of this, all the five models have same ratings as all the biodigester under the framework of the study are designed for the same purposes.

8.5. Performance of existing models in the local and/or regional conditions

8.5.1. Existing physical status and functioning

The history of biogas in Lao PDR date backs to more than 15 years, when Indian experts introduced the technology for pig farmers (Felix, 2003). The exact number of plants constructed is not recorded. However, the program could not get momentum. Likewise the pilot plant constructed by PADETC, and NGO involved in rural development and training, some 8 years ago was also not successful in motivating farmers to adopt the technology.

A total of eighteen biogas plants were constructed in 1999 under the Canada-Thailand Trilateral Environment Sub-project. The following table illustrates the location and size of biogas plants constructed under this project.

Table-2: Location and Sizes of Lao-German Biodigesters

Name of Province	Number of Biogas plant	Capacity m^3/one BP
Huaphanh	2	16
Xiengkhuang	4	8
Vientiane	4	12, 16, 18
Savannakhet	3	16
Champasak	2	16
Attapeu	2	16
Saravane	1	16
Total:	**18**	

Later in March 2005, under the Chinese support 30 biodigesters of Chinese fixed dome models have been installed in Ban Nong Phou Vieng, Park Ngum District in Vientiane province.

The existing physical status and functioning of majority of the plants constructed in Laos under Canada-Thailand Trilateral Environment Sub-project, in general, is poor. Most of them are not working at all. Several reports (Final Report of Second Fact Finding Mission-2003, Field Visit Report, Auke Koopmans-2006) have reported that most of the plants are not working. The recent field investigation and observation by a team of SNV advisors to the northern provinces of Laos

in the process of getting input for finalisation of the best model also revealed that none of the plants among 6 installed in Huapanh and Xeingkhuan provinces are working. The Lao-GTZ and Chinese models introduced in these areas have not been successful. Though the reason of failure was not merely the technical defects on the plant, which could be attributed to faulty site and size selection, poor operation and maintenance activities and ineffective monitoring from installer's behalf, these plants have caused negative effects in the community on usefulness of biodigester technology. The recently constructed Chinese model plants are satisfactorily operating.

In its effort to popularise the biodigester technology in the country, Sunlabob, a private sector company working in the Solar Home System, has recently installed a demonstration Chinese Model Plant in Bom Xok, Sang Thong district of Vientiane Province. This biodigester is functioning satisfactorily. However, gas leakage was observed from the joint of main valve during the field observation.

Poor functional status of existing Lao-GTZ and some Chinese models plant and associated negative feelings of people towards these plants is a matter of concern for the proposed pilot program. It is important that the initial phase of the biogas program in Laos include interventions to repair and maintain the already existing plants in different parts of the country as far as possible. Such endeavours to retain and sustain the serviceability of the non-functional plants will be instrumental in getting appreciations from the users, which in turn will be beneficial for speedy promotion and extension of the technology.

The recent User's Survey (2005/6) conducted in Vietnam suggested the 83% (67% are fully functioning and 16% are partly functioning) of the biodigesters are operational. Likewise the User's Survey conducted in 2004 in Nepal revealed that 96% of the plants are operational. Though no data and information exists on the functional status of Farmer's Friend Model, the similar model – Deenbandhu in India has functional rate of about 65% (TERI-1997). Likewise, 54% of the modified Deenbandhu biodigesters installed in Nepal are operational (SAP-Nepal, 2003).

8.5.2 Level of User's Satisfaction

Biodigester technology is relatively a new technology for majority of the population in Laos. Though some biodigesters of plastic tunnel, Lao-GTZ and Chinese models were installed in the past, people generally lack the basic knowledge on the harnessing of the technology. No data and information exists on the user's level of satisfaction related to the installed plant. During field observation and discussions with potential users they have positive feeling towards the need of the technology. However, they are not satisfied with the functioning of the installed plants, which is natural given the condition of most of the plants.

The User's Survey (2005/6) in Vietnam revealed that 77% of the users are satisfied with the working of their biodigesters. Likewise in Nepal, 83% of the users are fully satisfied and another 9% are partly satisfied. No data and information exists on the user's level of satisfaction related to Farmer's Friend model. However, BSP-Nepal had also supported installation of modified Deenbandhu Biodigester in addition to the widely used GGC models. Some 200 plants were installed in Nepal under the framework of the BSP. However, people prefer GGC more than Modified Deenbandhu and the company specialised in Deenbandhu technology had to close its office. The masons working with this company are now working with other companies that disseminate GGC technology.

