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Designing, Realisation and Testing of Combined Dryer-Smokehouse/Cow Dung Based Biogas Production Unit Module in Cameroon

Benjamin Diboma[1,2*] and Jacques Bikai[1]

[1]Advanced Teachers Training College for Technical Education, P.O Box 1872, Douala, Cameroon.
[2]National Advanced School of Engineering, P.O box 8390, University of Yaoundé I, Cameroon.

Authors' contributions

This work was carried out in collaboration between all authors. The corresponding author designed the study, but the two authors work together at all stage of this manuscript. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

This article deals with the setting up of a module combining a biogas production unit and a fish dryer-smokehouse. The prototype was designed at the Thermal and Environmental Laboratory (LATE) of the University of Douala, and then experimented during 66 days. The dryer-smokehouse bears a drying or smoking compartment of volume 0.162m^3 partitioned with three perforated grids separating each other by 20cm. On the back part of the drying compartment is mounted a fan which will assure the mixing of the dying air. The combustion compartment of 0.4m^3 locks up the oven which produces heat from the combustion of biogas, regulating organs and air entries. The biogas produced from cow dung serves as fuel to the dryer-smokehouse. The digester used is a batch reactor loaded one time with 150 kgs of cow dung diluted at 45%. The biogas was measured by a liquid displacement method. Experimentations show that the cumulated biogas production is of about 9.13m^3 in 66 days. The average drying time of 4 kgs of fish (*salmo salar*) was 8 hours with our combined module and 7 hours with other traditional dryers. The dried fishes are unblemished compare to that dried by traditional biomass dryers. The designed

**Corresponding author: E-mail: benjamin_diboma@yahoo.fr;*

prototype with an overall efficiency of 1.7 kg of dried fish/ kg of cow dung input is cheaper (€ 600) and ecological, therefore could be a green alternative to traditional biomass dryers.

Keywords: Digester; drier; fish; biogas; drying kinetics.

1. INTRODUCTION

The ministry of rearing, fisheries and animal industries [1], in its annual report indicates that the quantities of fishes produced in Cameroon for the year 2011 has been of 205,000 tons. These quantities of fishes are of a decrease by 5% compared to that of the year 2010, this pushed economic operators to import 195,000 tons of fishes which imputed a cost of €153 millions in order to satisfy in parts the needs of the country estimated to 435,000 tons during the year 2011. Fish is the most consumed alimentary staple (17.9kg/person/year), and its sales contributed for 17% of the GDP of Cameroon within the year 2011. Valuable quantities of fishes are generally preserved for a latter consumption, but given the poor conservation conditions, a loss of about 30% of the conserved quantity is experienced [2].

Modern conservation processes are based on temperature and humidity controls during storage, this entails conservation by cold Collin [3]. Artificial cold conservation requires equipment such as refrigerators or deep freezers to maintain appropriate temperatures, but these consume valuable electrical energy [4]. The extraction of part of water contained in the fish by drying reduces the microbial activity and consequently increases the conservation duration. The three main factors that influence the drying of the food include air temperature, air flow rate, and humidity, which are all independent factors. Although several differing opinions exist, the ideal drying temperature ranges from 35 to 82°C [5]. Echechukwu presented an important review of the fundamental principles and theories of drying processes [6]. Two generic groups, namely, natural circulation solar energy dryers and forced convection dryers were identified [7]. A state of art on solar dryer technologies is presented in the reference [8]. Most solar dryers have a complex functioning and due to their high cost, are rendered unaffordable to the rural populations.

Traditional drying coupled to smoking appears to be the propitious way of conserving fish. This ancient and traditional technique consists of placing the entire or sliced fish (piece) over heat and/or smoke liberated by the combustion of wood [9]. In Cameroon, many studies and projects conducted, lead to the development of a variety of dryers [10-12]. A team from the international cooperation of agronomic research for development (CIRAD) solicited to ameliorate the smoking and drying conditions within Developing countries (DC) was able to put in place a dryer-smokehouse which permitted the cooking, the drying and smoking of fishes [9]. Notwithstanding, this dryer-smokehouse has the inconvenient of using wood whose massive consumption leads to uncontrolled deforestation, putting in danger the stability of the ecosystems. Opened burners are source of lost heat from the excessively burnt wood, and thus are an inefficient way to carry out the drying process. The pyrolysis of wood liberates cancerous-like by-products [13-14] onto the fish during their smoking. Even if the hot smoking associated to salting, permits the obtaining of appreciated products embellishing source dishes [9] the quality of these foods remains questionable. The quality of dried products is altered by relatively high acetic acid concentration and smoke taste [15]. The main inconvenience with biomass dryers come from the fact that, if biomass is wet, the evaporation of the water absorbs part of the available energy, thus reducing the efficiency of the system [16].

