The Biogas Role in a Cassava Starch Factory in Nigeria: A Case Study

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Abstract

Biogas, as renewable energy form, can properly substitute conventional sources of energy (fossil fuels, oil, etc.) which are causing ecological–environmental problems as fast increasing of CO_2 emissions. The biogas consists essentially of methane (CH_4, 50÷75% by volume), carbon dioxide (CO_2, 25÷45%) and water vapor (H_2O, 2÷7%), as well as other gases in smaller concentrations, including hydrogen sulfide (H_2S). The heating value of the biogas is a function of its content in CH_4. On average the Net Heating Value can be considered equal to 20,000÷24,000 kJ/Nm^3. Biogas plays a fundamental role for energy production in the food processing industries, a case study of a biogas implementation in a cassava starch factory in Bayelsa State, Nigeria is reported. Cassava peels and roots, wastewater from washing and cleaning cassava tubers are used in thermophilic / mesophilic anaerobic reactors to produce biogas suitably used in internal combustion engines. Hot water and electricity are produced, which are able to support the energy needs of the factory and the village located around it.

Keywords: *Biogas, Anaerobic Digestion, Cassava, Combined Heat and Power Plant, Methane*

Introduction

Cassava is one of the most important edible root-vegetables which is totally produced and consumed in developing countries. It is the sixth crop in the world after maize, rice, sugar cane and potato in terms of global annual production. It affects over half a million inhabitants of more than 100 tropical and subtropical countries. In developed countries, where it is a foodstuff of minor importance, cassava is commonly known only in the forms of tapioca, starch pearls or flakes, or as a component of animal rations. In developing countries, however, it is a major food staple. Its cultivation is largely widespread in these areas and this is due to the fact that cassava is highly productive and the crop grows well in various soil types and ecologies, also if they are poor soils. It is also tolerant to periods of drought in fact even under harsh environmental conditions cassava will provide some food when other crops fail. This is also relatively disease free and pest resistant. It can be planted alone or in association with many other crops (such as maize, groundnuts, vegetables, rice) in order to improve soil properties. Four primary industrial products from cassava are: cassava flour, crude ethanol, native starch and animal feed/cassava chips and pellets. These products are commonly traded and show the highest potential for growth in demand. They are associated with medium and large scale processing. In the domestic market, industrial cassava products compete with traditional cassava products mainly gari. Furthermore, each of the main industrial products (cassava flour, chips for animal feed, chips for food grade ethanol, and cassava starch) faces competition from identical imported products, and substitute products that are either being imported or locally grown. For domestic cassava flour the main competitive product is wheat flour. For cassava chips/pellets it is feed grains. For ethanol it is ethanol from other sources, and for starch it is corn/maize starch.

Starch is composed by a large number of glucose units which are joined together by glycosidic polymeric carbohydrate. This polysaccharide is produced by most of green plants as an energy store. In fact during the growing season, the green leaves collect solar energy and in the plant with tuberous roots, this energy is transported as a sugar solution to the tubers and here it is converted to starch in a granular form, occupying cell interior. This transformation is up to specific enzymes. As told before, one of the most important cassava products is starch.

It can be produced in different forms i.e. starch extraction industries produced both unmodified and modified starch which can also be manufactured into glucose or dextrin. The use of starch and starch products is not only in the food industry but it is also employed as chemical raw material such as in plastics or to tan leather. In particular the non-food use of starches (coating, sizing and adhesives), is round 75% of the output of the commercial starch industry. A significant consumption of starch is about food industries. In the years before the Second World War cassava starch was largely used for food but, because of the war, the world trade was disrupted. Only in recent years cassava starch production has grown significantly. Starches used in food industries can be unmodified, modified and glucose and they are mainly used as:

- Thickener for soups, baby foods, sauces and gravies, etc.;
- Filler contributing to the solid content of soups, pills and tablets but also of some pharmaceutical products, etc.;
- Binder allowing the consolidation of the mass; in this way it is prevented from drying out during cooking (sausages and processed meats);
- Stabilizer, owing to the high water-holding capacity of starch (e.g. in fee cream);
- Cooked starch food, custard and other forms.