8.6 Quality and quantity of available feeding materials

The National Statistical Data – 2004 suggests that there are 1,112,000 buffalo, 1,249,000 cattle and 1,728,000 pigs in Laos. Buffalo and Cattle are open-grazed in most of the cases where as pigs are kept in a sty near the house. The government's policy directions not to keep cattle near the residential household premises may to some extent discourage the installation of buffalo or cattle dung fed biodigesters. However, the trend of keeping cattle and buffalo in their premise is increasing in some of the provinces like Xeingkhuan and Huapanh where the quality of soils is very poor, to supplement the organics manure for their agricultural lands. Tentatively, it can be assumed equal numbers of dung-fed and pig manure fed plants to be installed in the country.

Chinese, Lao-GTZ and KT2A plants are primarily designed to receive pig manure as feeding material and these models have an added advantage over GGC and Farmer's Friend models in this case. In contrary, GGC and Farmer's Friend models have added advantage over other three models when it comes to the case of cattle dung feeding. Technical modification is possible in all the models to suit both the conditions.

KT2A, GGC and Farmer's Friend models have favourable conditions in areas with scarcity of water as mixing is done in a pit. Other three models need flushing of manure from stable to the digester via conveyance channel which need more water. However, availability of water is not a serious problem in Laos in most of the areas.

The average numbers of cattle, buffalo and pig per household in Laos are 1.3, 1.2 and 1.9. The collective average therefore is 4.4 per household. This indicates relatively small number of holdings which in turn points out the potential of smaller plants. The Chinese model has smallest plant size of 6 cum capacity and that for Lao-GTZ model is 8 cum. Other three models have designs with a smallest size of 4 cum. KT2A model are available in sizes 4 to 20 cum where as GGC and Farmer's Friend are available in 4, 6, 8 and 10 cum sizes. Lao-GTZ model is available with 8, 12 and 16 cum sizes. Therefore, Farmer's Friend, KT2A and GGC model are more suitable than Chinese and Lao-GTZ models when viewed the size of cattle, buffalo and pig holdings.

9. EVALUATION MATRIX AND RESULTS

The following tables (Table-3 and 4) show the comparative merits and demerits of the five models of biodigesters selected for the study.

Table-3: Evaluation Matrix

Evaluation Criteria	Chinese Model	Vietnamese KT2A Model	Cambodian Farmer's Friend Model	Nepalese GGC Model	Lao-GTZ Model
Climatic and Geological Conditions					
Ambient Temperature	++Top filling over dome is 37 cm as per design. -Not the whole area above dome is filled. -Risk of temperature fluctuation in digester is relatively low.	+Top filling over the dome is 12 cm. -Not the whole area above dome is filled. -Risk of temperature fluctuations in the digester is relatively high.	++Top Filling over dome is 40 cm. +The whole area above the dome is filled. +Less risks of temperature fluctuations in digester.	+++Top filling over dome is 50 cm. +The whole area above the dome is filled. ++Very little risks of temperature fluctuations in digester.	--There is no top filling over dome. The top of the dome is exposed. --Very high risks of temperature fluctuations in digester.
Condition of Soil	+Suitable for Lateritic and cohesive soils like clay. --Unsuitable for soils with less cohesive strength such as conglomerate, silt and sandy soil.	++Suitable for all types of soil.	++Suitable for all types of soil.	++Suitable for all types of soil.	++Suitable for all types of soil.
Condition of Ground Water Table	+More suitable for areas with low water table. +Also suitable for areas with higher water table.	+Suitable for both areas - either with high or low water table.	+Suitable for both areas. ++Best suitable for areas with high water table especially along the banks of Mekong River.	-Less suitable for areas with high water table. +Best suitable with areas with low water table especially in the hilly regions.	-Less suitable for areas with high water table. +More suitable with areas with low water table.
Technological Parameters					
Structural Durability					
Inlet Chamber and Inlet Pipe	-Prone to flood water entering. -Difficult to ensure quality mixing -Prone to leakage as inlet pipe penetrates the dome	+Effective to allow grits and soils to settle down. +The use of plug prevents the entry of unwanted materials inside the digester. -Designed to rest on back-filled surface wakening the durability.	+Effective to allow grits and soils to settle down. +Comfortable in mixing, makes the condition of mix suitable for anaerobic digester (better quality mix)	+Comfortable in mixing, makes the condition of mix suitable for anaerobic digester (better quality mix)	-Very small tank, difficult to operate.