Since the last decade, literature on biogas productions, more precisely methane from organic matter is fast growing. Biogas production is mainly brought about through efforts of a high group of various anaerobes (acidogen, acetogen and methanogens) via anaerobic digestion to produce a gas that contains mainly methane(CH_4) (50-70%), CO_2 (20 - 40%) and traces of other gases like CO, H_2S, NH_3, N_2, H_2 and water vapour [17]. In Cameroon, biogas is essentially produced from domestic waste[18-19], the energetic potential of animals excrements (cow dung, etc) is often being neglected despite the biomass and livestock resources of the country evaluated to be of about 9.5 million animals in 2010 [20]. Biogas produced from cow dung is used as fuel for the dryer-smokehouse. This combined unit presents many advantages as it contributes in ameliorating health conditions and in the safety of alimentary staples compared to biomass (wood, charcoal) dryers, it is also cheaper (€ 600). The system is tested over fish drying and can be used for smoking. Even in Africa, fish is one of the most consumed foods, but unfortunately it is the seat of degradations coming from the combined actions of bacteria, enzymes and chemical reactions [21]. The total food fish supply and per capita food fish supply in Africa are shown in Fig. 1. We think that this equipment will contribute to increase the financial revenues coming from fishing and fish sales. The rest of the paper is organized as follows: In Section 2, we present the experimental apparatus and the details of the methods used, while the results obtained are presented and discussed in Section 3.

2. MATERIALS AND METHODS

2.1 Primary Materials

The main constituent of cow dung is debris from cells within the digestive tract and secretion from body as salts, sloughing of animal cells and mucus. Cow dung also includes undigested diet comprising cellulose and lignin. Cow dung is a good source of bacteria [22] and it is reported that abundant proteolysis organism was found to be present in cow dung-fed digesters. Livestock waste is a source of methane emissions, particularly in DC where a large number of animals are intensively housed [23]. The salmon Atlantic breed fish (*salmo salar)* and sold in the local markets has been chosen for drying. This fish whose cost of €1.25/kg is the most consumed in Cameroon.

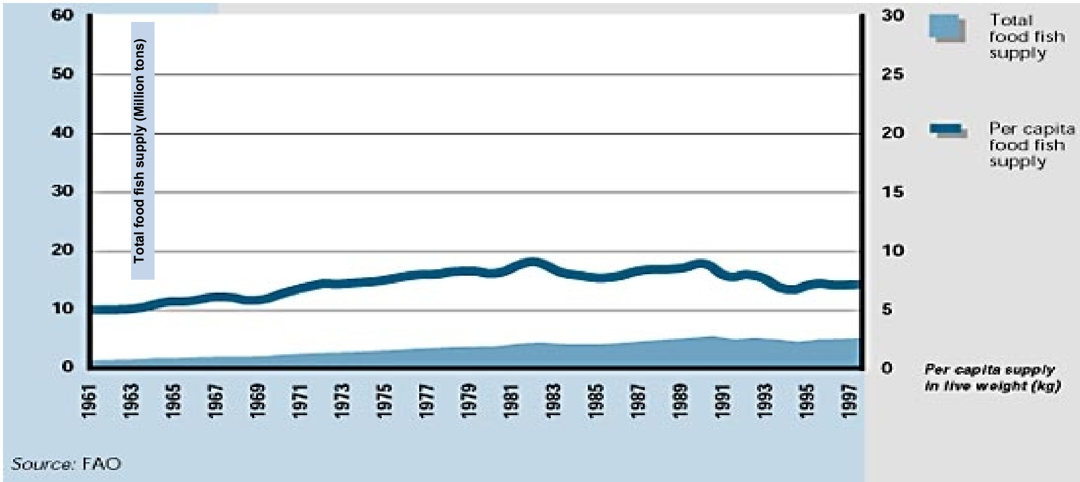


Fig. 1. Total food supply and per capita food fish supply in Africa [24]

2.2 Description of the Experimental Apparatus

The described experimental apparatus, shown in Fig. 2 constitutes of a biogas production unit and a dryer-smokehouse.