One of the main non-food uses of cassava starch is as adhesive. In fact, thanks to its properties it is a natural adhesive and two different types of adhesives are produced: roll-dried adhesives and liquid adhesives. In manufacture of glue, starch is gelatinized in hot water or by the use of chemicals while for the conversion into dextrin it is subjected to the action of chemicals, heat and enzymes which disrupt it. In these kinds of uses a different level of starch purity is required: to produce gelatinized starch adhesives, starch of medium-quality can be employed while in dextrin manufacture only the purest starches with a low acid factor must be used. Cassava dextrin is preferred in remoistening gums for stamps, envelope flaps and so on because of its adhesive properties and its agreeable taste and odor.

Starch is used in the following manufacture processes:

- Textile industry: the modified starch is used as warp sizing or to dye clothes. In this way the finished fabrics look brighter and harder. In particular cassava starch is usually preferred because, differently from other starches, it is suitable for sizing coarse yarn (wool). The other important applications are the textile printing and the impression of a design on fabrics which requires a carrier for the dyes and pigments. Furthermore the usage of cassava starch allows the reduction of energy consumption, because it is able to stick also at low temperature differently from other kind of starch, i.e. maize starch is totally sticky when boiled. In Africa, in particular in Ghana and Nigeria, there is the habit to use homemade cassava flour to stiffen fabrics. Cassava starch is also used to make bed sheets and table clothes to give them better quality, maintain their firmness and for their completion. In modern laundries soluble starch is usually used, wrapped with an appropriate propellant in air spray container for applying starch to clothes during steam ironing.

- Wood furniture. Before the Second World War the manufacture of plywood and veneer relied mainly on cassava as glue. The basic material in this case is gelatinized at room temperature with about double the amount of a solution of sodium hydroxide. After prolonged kneading of the very stiff paste in order to give it the required stringy consistency, the glue is applied to the wood with rollers. As the presence of a certain amount of the pulp is useful, medium- to low-quality flours are acceptable or even preferable, although the presence of sand is objectionable.

- Pharmaceutical industries. Another significant use of cassava starch is in the drug making process. It is employed as a bonding and filler element in order to produce tablets in powder formulations. In Nigeria sugar syrup is highly required and for its production a high quality and inexpensive cassava starch is needed. This starch is widely used in the making of tablets, capsules and powder formulations.

- Detergent industries. Also in manufacturing of soap and detergents cassava starch is used, in this way the shelf life of detergents is improved. The main function of the starch in this case is as filler for the soap and it is mixed with the soap particles before milling. The only cassava starch is so widely used thanks to its abundance in Africa.

- Plastic industries. Cassava starch has also been used in order to develop a partially degradable film, replacing the polyurethane and polyethylene films which are pollutant. So new films consist of a combination of 40% of cassava starch and a 60% of polyethylene polymer. In this way a highly degradable product is obtained, but it has the drawback that its production is expensive.

- Production of adhesives. Because of its properties such as a clear paste, water holding, stable viscosity the starch plays an important role in adhesives manufacturing for example in corrugation box industry, paper conversion industry and liquid gum industry. The adhesive matter made of cassava starch is characterized by very low costs thanks to the recovering of that products which otherwise will be wasted. If maize starch is used, it will be necessary to add caustic soda to decrease the pasting temperature from 80°C to 65°C while the use of cassava starch does not require the addition of chemicals. Cassava dextrin which derives from cassava starch is used for the production of carton boxes and other packing materials.

- Production of bioethanol. Cassava starch can also be used to produce bio-fuel, in particular bioethanol. The advantages related to the use of cassava instead of sugarcane, rice or wheat derive from the properties of cassava which can grow also in marginal lands. In Nigeria there are several distilleries which use cassava flour for the production of ethanol.

1 Process Description and Mass Balance

The cassava starch extraction plant is located in Bayelsa State. Bayelsa State is one of the 36 federal States of Nigeria located within the lower delta plain, so in the core of Niger Delta region.

The production of starch which is taken into account in this work consists in two main processes:

- the cassava starch extraction process;
- starch modification process.