Evaluation Criteria	Chinese Model	Vietnamese KT2A Model	Cambodian Farmer's Friend Model	Nepalese GGC Model	Lao-GTZ Model
Digester and Gas Holder	+Digester base, walls and the gas holder are monolithic, hence no joints in between them. Structurally very sound. -Inlet pipe passes through the concreting area in the dome making it prone to gas leakage. -Manhole at the top increases the risk of gas leakage. -Difficult to break scum -Two manhole openings (access points) increase the risk of gas leakage and add the complexities in construction.	+Conical base and spherical top provides better stability. -Manhole at the top increases the risk of gas leakage. -Difficult to break scum	++ Spherical shapes at the bottom and the top is best for load bearing purpose +Closed top of gas holder is less prone to gas leakage. +Manhole in the side eliminates the risk of gas leakage from the top. +Arch frame over the manhole is structurally sound. -The small size of manhole opening makes it difficult to enter into the digester.	+Closed top of gas holder is less prone to gas leakage. +Manhole in the side eliminates the risk of gas leakage from the top. +Manhole in the side with adequate height provides best situation to enter into the digester to monitor the construction and break the scum. -Joints in the base and bottom of dome makes the structure less stronger	+The bottom ring provides structural safety. -Manhole at the top increases the risk of gas leakage. -Difficult to break scum -Exposed dome increases the risk of cracks in gas holder.
Outlet Tank	+Circular structure more durable and less chance of formation of dead volumes in the corners -The overflow opening is designed to be below the ground level which increases the risk of flood water entering into the tank and makes the flow of slurry difficult.	+Circular structure more durable and less chance of formation of dead volumes in the corners +Pipe used to convey slurry from digester to outlet tank, which preserve the heat. -The overflow opening is designed to be below the ground level which increases the risk of flood water entering into the tank and makes the flow of slurry difficult.	-Rectangular structure, chances of formation of dead volume and cracks in the corner if backfilling is not provided +The overflow opening is designed to be above the ground level which facilitates the flow of slurry by gravity and also decreases the chance of flood water entering into the tank.	-Rectangular structure, chances of formation of dead volume and cracks in the corner if backfilling is not provided +The overflow opening is designed to be above the ground level which facilitates the flow of slurry by gravity and also decreases the chance of flood water entering into the tank.	+Circular structure more durable and less chance of formation of dead volumes in the corners +Pipe used to convey slurry from digester to outlet tank, which preserve the heat. -The overflow opening is designed to at the ground level which increases the risk of flood water entering into the tank.

Evaluation Criteria	Chinese Model	Vietnamese KT2A Model	Cambodian Farmer's Friend Model	Nepalese GGC Model	Lao-GTZ Model
Methods of Construction					
Digging of Pit	---Very very complicated excavation	-Complicated excavation	--Very complicated excavation	+No complications in excavation	Less complications in excavation
Construction of Base	-Bit complicated base concreting as it calls for slope adjustment -Consumption of more construction materials	-Complicated base concreting as it demands conical shape --Consumption of more construction materials	--Very complicated base concreting as it demands spherical shape and properly adjusted collar --Consumption of more construction materials	+Easy in preparing the base + Consumes less materials, broken bricks bats are used	-Slightly complicated base concreting as the ring has to be casted accurately -Consumption of more construction materials
Construction of Digester	+Digester wall is constructed very quickly. Less time consuming. -Bit cumbersome as heavy moulds have to be fitted in place -If by mistake or because of natural constraints more excavation is done, it consumes more concrete -Difficult to take out mould after concreting -Labour intensive to mix and pour concrete	-Skilled person needed to construct --Not suitable in areas where brick is not available and stone are widely used, such as areas in northern Laos -Only limited number of brick layers could be constructed in one day to allow the brick to set properly, time consuming	-Skilled person needed to construct -Fixing of curvature constructing of arch needs careful attentions --Not suitable in areas where brick is not available and stone are widely used, such as areas in northern Laos -Only limited number of brick layers could be constructed in one day to allow the brick to set properly, time consuming	+Construction is easy; mason with a skill to construct masonry walls can do it with a little orientation. ++ Suitable for both brick and stone masonry walls +Construction of digester wall can be finished in one day, no need to wait for the brick to set. Less time consuming. -Care has to be given to maintain the wall perfectly vertical	-Skilled person needed to construct --Not suitable in areas where brick is not available and stone are widely used, such as areas in northern Laos -Only limited number of brick layers could be constructed in one day to allow the brick to set properly, time consuming