2.2.1 Biogas production unit

The digester used is a batch reactor loaded one time with 150 kgs of diluted cow dung. The digester is constructed from a cylindrical mild steel tank of height (0.90m) and diameter (0.58m). Anti-corrosive painting was applied inside the cylindrical shell. The inlet pathway of the waste into the digester system is created at 0.55 cm from the base of the mild steel tank. This waste inlet pathway has a diameter of 0.15 m and it is situated directly opposite the filter influent pathway, linked the digester to the filter via a pressure control U-tube. An exit is created at the front base of the digester so that the sample of the slurry can be removed for observations to be carried upon or for others uses such as organic fertilizer.

The water purification system is preferable to be enclosed so as to ensure that the purifying water does not serve as a breeding ground for mosquitoes. The design filtration system consists of a hollow cylindrical container made up of steel material, reduced at it's underneath level into an exit pipe which removes the filtrate out of the purification. The hollow cylinder is filled with fine, coarse sands and gravels. The replacement of the fine sand, coarse sand and gravel is done after three cycles of biogas production.

The gas collection system's primary role is to collect the biogas produced during the digestion process. The design of the gas collection system in Fig. 3 was systematically made for three functional sections of the system: piping, storage facility and flame trap/outlet. The chosen designed consists of a one-sided open cylindrical container inverted downward over another standing upward. The one-sided open cylindrical container standing upward is filled with a fluid. The fluid provided a gas seal between the inverted cylindrical container and the surrounding environment. At the end of the inverted cylindrical container is attached a meter rule stalk. This rule serves to measure the displacement of the inverted cylindrical container, thus evaluating biogas productions.