The plant consists in several machineries and the major are hoppers, cyclones, centrifuges, extraction chamber which houses screw conveyor (auger) and sieve, discharge outlets and the power unit. The first stage of the cassava starch processing is necessary in order to remove stems, branches and other impurities such as sand or gravels. Peels and woody tissues are removed with the aim of improving the rasping machines yield and so to make them work better. It is now interesting to analyze the mass balance which characterizes this process. For sake of simplicity, each phase can be represented by a single block, the so called "black box". In order to calculate the different flows outing form each phases it is necessary to know the cassava composition.

Table 1 Cassava roots composition.

Cassava compositions	Values	U.M. (%)
Starch	32	%
Fiber	3	%
Water	60.8	%
Protein	1.3	%
Organic	1.4	%
Salts	1.5	%

Furthermore it is necessary to know which is the percentage of cassava peels on the root fresh weight (round 20%). Then it is necessary to know which are the other materials involved in the process, and in this case they are mainly water, steam and air. It is necessary to underline that no chemical additives are required in the starch extraction process. It is also necessary to understand which the wastes that derive from the process are. At first the removal of sand, gravels, stems and branches occurs. Then cassava roots are peeled so that in the centrasieving and starch washing steps the removal of fibre and pulp is done. The final product of the extracting process is unmodified starch whose flow is round 3.2 t/h. Then 2.5 t/h of unmodified starch are sent to the modifying starch process. Here the consumptions of water, additives, steam and compressed air occur. The final product is modified starch at 14% moisture.

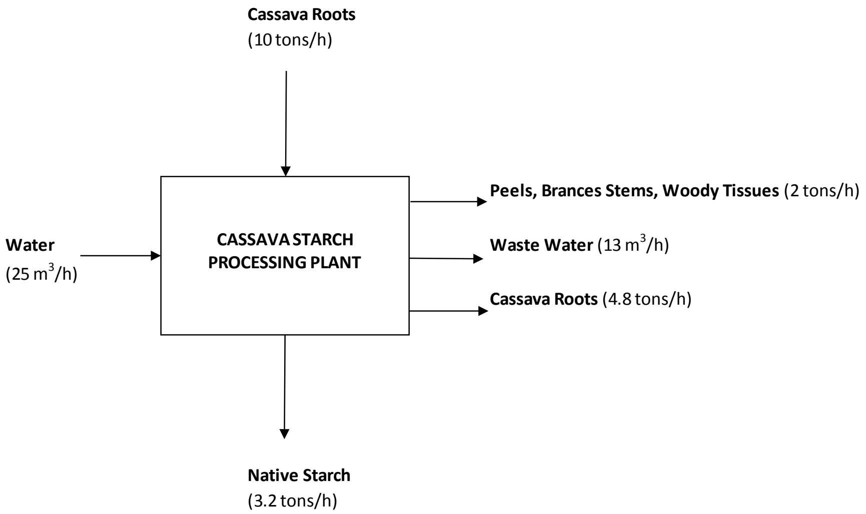

Figure 1 Mass Balance

2 Cassava Biogas Production

The anaerobic digestion consists in a series of biological processes. In particular, four different stages can be distinguished and each one of these is characterized by the activities of several microorganisms that break down biodegradable material in order to degrade complex substances such as lipid, carbohydrates and proteins. So the anaerobic digestion is the biodegradation of the organic matter in anaerobic conditions which means without molecular oxygen O_2or bounded with other elements such as NO_3^-. The end products are:

1. Biogas which can be combusted to generate electricity and heat, or can be processed into renewable natural gas and transportation fuels. Biogas is a combustible gas, composed primarily of carbon dioxide and methane. However in order to use methane as energy vector the removal of non-methane components is necessary.
2. Wet and mineralized sludge which is a metastable product, subject to very slow decomposition with improved fertilizing characteristics.

The yield of anaerobic digestion is strictly related to the growth of bacterial species involved in the process. Among the several factors which influence the efficiency of the process, the temperature is very important because the presence and also the growth kinetics of bacterial populations are affected by the temperature conditions. So the choice of the best temperature is very important to carry out digestion.