Evaluation Criteria	Chinese Model	Vietnamese KT2A Model	Cambodian Farmer's Friend Model	Nepalese GGC Model	Lao-GTZ Model
Construction of Gas Holder	+Gas holder is constructed very quickly, less time consuming -Bit cumbersome as heavy moulds have to be fitted in place -Construction of manhole in the top needs more skills and care -Removal of mould from manhole after concreting is difficult -Labour intensive to mix and pour concrete	-Only limited number of brick layers could be constructed in one day to allow the brick to set properly, time consuming -Hooks and counterweights are needed for each and every freshly laid brick, which is a cumbersome task to do -Joints between bricks should be filled well to make it gas tight – more care is needed -Cracks developed during construction have to be monitored properly and work has to be stopped immediately if cracks appear. Masons tend to violet this in quest to complete work quickly. -Construction of manhole in the top needs more skills and care.	-Only limited number of brick layers could be constructed in one day to allow the brick to set properly, time consuming -Hooks and counterweights are needed for each and every freshly laid brick, which is a cumbersome task to do -Scaffoldings are needed from inside and outside to close the dome which adds more complications -Joints between bricks should be filled well to make it gas tight – more care is needed -Cracks developed during construction have to be monitored properly and work has to be stopped immediately if cracks appear. Masons tend to violet this in quest to complete work quickly.	--The whole part of the digester has to be filled with soil to erect a framework for casting concrete for the gas-holder which is very cumbersome job demanding more unskilled labours -Templates have to be used to shape the soil mould; carrying of such moulds though not very difficult is an added job. -Made up of concrete, consumes more construction materials -Labour intensive to mix and pour concrete	-Only limited number of brick layers could be constructed in one day to allow the brick to set properly, time consuming -Hooks and counterweights are needed for each and every freshly laid brick, which is a cumbersome task to do -Construction of manhole in the top needs more skills and care -Joints between bricks should be filled well to make it gas tight – more care is needed -Cracks developed during construction have to be monitored properly and work has to be stopped immediately if cracks appear. Masons tend to violet this in quest to complete work quickly.
Inlet and Outlet Tanks	-Construction of inlet is complicated as it has to be attached properly with the concrete digester -Circular outlet tank, relatively difficult to construct -Overflow opening is below the ground level, construction of drain in needed to facilitate the slurry flow.	-Inlet tank is constructed on back-filled soil in order to gain steep angle for the inlet pipe -Circular outlet tank, relatively difficult to construct -Overflow opening is below the ground level, construction of drain in needed to facilitate the slurry flow.	+No major difficulties in constructing inlet tank. +Rectangular tank, easy to construct +Overflow opening is above the ground level, slurry flows by gravity -Care needed to fix the mixing device properly	+No major difficulties in constructing inlet tank. +Rectangular tank, easy to construct +Overflow opening is above the ground level, slurry flows by gravity -Care needed to fix the mixing device properly	+No major difficulties in constructing inlet tank. -Spherical outlet tank, difficult to construct -Overflow opening is on the ground level, construction of drain in needed to facilitate the slurry flow.