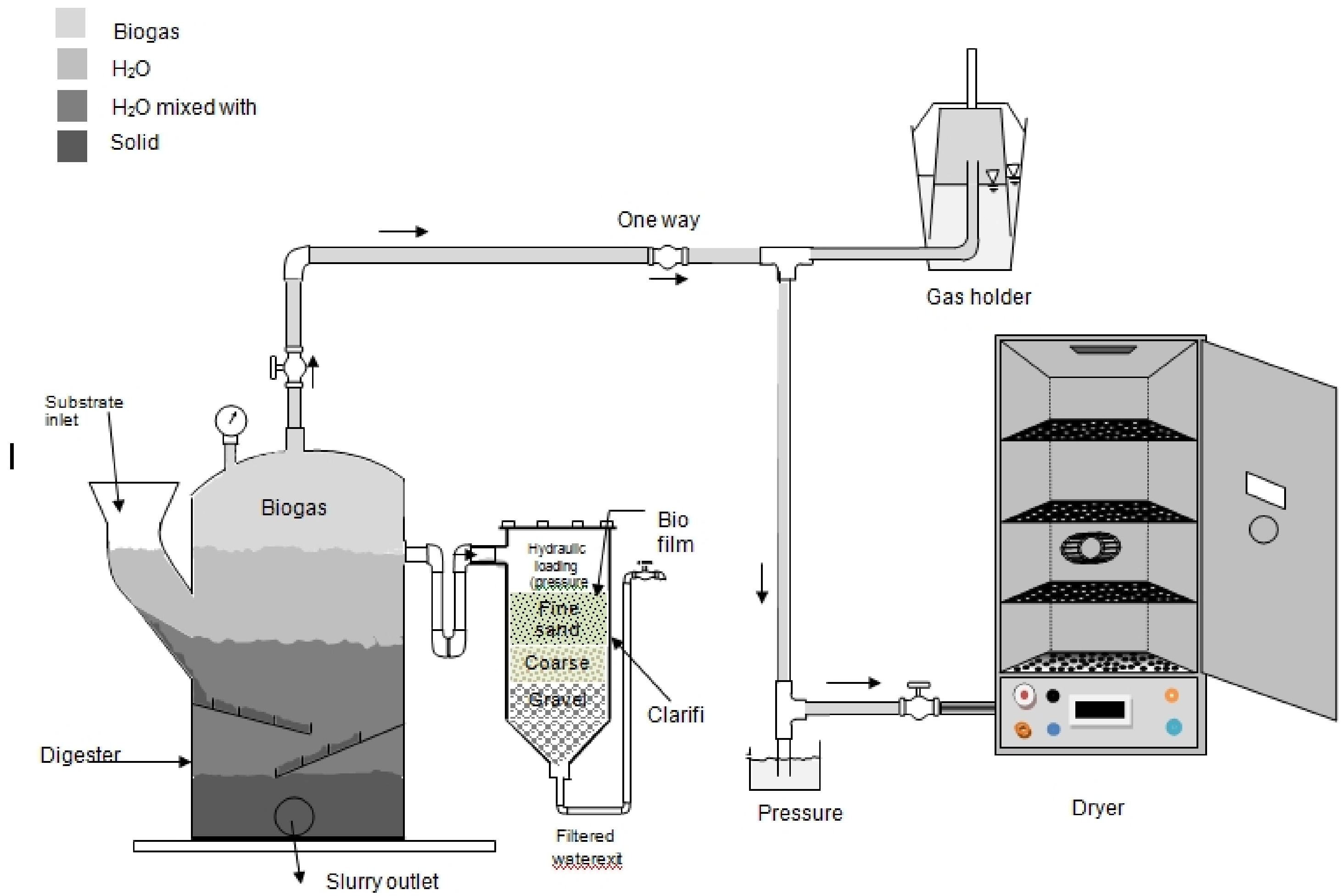
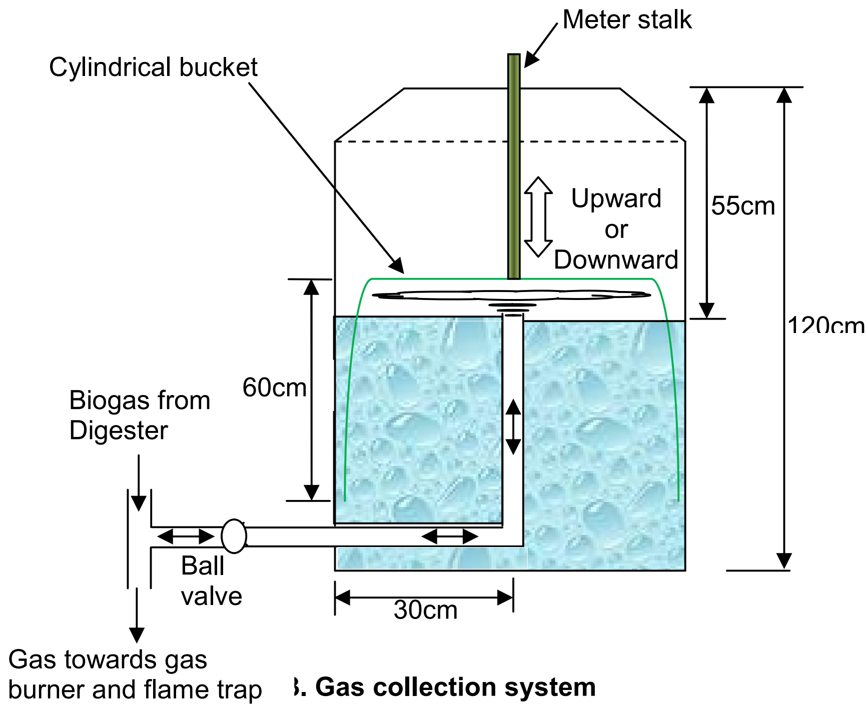


Fig. 2. Combined Module



3. Gas collection system

2.2.2 Dryer-smokehouse

The chimney of 5 cm height and 10 cm width plays the role of exit by which the saturated vapours are evacuated at the time of drying and smokes at the time of smoking. In the drying or smoking room there are three perforated grids separated from each other by a distance of 20cm. It is covered on its four faces by smooth aluminium metal sheets and offers a volume of 0.162 m^3, bearing 0.2 m height, 0.46 m length and 0.44m width. The pieces of fish to be dried are displayed on grids. The capacity of the dryer-smokehouse is of about 1.3 to 1.5 Kg of fish/m^2 of ponds. A fan is mounted on the rear face of the room to assure forced convection. The combustion compartment bears an oven that produces the heat as well as the regulation organs and air entries. The volume of the combustion compartment is of 0.4 m^3. The air entries have a sliding trap-door which permits to regulate the air entry rate.