1. Biogas can be obtained from agricultural products, plant materials, animal manure and slurry but also from the organic fraction of municipal waste, sewage slurry. In the last years several studies have been done on the so called energy crops which are dedicated crops. The benefits which involves with the production and use of biogas from anaerobic digestion are both environmental and socio economic for the society but also for the farmers.
2. Thanks to biogas production local economic situation, working possibilities in rural regions and the capability of buying power have enhanced. At the same time life conditions, economic and social growing have improved too. The benefits are the following:
3. Renewable source of energy. Biogas is a permanently renewable fuel because it is a product of the anaerobic digestion of the biomasses.
4. Reduction of greenhouse effect. The use of fossil fuel causes an increase in the CO_2 concentration in the atmosphere. Carbon dioxide is only one of the six greenhouse gases; the others are methane, nitrous oxide, ozone, water vapor, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride. These gases (GHG) are the main responsible of the global warming.

   It is necessary to underline that the combustion of biogas liberates CO_2, however this is different from fossil fuel because the carbon in biogas was recently up taken from the atmosphere, by photosynthetic activity of the plants.

5. Waste reduction. Anaerobic digestion process can be employed as transformation of waste materials into a valuable resource, by using them as a substrate for anaerobic digestion. So by the use of anaerobic digestion, the volume of waste the costs for waste can be decreased and so disposal can be reduced.
6. Use of biogas. Biogas is a flexible fuel vector and so it could be used for cooking and lighting but nowadays it is in particular used for combined heat and power generation (CHP) or it is upgraded and fed into natural gas grids used as vehicle fuel or in fuel cells.
7. Job creation. The anaerobic digestion process could be seen as a potential source of work. In fact the activities related to a biogas plant are several such as the collection and transport of the feedstock, the operation and maintenance of this kind of plant. The diffusion of this activity implies the development of a new market sector which includes the manufacture of the necessary equipment. This are the reasons why anaerobic digestion process creates new job opportunities. Moreover, its diffusion in rural areas helps the increasing of the incomes because it is a decentralized technology so it is affordable also to these people who live there.
8. An excellent fertilizer. One of the products of anaerobic digestion is the digested substrate, also called digestate. It is rich in nitrogen, phosphorus, potassium and micronutrients and so for its chemical properties it is suitable to be a valuable soil fertilizer. It is already used in agriculture in particular in those soils where usually liquid manure are used. It is interesting to notice that, due to a better C/N ratio, higher homogeneity and nutrients availability, digestate has an higher fertilizer efficiency than the one of raw animal manure.
9. Reduced odors and flies. During anaerobic digestion microorganisms use most of the organic matter as a nutrient. So the digestate percentage of organic matter is reduced. As a consequence persistent and unpleasant odors together with attract flies are almost completely (up to 80%) eliminated. Digestate is almost odorless and the remaining ammonia odors disappear shortly after application as fertilizer.

The biogas plant is fed by the effluents which derive from the cassava starch processing plant. So the resulting wastes are roots, branches, leaves or steams but the major products are peels. Waste water flow which enters is round 25 m^3/h of which 12 m^3/h is water which contains sand and gravels and of which 13 m^3/h of water with an organic matter content round 18,000 mg/l of COD (Chemical Oxygen Demand).

The flow of wastes which come out from the starch production process and which can be used in anaerobic digestion is as follow:

Table 2 Feedstocks flow calculations (7,200 working hours per year)

Substrate	**Quantity**			**Percentage (%)**
	(t/h)	**(t/d)**	**(t/year)**	
Cassava Peels	2	48	14,400	10.10
Water treatment	13	312	93,600	65.66
Cassava roots	4.8	115.20	34,560	24.24
Total	19.8	475.20	142,560	100

Table 3 Volatile solids percentage in feedstocks

Substrate	**Quantity (t/h)**	**TS (%AR)**	**VS (%TS AR)**	**VS (%AR)**
Cassava Peels	2	23.15	83.93	19.43
Water Treatment	13	1.63	50	0.82
Cassava Roots	4.8	38	99	37.62
Total	19.8	12.62	65.31	11.62

Table 4: Biogas and methane production

Substrate	Quantity (t/h)	Biogas (m^3/h)	% CH4	Methane (m^3/h)
Cassava Peels	2	104.53	51.4%	53.7
Water Treatment	13	121.49	50.0%	60.7
Cassava Roots	4.8	855.93	50.0%	428.0
Total	19.8	1081.96	50.1%	542.4

In the table above the percentage of biogas production are reported and it can be noticed that the major contribute to its production is given by the cassava roots which are wasted or the parts of the cassava roots (not the peels) which are solid waste products of the process. The value of the methane produced in a year allows the calculation of the energy which can be obtained by the biogas outing from the anaerobic digestion process, assuming a methane net heating value round 50,000 kJ/kg. Then both the electrical and thermal power are calculating using gensets which are a CHP Plant (Combined Heat and Power Plant).