Evaluation Criteria	Chinese Model	Vietnamese KT2A Model	Cambodian Farmer's Friend Model	Nepalese GGC Model	Lao-GTZ Model
Operation and Maintenance					
Operational Activities	-Care need to be provided not to use more water while flushing pig sty or cattle stable. -Special attention needed to avoid grits and other unwanted materials from entering into the digester -Difficult to inspect and clean overflow opening (blocked overflow may invite slurry into the pipeline) -Difficult to break the scum layer	-Difficult to inspect and clean overflow opening (blocked overflow may invite slurry into the pipeline) -Difficult to break the scum layer -Adds time to collect and transport dung from the cattle shed to the inlet tank, if it is not flushed	+Easy to inspect and clean over-flow opening +Relatively easy to break scum layer from manhole -Adds time to collect and transport dung from the cattle shed to the inlet tank	+Easy to inspect and clean over-flow opening +Easy to break scum layer from manhole -Adds time to collect and transport dung from the cattle shed to the inlet tank	-Difficult to inspect and clean overflow opening (blocked overflow may invite slurry into the pipeline) -Difficult to break the scum layer
Maintenance Activities	-Breaking of the seal at the manhole and repositioning it is difficult when the digester and gas holder need maintenance. -Repeated breaking of this seal may lead to gas leakage	-Breaking of the seal at the manhole and repositioning it is difficult when the digester and gas holder need maintenance. -Repeated breaking of this seal may lead to gas leakage	+Emptying of digester is easy and it does not effect on structural stability	+Emptying of digester is easy and it does not effect on structural stability	-Breaking of the seal at the manhole and repositioning it is difficult when the digester and gas holder need maintenance. -Repeated breaking of this seal may lead to gas leakage
Top-filling and protection of plant	-The whole structure above the dome could not be back-filled to allow constant monitoring of the manhole seal -Chances of mosquito breeding is high in the stagnant water	-The whole structure above the dome could not be back-filled to allow constant monitoring of the manhole seal -Chances of mosquito breeding is high in the stagnant water	+The whole structure above the dome could be back-filled and protected well under ground	+The whole structure above the dome could be back-filled and protected well under ground	-The whole structure above the dome could not be back-filled to allow constant monitoring of the manhole seal -Chances of mosquito breeding is high in the stagnant water

Evaluation Criteria	Chinese Model	Vietnamese KT2A Model	Cambodian Farmer's Friend Model	Nepalese GGC Model	Lao-GTZ Model
Applicability/Adoptability in different Geographical context	+Suitable for all areas where aggregates, sand and cement are available -Moulds could not be transported to rural areas hence, installation is limited only in areas with good transport facilities.	-Not suitable in areas where bricks are not available or could not be transported easily	-Not suitable in areas where bricks are not available or could not be transported easily	+Suitable for all the areas. Bricks could be supplemented by stone in areas where bricks are not available	-Not suitable in areas where bricks are not available or could not be transported easily
Prospects for sharing of Technical Information and Know-how	-Little information exists on the R&D aspects of the plant model	+Information are widely available which could be shared	+Information are widely available which could be shared	+Information are widely available which could be shared	-Very little information exists on the R&D aspects of the plant model
Affordability of Farmers to install biodigesters					
Availability of construction materials at the local level	+Aggregate and sand are available elsewhere -Cement and brick are not available everywhere	+Aggregate and sand are available elsewhere -Cement and brick are not available everywhere	+Aggregate and sand are available elsewhere -Cement and brick are not available everywhere	+Aggregate and sand are available elsewhere -Cement and brick are not available everywhere +Bricks could be supplemented with the use of locally available stone	+Aggregate and sand are available elsewhere -Cement and brick are not available everywhere
Availability of human resources	+Trained technical manpower available in Laos to a small extent	-Trained technical manpower is not available in Laos -Needs intensive training	-Trained technical manpower is not available in Laos -Needs intensive training	-Trained technical manpower is not available in Laos -Needs training	+Trained technical manpower available in Laos to a small extent
Cost of Installation (excluding transportation, guarantee and after-sales-services)	USD 274 for 6 cum biodigester	USD 303 for 6 cum biodigester	USD 325 for 6 cum biodigester	USD 314 for 6 cum biodigester	USD 383 for 6 cum biodigester
Operation and maintenance cost	This cost is similar for all types of digester.				

