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Construction Technology of Biodigesters in Senegal

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Abstract

Faced with the depletion of fossil energy resources and given the current context of the fight against climate change, Renewable Energies (RE) represent an increasingly growing challenge. Of all these energies, those resulting from the biomethanization of biomass now provide an opportunity in the world of farmers and breeders. The treatment of agro-pastoral residues by anaerobic digestion has been the subject of renewed interest in recent years, thanks in particular to the production of energy from biomass, not to mention the production of fertilizers from effluents. Expelled from the digesters. This method of transformation offers many environmental, socio-economic and agricultural interests. Indeed, the biogas obtained from organic matter allows, among other things, to cook, light houses, and produce electricity and heat. The objective of this study is to compare the construction techniques and costs of the biodigester models that exist in Senegal. There are many biodigesters, the choice of an installation depends on the available space and the nature of the soil. Several types of biodigester technologies are installed in Senegal. The GGC 2047 fixed dome, the RMB geomembrane and the BEG geomembrane. First we will describe the construction techniques of the modified GGC model fixed dome biodigester, then of the RMB model geomembrane and finally of the BEG model geomembrane.

Keywords

Biodigester, Biomass, Fixed Dome, Geomembrane, Renewables Energies

1. Introduction

Faced with the depletion of fossil energy resources and given the current context of the fight against climate change, Renewable Energies (RE) represent an increasingly growing challenge. Of all these energies, those resulting from the biomethanation of biomass now provide an opportunity in the world of farmers and breeders. The treatment of agro-pastoral residues by anaerobic digestion has been the subject of renewed interest in recent years, thanks in particular to the production of energy from biomass, not to mention the production of fertilizers from effluents expelled from the digesters. This method of transformation offers many environmental, socio-economic and agricultural interests. Indeed, the biogas obtained from organic matter makes it possible, among other things, to cook, light houses, and produce renewable electricity and heat. Biogas is a clean cooking energy that is an alternative to using firewood. This choice results from a double interest: on the one hand, at a time when the planet is concerned about climate change, sectors related to sustainable development, renewable energies and green economies are of paramount importance. Indeed, biogas contributes to the fight against deforestation, to the reduction of the emission of methane into the atmosphere, to the improvement of the living conditions of the populations as well as to the recovery of organic waste. Indeed, the household supply of cooking fuel shows that firewood and charcoal constitute more than 75% of cooking energy sources. The negative impacts of the extraction of these resources of woody origin and their use for cooking purposes on the health of populations and on the environment have pushed the government of Senegal to look for alternative solutions. The production of biogas for domestic needs constitutes one of the answers to this problem [1]. Rising fuel prices, green house gas emissions and over-reliance on non-renewable energies have pushed researchers in recent years to find alternative methods to obtain a sustainable form of energy [2]. Urbanization has also caused rapid generation of a considerable amount of waste, resulting in poor waste management practices in developing countries [3] [4]. All of this emphasizes the fact that environmentally friendly renewable energy sources remain a viable option for meeting rising energy demand and fossil fuel depletion [5]. Moreover, local and global energy shortages have become more prevalent [6]. Renewable energy development is currently rising, in line with the United Nations Sustainable Development Goal 2030 [7].

Anaerobic digestion or anaerobic digestion allows the biodegradation of organic waste by producing a combustible gas, methane. It mainly applies to wet waste rich in organic matter, predominantly cellulosic. Thus, both liquid effluents rich in organic matter and solid waste can be treated by methanization. The methanization process (in the total absence of oxygen) takes place in a closed reactor and results in the formation of 2 co-products: biogas and a methanized residue or digestate. It is a natural process resulting from complex microbial activity. While in the presence of oxygen the aerobic fermentation of waste, or more commonly their composting, consists of a strongly exothermic reaction of carbon oxidation, we are instead witnessing a weakly exothermic phenomenon of carbon combustion under anaerobic conditions. Methanization takes place in three main stages: Hydrolysis, by which organic macromolecules are broken down into simpler products; action of fermentative bacteria; acidogenic, which leads to the formation of various volatile fatty acids, in particular acetic acid; action of acidogenic and essentially acetogenic bacteria; methanogen, final stage during which biogas is produced from acetic acid, carbon dioxide and hydrogen from previous stages; action of methanogenic bacteria. All this mixed bacterial flora is generally present naturally, in greater or lesser quantities, in most organic waste. The start of methanization can be accelerated by inoculating the digester with specific flora, for example by adding stercorary materials (rumen contents) from cattle or a digestate from another reactor in operation. Methane and carbon dioxide are the essential components of biogas, but it also contains very small proportions of nitrogen, hydrogen, carbon monoxide and hydrogen sulphide. Produced in a humid environment, the biogas is also saturated with water at the digester outlet. The richness of biogas in methane, which determines its use as fuel or fuel, depends on the nature of the digested substrate and is expressed in volume fraction (%). Biogas is rich in methane (65% to 70%) when the waste is rich in nitrogen as in the case of livestock waste and certain agro-industrial effluents. On the other hand, the richness decreases (50% to 60%) for plant waste and household waste, which are lower in nitrogen [8] [9]. For developing countries in warm regions, we will limit our presentation to digesters suitable for solid waste, the latter being the most frequently available. As explained previously, the term "solid" means organic waste with a high dry matter content, called "shovelable", such as for example straw manure, stercorary materials from slaughterhouses, coffee pulp, cassava peelings, the organic fraction of household waste…