2.3 Experimentation Methods

2.3.1 Biogas production method

Experimentations were carried out during 66 days in the dry season in the Kedjum-ketum village (Cameroon). The ambient air temperature fluctuates between 27.5ºC and 31.5ºC for an air flow rate of 0.1±0.03m/s. After the recovery of cow dung, weigh (150 kgs) and dilute up to 45%, the digester is supplied with the digested substrate. In order to favour anaerobic digestion of the substrate, the digester is hermetically closed. The substrate is manually mixed by the help of a mixer to obtain a homogenous influent in view of optimising the biogas production process. After the latency phase, the production of biogas begins with biomethanisation. The produced biogas is quantified and stored in a gasometer. The quantification of the biogas is done by the fluid displacement method. When biogas production begins, we observe a displacement Δh which is measured by the help of a meter stalk fixed at the superior part of the gasometer. The daily volume of biogas produced is deduced while taking into account the geometric dimensions of the gasometer and of the registered subsidence/slope Δh. Assumptions were made upon the internal pressure of the gasometer to be greater or equal to atmospheric pressure. A comparative study of this method and the use of Gallus ARCTARIS-2004CF02 mark gasometers carried out on many biogas production prototypes in LATE of the University of Douala (Cameroon) showed a maximum difference of less than 5% of the values obtained [25,12]. The choice of the fluid displacement method for the biogas quantification was privileged because of the acquisition difficulty and maintenance of a gas counter which would render our combined unit more costly.

2.3.2 The fish drying method

During drying experimentations, the temperature in the dryer/smokehouse is measured by a thermo-hygrometry of mark VOLTCRAFT whose temperature ranges between 20ºC and 120ºC. The fish to be dried is hallowed out, washed and soaked/dipped into salt solution for 15 to 20 minutes, then spread on a grill for drainage. It is hence sent into the dryer-smokehouse for drying. The initial mass of the fish to be dried is of 4kgs. Weight measurements of the fish are taken every 45 minutes using a weighing scale of 0.01g accuracy. The weighing method used was the gravimetric method. These weights permitted us to determine the drying ratio and the moisture content loss curve. The drying ratio D_r is calculated as indicated [26]:

$$D_r = \frac{M}{M_i} \tag{1}$$

The moisture content loss curve represents the mass percentage of water contained in the fish with respect to its total mass. The moisture content of fish before drying was estimated using the ASTM test procedures [27]. The tests are performed in the following sequence: the moisture content of the fish W is determined by heating a fish sample of initial mass m_1 *at 110ºC* and measuring the residual mass m_2. Moisture content is calculated as:

$$W(\%) = \frac{m_2 - m_1}{m_1} \times 100 \tag{2}$$

In view of comparing the performances of our system with those already existing, the same quantities of fish (4kgs) were dried in the multipurpose dryer [25] set up in LATE of the University of Douala. The multipurpose dryer bears a drying cell, a smoking cell, a heating plate for cooking and a heating system that use solid biomass as fuel. The drying process presented in Fig. 4 is such that air penetrates at the base of the dryer/smokehouse. This air is filtered and heated, favouring the lowering of its relative humidity. The dehumidified air is then pulsed by force convection into the drying compartment. The displayed fish on the grids progressively dries up liberating its humidity to the drying air.