Evaluation Criteria	Chinese Model	Vietnamese KT2A Model	Cambodian Farmer's Friend Model	Nepalese GGC Model	Lao-GTZ Model
Transportation facilities	+Highly suitable for areas with good transportation facilities -Less suitable for areas without road networks as the moulds have to be transported	+Highly suitable for areas with good transportation facilities -Less suitable with areas where bricks has to be transported	+Highly suitable for areas with good transportation facilities -Less suitable with areas where bricks has to be transported	++Suitable in all the parts of the country as bricks can be replaced with stones	+Highly suitable for areas with good transportation facilities -Less suitable with areas where bricks has to be transported
Purpose of the use of Biodigester Products	All the biodigester under the framework of the study are designed for the same purposes.				
Performance of Existing biodigesters in local/regional context					
Existing physical status and functioning	-The physical status and functioning of majority of the biodigesters installed in Laos before 2003 is not satisfactory. -Newer plants are functioning satisfactorily.	+83% (67% are fully functioning and 16% are partly functioning) of the biodigesters installed in Vietnam are operational and have good physical status.	+65% of the biodigesters installed in India are functional and have good physical status. -54% of the biodigesters installed in Nepal are operational	+96% of the biodigesters installed in Nepal are operational and have good physical status.	-The physical status and functioning of majority of the biodigesters installed in Laos is very poor.
Level of Satisfaction of Users	-Information on level of satisfaction of users does not exist.	+77% of the users are satisfied with the performance of their biodigesters in Vietnam	-No data was found no the level of user's satisfaction, however, users in Nepal are not satisfied with the performance of their digesters.	+83% of the users in Nepal are fully satisfied and 9% of them are partly satisfied +User's in Nepal prefer GGC more than Deenbandhu (Farmer's Friend)	-Most of the biodigesters are not functional – it can be assumed that user's are not satisfied with the performance.
Quality and Quantity of available feeding materials	+Best suited for pig manure feeding -Modifications in inlet needed for cattle dung feeding -Design of smaller size (less than 6 cum) is not available.	++Suitable for both types of feeding -Design of smaller size (less than 6 cum) is also available.	+Best suited for cattle dung feeding -Modifications in inlet needed for pig manure feeding -Design of smaller size (less than 6 cum) is also available.	+Best suited for cattle dung feeding -Modifications in inlet needed for pig manure feeding -Design of smaller size (less than 6 cum) is also available.	+ Relatively suitable for both types of feeding -Design of smaller size (less than 8 cum) is not available. Not suitable for families with small cattle holding

Table -4: Evaluation Results

SN	Evaluation Criteria	Chinese Model	Vietnamese KT2A Model	Cambodian Farmer's Friend Model	Nepalese GGC Model	Lao-GTZ Model
1	**Climatic and Geological Conditions**					
1.1	Ambient Temperature	3	2	4	5	1
1.2	Condition of Soil	3	5	5	5	5
1.3	Condition of Ground Water Table	3	4	5	1	2
2	**Technological Parameters**					
2.1	***Structural Durability and functioning***					
2.1.1	Inlet Chamber and Inlet Pipe	3	4	5	5	4
2.1.2	Digester	5	4	5	3	4
2.1.3	Gas Holder	4	3	4	5	3
2.1.4	Outlet Tank	5	5	4	4	5
2.2	***Methods of Construction***					
2.2.1	Digging of Pit	2	3	2	5	4
2.2.2	Construction of Base	4	3	2	5	4
2.2.3	Construction of Digester	4	3	3	5	3
2.2.4	Construction of Gas Holder	5	3	4	2	3
2.2.5	Inlet and Outlet Tanks	4	5	5	5	4
2.3	***Operation and Maintenance***					
2.3.1	Operational Activities	4	4	5	5	4
2.3.2	Maintenance Activities	4	3	5	5	3
2.3.3	Top-filling and protection of plant	3	2	4	5	1
2.4	***Applicability/Adoptability in different Geographical context (including suitability with locally available construction materials)***	***3***	***4***	***4***	***5***	***4***
2.5	***Prospects for sharing of Technical Information and Know-how***	4	5	5	4	4
3	**Affordability of Farmers to install biodigesters**					
3.1	Availability of construction materials at the local level	5	4	4	5	4
3.2	Availability of human resources	5	2	2	2	4
3.3	Cost of Installation	5	4	2	3	1
3.4	Operation and maintenance cost	4	4	5	5	4
3.5	Transportation facilities	3	4	4	5	4
4	**Purpose of the use of Biodigester Products**	5	5	5	5	5
5	**Performance of Existing biodigesters in local/regional context**					
5.1	Existing physical status and functioning	3	4	3	5	1
5.2	Level of Satisfaction of Users	3	4	3	5	3
6	**Quality and Quantity of available feeding materials**	4	5	5	5	3
	Total Marks obtained	**99**	**98**	**105**	**114**	**87**
	Ranking	**Third**	**Fourth**	**Second**	**First**	**Fifth**

Note: ***5 points- Most Favorable Condition***
1 point- Least Favorable Condition