In digesters for solids, the substrate is either not immersed or immersed with or without recirculation of liquids. The treatment cycle can be discontinuous or continuous. In discontinuous mode, the entire contents of the reactor are renewed periodically at once, while in continuous mode, only a fraction of the contents is renewed at a regular time step. We will describe 2 technologies adapted for small to medium treatment capacities, the batch digester and the Transpaille digester [10] [11].

The first point is devoted to the introduction. It will be followed in the second point the different types of Biodigester will be presented. The subject of the third point concerns the construction techniques of the modified GGC 2047 Biodigester. The fourth and fifth respectively deal with the construction techniques of the RBM Biodigester and those of the BEG. In the sixth point we bring together the costs of the different types of Biodigester. Finally, a conclusion will be drawn.

On the other hand, there are many biodigesters, the choice of an installation depends on the available space and the nature of the soil. Several types of biodigester technologies are installed in Senegal: the GGC 2047 fixed dome, the RMB geomembrane and the BEG geomembrane.

2. Different Types of Biodigesters

The biodigester is a device powered by animal or vegetable organic matter which by fermentation, in the absence of oxygen, produces two by-products which are: biogas and liquid fertilizer. Biogas used for cooking and lighting needs and liquid fertilizer is used for soil amendment. In Senegal, we note 3 types of biodigesters: the modified GGC 2047 model fixed dome, the RMB model geomembrane and the BEG model geomembrane.

2.1. Fixed Dome Biodigester Model GGC 2047 Modified

This model provides a good pressure that can reach up to 12 kPa, its construction is very technical and lasts 15 to 20 days. The fixed dome digester is also known by the acronym of the Chinese model. It was developed and created in China in 1936. It is composed of an underground compartment constructed of masonry bricks in a rounded shape (fermentation chamber) with a dome on top to store gas. The gas line is provided by PVC type pipes of reduced diameter, heavy valves which allow opening and closing for the gas supply.

2.2. RMB Model Geomembrane

The RMB geomembrane can reach a pressure of 7 kPa, it is a pre-made biodigester and its installation is simple and lasts 5 to 7 days. The RMB biodigester is a biodigester that is manufactured like the fixed dome except for the manhole. For the RMB, there is a connection between the tarpaulin room and the outlet chamber allowing the effluent already degraded in the room to circulate under the effect of the slope and the pressure exerted by the gas within the room. There is a perfect balance between the tarpaulin room and the inspection chamber which ensures that the gas pressure at the tarpaulin level remains constant.

2.3. BEG Model Geomembrane

The BEG geomembrane can reach a pressure of 6 kPa, its construction is simple, and requires less building materials. It lasts 5 to 7 days. The BEG geomembrane type biodigester is a biodigester with a plastic membrane (tarpaulin), most often black in color. Like the RMB, its installation requires the construction of containment walls to accommodate the tarpaulin (reactor). The black color of the tarpaulin encourages an increase in temperature due to the effects of solar rays. This helps accelerate gas production. For rocky areas, it is advisable to install the geomembrane, because of the exorbitant cost of excavations.

3. Technique for the Construction of a GGC 2047 Model Fixed Dome Biodigestor

The modified GGC 2047 type biodigester is a fixed dome digester, the cycle is continuous. The 4, 6, 8, 10, 12, 14, 16 and 18 m^3 modified GGC type digesters are the volumes offered in Senegal. The most important parameters for choosing a biodigester remain the availability of fresh cow dung and water. Table 1 shows some basic information related to the different dimensions of the biodigester depending on the number of semi-stalled cattle heads required. This number

Table 1. Amount of fresh dung feed and water required.