Table 4 Electric and thermal power production

Index	Definitions	Calculation	U.M.	Value
a	Methane density		kg/Sm^3	0.72
b	Methane net heating value		kJ/kg	49.99
c	Methane net heating value	c=a*b	kJ/Sm^3	35,782.67
d	Methane flow		m^3/h	542.40
e	Inlet power biogas	e=(d*c)/(3,600*10^3)	MW	5.39
f	Electrical efficiency		%	36.10
g	**Electrical power**	g=e*f	MW_{el}	**1.95**
h	Thermal efficiency		%	53
i	**Thermal power**	i=e*h	MW_{th}	**2.86**
l	Losses percentage		%	10.90
m	Losses	m=e*l	MW_{losses}	0.59

It is necessary to underline that methane density has been calculated as:

Table 5 Methane density

Index	U.M.	Value
C	12	g/mol
H	1.0079	g/mol
CH_4	16.03	g/mol
V_{mol}	22.04	l/mol
Density CH_4	0.72	kg/Sm^3

Factory needs only 1,000 kW electrical energy to run this means that electrical energy in surplus can be used to feed village around it.

3 Environment Impact of the Factory

The environmental impact of the factory is mainly due of emissions from transport of raw cassava and from two internal combustion engines that run the factory. Biogas plant is an anaerobic digestion plant and its emissions are considered not significant and so no authorization is necessary. Then, no emissions of odors or aerosol occur because the system is correctly designed and sealed. Moreover is interesting to calculate the CO_2 emissions saving using biowastes derived from the processing of cassava.

Table 6 Estimation of equivalent CO_2 saving

Index	**Definitions**	**Calculation**	**U.M.**	**Value**
a	Electric power		kWel	1,950
b	Thermal power		kWth	2,860
c	Reference generation plant consumption		Kgoil_eq/kWh	0.187
d	Net Heating Value Oil		MJ/kg_{oil}	41.86
e	Net Heating Value Diesel		MJ/kg_{diesel}	42.69
f	Reference generation plant consumption	f=c*d/e	Kg_{diesel}/kWh	0.183
g	Reference generation plant consumption	g=f*e	MJ/kWh	7.81
h	Reference boiler efficiency		%	90
i	Thermal power recovered referred to electrical energy	i=b/(h/100)*3.6/a	MJ/kWh	5.87
l	Primary energy saving	l=g+i	MJ/kWh	13.68
m	Primary energy saving	$m=(l*a/d)/10^3$	TOE/h	0.637
n	Working hours		h/y	7,200
o	Yearly energy saving	o=m*n	TOE/y	4,586
p	CO_2 emission coefficient (oil equivalent)		tCO_2/TOE	3.164
q	Oxidation coefficient			0.99
r	**Yearly CO_2 saved**	r=m*p*n*q	tCO_2/y	**14,366**

4 Conclusions

From this research emerges the common problem, present in Nigeria, related to the use of diesel as main fuel for the electric power generation. As said before this indiscriminate usage is principally due to the “epileptic” power supply of the country. For that reason, diesel is the most favored choice as fuel both for domestic and industrial generators. Furthermore, in the last years, an increase in industrialization in Nigeria occurs. Its use causes the production of harmful pollutants which have negative effects not only on human health but also on vegetation. In particular burning diesel, it has been seen that are produced Nitrogen Oxides, Sulphur Oxides, Carbon Monoxide and Particulate Matter while the PM are. This technology allows the reduction of emissions due to diesel engines but not only: solid wastes and the wastewater deriving from the process can be enhanced using them as feedstocks for the production of biogas. In this way, considering a methane content of 50.1%, the electric power produced is round 1.95 MWel and the thermal one is round 2.86 MWth. The last is used in order to produce half of the required flow of steam involving an additional emissions saving. Furthermore, another products which derives from this process is the digestate which can be used as fertilizer. So, it is possible to increase profits by selling it.

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