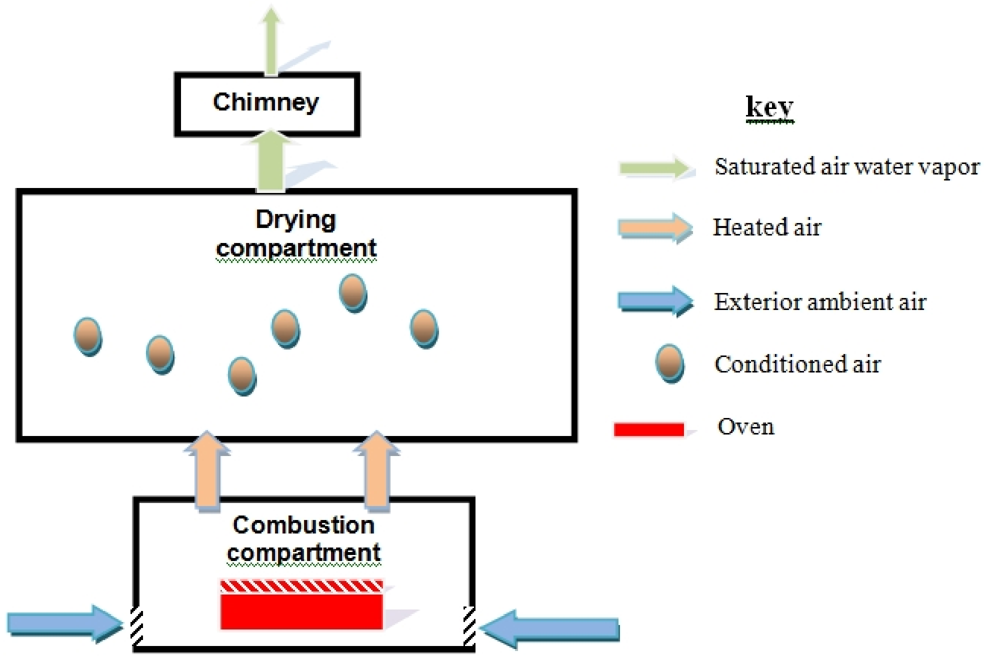


Fig. 4. Drying Process

2.4 Analysis

Three biogas samples were withdrawn on the 17th, 34th and 51st days for chromatography in the gaseous state analysis. The process of chromatography which consists of sending a highly pressurised gas through a column necessitates a chromatograph. The chromatograph used is of type HP 5890 series II, possessing a filamentous thermal conductivity detector (TCD). The operating conditions being as follows:

Detection temperature : 200ºC
Injection temperature : 150ºC
Column temperature : 120ºC
Gas vector flow rate : 30 ml/min

This chromatography takes place in three stages, the injection of mixture into the column by the injection system, separation of mixture components due to their respective affinities for the stationary phase and the detection of the mixture components.

3. RESULTS AND DISCUSSION

3.1 Biogas

3.1.1 Quantity of biogas produced

Fig 5 presents the cumulative biogas produced while the daily biogas produced is shown in Fig 6. The cumulative biogas produced is 9.13 m^3 in 66 days after closing the digester. The effective biogas production period begins from the 11th day to the 66th day. The biogas daily production outlines three successive phases. These are, the latency phase of a period of 11days characterized by a very weak biogas production (0.27m^3), an exponential production phase beginning from the 12th day to the 31st day with a daily peak biogas production of 0.35m^3 and lastly a decreasing production phase which ends on the 66th day.