NS	Digester capacity (m^3)	Daily gas production (m^3)	Fresh livestock dung required (kg)	Each day water required daily (liter)	Number of cattle in semi-stabling (heads)
1	4	1 - 1.6	20 - 40	20 - 40	3 to 4
2	6	1.5 - 2	40 - 60	40 - 60	4 to 5
3	8	2 - 2.5	60 - 80	60 - 80	6 to 8
4	10	2.5 - 3	80 - 100	80 - 100	9 to 10
5	12	3 - 3.5	100 - 120	100 - 120	10 to 12
6	14	3.5 - 4	120 - 140	120 - 140	12 to 14
7	16	4 - 4.5	140 - 160	140 - 160	14 to 16
8	18	4.5 - 5	160 - 180	160 - 180	16 to 18

guarantees the availability of fresh cow dung. You should also note the amount of water needed daily. The maximum pressure is 12 kPa for temperatures around 20˚C to 30˚C with a lifespan of 15 years.

3.1. Technical Information on Biodigesters

Table 1 below gives information regarding the feeding of different sizes of biodigesters, namely each quantity of dung with its corresponding quantity of water. For daily gas production, Table 1 also provides information on the number of semi-stalled beef required for each size of biodigester to be fed.

Table 2 below gives the approximate parameters of energy requirements and the number of beef required in semi-stalls in the household for each size of biodigester.

3.2. Steps in the Construction of a Biodigester

They are 13 in number: search for local materials. Location of the different parts of the biodigester away from trees (offset 3 to 5 m), 2 m from existing structures, choose high points to avoid flooding. Excavation of the land, leveling of the bottom of the excavations, verification of the axes of implantation, compacting of the bottom of the excavations. Pouring the slab with a 1-2-3 dosage concrete: 1 bag of cement, 2 wheelbarrows of sand and 3 wheelbarrows of gravel. Making the slabs of the scrap exit chamber with a concrete dosage of 1-2-3. Construction of a circular wall, plaster in the dosage 1 - 3. Plastering, backfill compacted against the wall, groove for the pipes and construction of the manhole. Casting of the dome and implementation of a separation device with clean sand between the formwork backfill and the concrete. Installation of reminders for the implementation of concrete. Preparation and implementation of concrete with a 1-2-3 dosage. Cleansing, extraction of the formwork backfill after five days, embankment above the dome, and sealing treatment of the dome. A leaky dome will not supply gas normally. Because tightness is necessary for the production of gas in

Table 2. Biodigester size according to household size.

Number of people in the family	Biogas requirements for cooking and lighting (m^3)	Volume of digester required (m^3)	Number of oxen required in semi-stabling (heads)
Up to 4 people	1	4	3 to 4
5 to 6 people	1.5	6	4 to 5
7 to 9 people	2.25	8	6 to 8
10 - 11 people	2.75	10	9 to 10
12 - 13 people	3.25	12	10 to 12
14 - 15 people	3.75	14	12 to 14
16 - 18 people	4.5	16	14 to 16
19 - 20 people	5	18	16 to 18

anaerobic conditions. Compaction of the raft support soil, installation of the concrete raft at a 1-2-3 ratio, construction of the walls of the manhole, respect the height of the overflow. Realization of the gas supply line from the digester to the kitchen, Install the water trap at the lowest point of the network, install the inside network, connect the stove, pressure gauge, the lamp to the network and for galva-galva connections, use Teflon instead of oakum, for pvc-pvc connections use parabond glue or similar. Establish the level of the entrance chamber baseplate using the water level and build the entrance chamber. Dig two compost pits whose volume is equivalent to the volume of the digester. Cleaning of the construction site, works receipt, fallback and delivery of the structure to the beneficiary for filling.

4. RMB Model Geomembrane Biodigestor

4.1. Technical Information on Biodigesters

The RMB biodigester is a biodigester which is manufactured like the fixed dome except for the manhole. For the RMB, there is a connection between the room of the tank and the outlet chamber allowing the effluent already degraded in the room, to circulate under the effect of the slope and the pressure exerted by the gas within the tarpaulin. There is a perfect balance between the tank room and the inspection chamber which means that the gas pressure at the level of the tank remains constant. Each time the gas is used, the height of the effluent drops to the level of the manhole. If the gas pressure is high, the effluent at the inspection chamber flows into the compost pits. The initial loading is done as follows: water must be poured into the tarpaulin, through the entrance manhole, up to a height of 30 cm; begin loading with organic matter. When the mixture, in the tank, reaches 50 cm in height, the loading is stopped and the production of gas is awaited. This is manifested by a swelling of the tarpaulin and it is at this moment that the daily loading begins. It can reach a maximum pressure of 7 kPa with temperatures ranging from 20˚C to 40˚C. With proper maintenance, it can last for ten years. Less expensive than the fixed dome, in the event of a leak at the level of the tarpaulin, the repairs are easy to manage, unlike the fixed dome where the solution that arises is to destroy in order to rebuild.