10. CONCLUSION AND RECOMMENDATION

10.1 Conclusion

The suitability of different models of biodigester as discussed above were ranked (Table-4) based upon the criteria shown in the evaluation matrix (Table-3). The outcome of the ranking exercise revealed that there is not a wide difference on ratings among the five models under study. The GGC model being disseminated under the Biogas Programme in Nepal has been the most suitable plant for mass dissemination in Lao PDR. The suitability of this design for both brick and stone masonry works; simplicity in construction; easy access for cleaning and maintenance of digester and gas holder; higher level of user's satisfaction; and proven track record of successful functioning make this model more suitable than others. Labour intensive construction of gas holder and relatively less suitability of the model in areas with high water table are the main shortcomings of this design.

Farmer's friend model has stood second in terms of its suitability in Lao PDR because of its better structural design owing to the curved shaped base as well as digester and gas holder; fairly easy access to cleaning and maintenance of digester and gas holder; higher suitability in areas with high water table; and availability of technical know-how in the neighbouring country (Cambodia) which can easily be transferred. Requirement of skilled persons for construction, higher risk of product to be poor because of the negligence from masons to monitor the minute cracks in masonry walls during construction, unsuitability of the design for stone masonry and relatively higher cost of installation are some of the major drawbacks of this model.

Chinese fixed dome model has been ranked third among the five models under evaluation. The main favourable situations for this model have been the availability of skilled masons in Laos, lowest cost of installation, availability of construction materials across the country and less time for construction (less time consuming). Unsuitability of the model in soils with less cohesive strength, difficulty in transporting heavy moulds that are needed for the construction, requirement of skilled manpower for construction, difficulty in fixation and removal of the moulds and less effective inlet structure are main weaknesses of this model.

KT2A model have the proven track records of success and relatively higher level of user's satisfaction, stronger structural strength and good prospects of transferring knowledge and skills from neighbouring Vietnam. Designs of biodigesters of different capacities ranging from 4 to 20 cum are available. Relatively complicated construction requiring skilled masons and location of inlet tank above the backfilled soil increasing the risk of cracks/failure are the main demerits of this model.

Lao-GTZ model has been ranked to be the least favourable models. Higher rates of failure of existing biodigesters installed in various parts of the country, higher cost of installation, unavailability of smaller design to cater farmers with small cattle-holding, relatively complicated construction methods, lower suitability in areas with high-water table, and exposure of dome above ground level endangering the safety of the structure are the main shortcomings of this design. However, some skilled persons are available in the local market who have knowledge and skills to construct this type of biodigester.

10.2 Recommendation

The GGC model is the best suited design of biodigester for wide-scale dissemination of biodigester technology in Lao PDR. However, prior to the commencement of construction works, series of training programmes are needed to build the technical capacity of local manpower to construct and supervise the installation of biodigesters. This necessitates considerable number of time and efforts. Keeping in view the urgency of the installation of 900 biodigester during 2006, it is recommended that:

a. An intensive Training of Trainers (TOT) be planned as early as possible on the construction and supervision of GGC model biodigester followed by training of supervisors and masons. The plan of action should be:

Activities	Tentative Schedule
Preparation of training materials: -Working drawings of different sizes of biodigester -Mason's Manual -Supervisor's Manual -Curricula and Guidelines for Mason's Training -Curricula and Guidelines for Supervisor's Training -Presentation slides	English version: Before 30th April, 2006 Lao Version: Before 15th May, 2006
Selection of Participants and other preparatory works for TOT	Before 15th May, 2006
Training of Trainers -Theoretical training with practical demonstration -Practical on the job training	 17th -22nd May, 2006 23rd May-6th June, 2006
Training of Masons and supervisors (two concurrent sessions)	12th-19th June, 2006
Installation of Demonstration Plants	July
Collection of demands and selection of households for biodigester installation	July
Installation of Household Biodigesters	August-December.

b. In the meantime, the locally available technical persons who are skilled to construct Chinese model biodigesters may be oriented and utilised to install some demonstration biodigesters of Chinese Model in different locations until all the preliminary works to construct GGC model are completed. The Chinese models could be installed in areas with good proximity to transportation facilities. Having installed two types of models, the potential farmers as well as the technical persons will have an option to select the best suited model for mass dissemination in future keeping in view the performance of the functional biodigesters and ease in construction.

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Annex-1: Drawing of Biodigesters under study