Table 3 shows for each size of biodigester, the number of livestock (cattle), the water/dung ratios that must be put in the biodigester to have the corresponding quantities of gas and effluent.

4.2. Steps in the Construction of a Biodigester

The delimitation of the area is the first activity to be done because it allows to respect the sizing plan. The excavations must respect the defined plan. They should neither be too big nor too small compared to the dimensions on the plan. The masonry work consists of building the raft (casting which requires a mixture of sand, water, gravel and cement), the walls of the tarpaulin room as well as the inspection chamber and the compost pits. For the RMB the work can last five to seven days. To delimit the overflow, it is necessary to measure from the slab 111 cm and create a passage where the already degraded effluent is evacuated. It should be noted that the overflow must be in the middle of the upper horizontal axis so that the flow occurs normally. The drainage channels must also each lead to a compost pit starting from the overflow. The preparation consists of passing the cap of the tarpaulin over the flexible pipe. The diameter of the pipe is slightly smaller than that of the plug, it is recommended to heat it to flatten the end and fix the plug. For more sealing at the junctions, glue is used. To install the tarpaulin, it is necessary to take into account its orientation. The cover contains two holes, the first connects to the entrance manhole and the second to the exit chamber. After installing the cover, it must be fixed so that it can have the correct shape and be able to contain the effluent. Fixing is most often done with tie wires, at the ends of the tarpaulin and held in place by stones or… Above all, do not reverse the tarpaulin and put the entrance to the hole in the tarpaulin intended for the entrance manhole at the entrance to the exit chamber. Otherwise, the effluent may rise towards the manhole. The base of the entrance manhole is built at the exit of the pipe. It is a concrete parallelepiped of dimension 1 × 1 × 0.15 (in meter). Its level must be higher than the overflow by a minimum height of 15 cm in relation to the overflow. After the slab has dried, the bricks must be laid in a circular fashion to obtain the entrance manhole. Leave 8 cm between

Table 3. Technical information on biodigesters.

Size of the biodigester	Cattle herd	Water/dung ratios	Daily loading Dung (kg)	Daily loading water liter	Quantity of gas (m^3)	Annual effluent production
RMB 4	4	1/1	50	50	2	30
RMB 6	5	1/1	60	60	3	50
RMB 8	7	1/1	80	80	4	57
RMB 10	8	1/1	90	90	5	68

the pipe and the peripheral brick closest to the pipe. The manhole must have an internal diameter equal to 60 cm and a height of 60 cm. To finish the entrance manhole, it must be troweled. The installation of the mixer will be done following, with a metal axis in the center and three hooks at the top. For the installation of the plumbing, it is necessary to dig up to the kitchen a passage of depth approximately equal to 30 cm to receive the PVC pipes of diameter 20. The PVC connections will be made with a PVC glue after having heated the end of the pipe. The heater will expand the head of one of the pipes to allow insertion of the other. The flexible pipe coming from the tank must be connected to the plumbing using a Pex 12/16 coupling then must be connected to a threaded end before being connected to the ball valve. The last step is to connect it to the stove and install the pressure gauge at the kitchen level.

5. Beg Model Geomembrane Biodigestor

5.1. Technical Information on Biodigesters

The BEG geomembrane type biodigester is a biodigester with a plastic membrane (tarpaulin), usually black in color. Like the RMB, its installation requires the construction of containment walls to accommodate the tarpaulin (reactor). The black color of the tarpaulin favors the increase of the temperature by the effects of the solar rays. This contributes to the acceleration of gas production. For rocky areas, it is advisable to install the geomembrane, because of the exorbitant cost of excavations. It is essential to respect the state of loading of the BEG which is 1/2 that is to say 1 kg of dung for 2 L in order to facilitate the dumping of the substrate already digested within the pits. There are 5 categories of geomembrane biodigester: BEG6, BEG8, BEG10, BEG12 and BEG14 in Senegal. The following table shows some basic information related to the different dimensions of the biodigester depending on the number of semi-stalled cattle heads required. This number guarantees the availability of fresh cow dung. The maximum pressure is 6 kPa with temperatures that can reach 20˚C to 40˚C for a lifespan of 20 years.

Table 4 shows for each size of biodigester, the number of livestock (cattle), the water/dung ratios that must be put in the biodigester to have the corresponding quantities of gas and effluent.

Table 5 provides information on the length, width and height of the trenches, chamfer and compost pits of the different sizes of biodigester.

5.2. Steps in the Construction of a BEG Biodigester

The delimitation of the area is the first activity to be done because it allows to respect the sizing plan. The excavations must respect the defined plan, they must not be either too large or too small in relation to the fixed dimensions. Supply of construction materials and the making of blocks for the start of work: cement, water, sand, gravel and start of masonry work: the construction will be done using the batches of plans provided for each size of Biodigester. Constructions of

Table 4. Technical information on biodigesters.

Type of biodigester	Size of the biodigester	Cattle herd required	Water/dung ratios	Dung daily load (kg)	Daily water load (liter)	m^3 of gas	Annual effluent production m^3
Geomembrane	BG6	5	1/2	52	104	2.1	41.5
Geomembrane	BG8	9	1/2	85	170	3.4	60
Geomembrane	BG10	10	1/2	97	194	3.9	97
Geomembrane	BG12	11	1/2	109	218	4.4	110
Geomembrane	BG14	12	1/2	125	250	5	120

Table 5. Dimension information.

Biodigester model	Trenches			Chamfer		compost pit		
	Length (m)	Width (m)	Depth (m)	Height (m)	Depth (m)	Length (m)	Width (m)	Height (m)
BG6	3	2.2	1.2	0.6	0.6	2	1.5	1
BG8	3.5	2.2	1.2	0.6	0.6	2	2	1
BG10	4	2.2	1.2	0.6	0.6	2.5	2	1
BG12	4.5	2.2	1.2	0.6	0.6	2.5	2,4	1
BG14	5.2	2.2	1.2	0.6	0.6	3	2.34	1

the base wall for the geomembrane, then the manhole, next two compost pits finally realization of chamfers at the level of the tarpaulin room and connect the PVC to the geomembrane that will connect the digester entrance manhole to the two compost pits. Finally, install the piping from the main valve to the kitchen. After spreading the geomembrane, it must be fixed so that it can have its normal shape and start the initial loadings. Normal operation of the biodigester boils down to: the initial load, daily loading, gas production and effluent production.

6. Costs of Biodigesters

The quotes were made taking into account the purchase of building materials, mason labor, plumbing labor, pit excavation labor and annual maintenance visits. The quotes for the different sizes of modified GGC 2047 fixed dome biodigesters, model RMB and BEG biodigester in Senegal are shown in **Table 6** below.

Table 6 provides information on the prices of different models and sizes of biodigester.

We notice that the BEG Biodigester is more expensive than the other two models. The RMB model biodigester is less expensive than the modified GGC 2047 fixed dome.

Table 6. Quotation of the different sizes of biodigesters.

FIXED DOME GGC 2047 MODIFIED SENEGAL MODEL						
	8 m^3	10 m^3	12 m^3	14 m^3	16 m^3	18 m^3
Bio + pit	756,291 CFA Francs	828,704 CFA Francs	864,777 CFA Francs	997,476 CFA Francs	1,047,771 CFA Francs	1,112,451 CFA Francs
RMB SENEGAL MODEL						
			RMB4	RMB6	RMB 8	RMB 10
RMB installation with blocks, without reactor			489,153 CFA Francs	606,845 CFA Francs	909,237 CFA Francs	1,063,640 CFA Francs
BEG BIODIGESTOR						
		BG6	BG8	BG10	BG12	BG14
Bio + pit		972,000 CFA Francs	1,057,383 CFA Francs	1,135,028 CFA Francs	1,203,406 CFA Francs	1,265,973 CFA Francs

7. Conclusion

We studied the construction technology of Biodigesters in Senegal. This study shows the different biodigesters used in Senegal. The results also show that it would be wise to encourage the installation of RMB model biodigesters because of the advantages they present in particular on gas production and the simplicity of its installation. It requires a cheaper price compared to the modified GGC 2047 model. It would be much more interesting if we managed to develop the use of biogas in generators given the advantages it has to offer.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Abbreviations List

BEG: Bio Energy Green
GGC: Global Gas Company
PNB: National Domestic Biogas Program
RMB: Red Mub Biogas

Units

m: Unit of length or width or height
m^3: Volume unit
kPa: Kilo Pascal: pressure unit
CFA Francs: Cuurency of Senegal