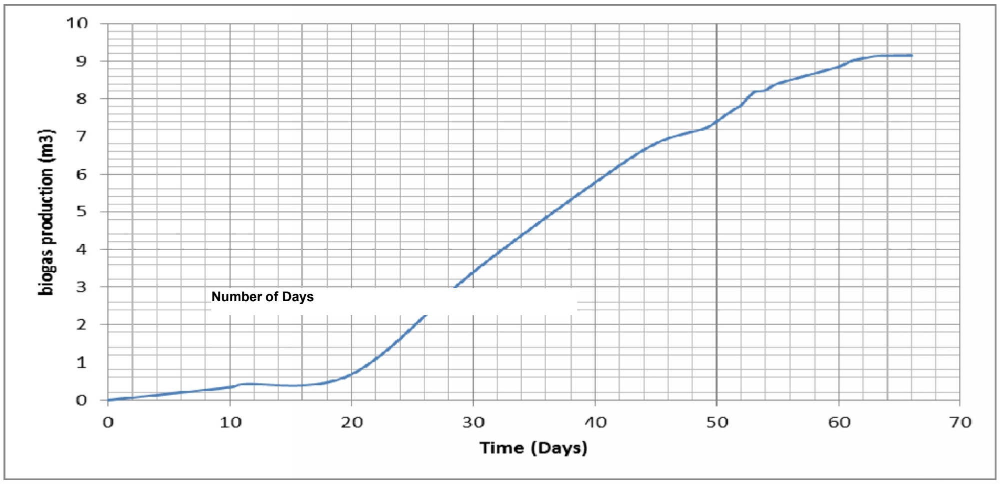


Fig. 5. Cumulative biogas production

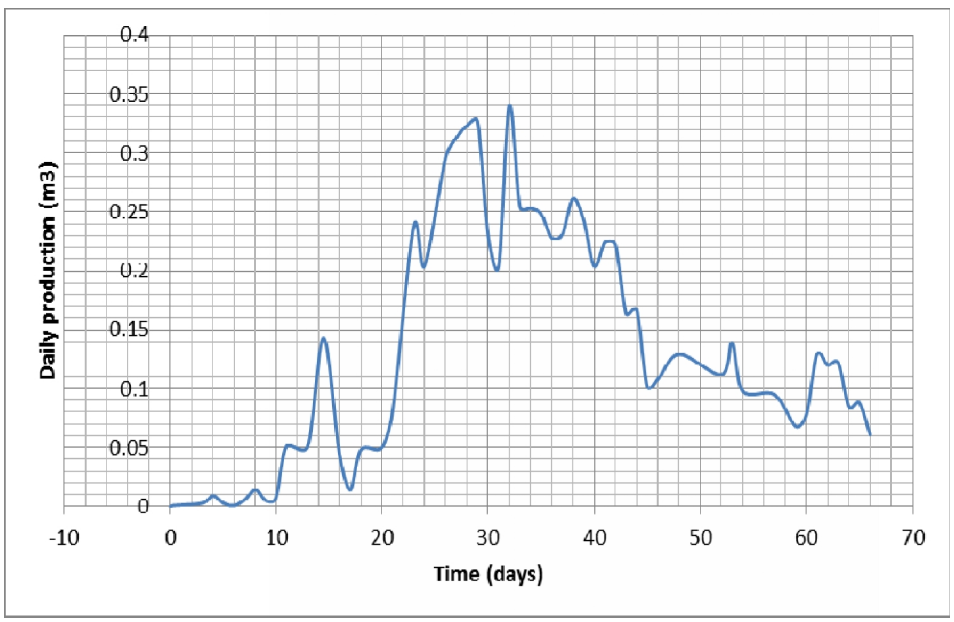


Fig. 6. Graph showing Daily trend of biogas production

The existence of these three phases in the biogas production is in line with the principles governing the biomethanisation process and the results found in the previous studies. A similar device put in place at the renewable energy development center (CDER) in Algeria, permitted the production of 26.8m^3 of biogas in 77 days from 440 kgs of cow dung diluted in

30% [28]. A study carried in Cameroon over the production of biogas from stercoraceous matter permitted to obtain a cumulative biogas production of 162 m^3 in 62 days from a mass of 800 kgs after closing the digester [29]. Stercoraceous matters are a mixture of products coming from slaughter houses (horns, blood, greases, dung contained in the belly, etc). A comparative survey of the biogas production from dairy cow, swine manure slurries in Canada, showed that after 272 days in a discontinuous digester, the production of the biogas varied respectively from 0.59 to 0.61 m^3/ m^3 of manure and from 7.34 to 7.43 m^3/ m^3 manure respectively for the dairy cow and the swine [30].

The production of biogas compared to the quantity of waste introduced into the digester of our combined unit is 0.060m^3/kg cow dung, almost identical (0.061m^3/kg cow dung) with the model put in place by the CDER. It is important to note that in the prototype put in place by CDER, heating the digester to a temperature of 35ºC increases the electricity consumption and its exploitation whereas in our combined unit, heating is carried out by natural convection. Our combined unit permitted us to obtain biogas with 45% dilution, permitting to make important economy in water given a dilution rate of 100% is recommended for animal waste biomethanisation [28]. The activity of micro-organisms favoring biomethanisation is influenced by the milieu's conditions. The pH evolution in Fig.7 can be divided into three phases: an acidification phase, an alkalization phase and a stabilization phase for the substrate's pH. Fig 6 shows a coincidence between the substrates phases of pH evolution and of biogas production. The acidification phase which goes from the 1st to the 14th day corresponds to the period of low biogas production and during which the substrate's pH decreases from 7.2 to 6.8 thus a reduction by 5.5%. The alkalization phase marked by a lower pH evolution (between 6.8 and 6.9) is the lengthiest (from the 15th day to the 38th day) and bears the optimum biogas production phase. The stabilization phase began from the 39th day, were marked by a return to the starting experimentation values followed by a stabilization of the latter.

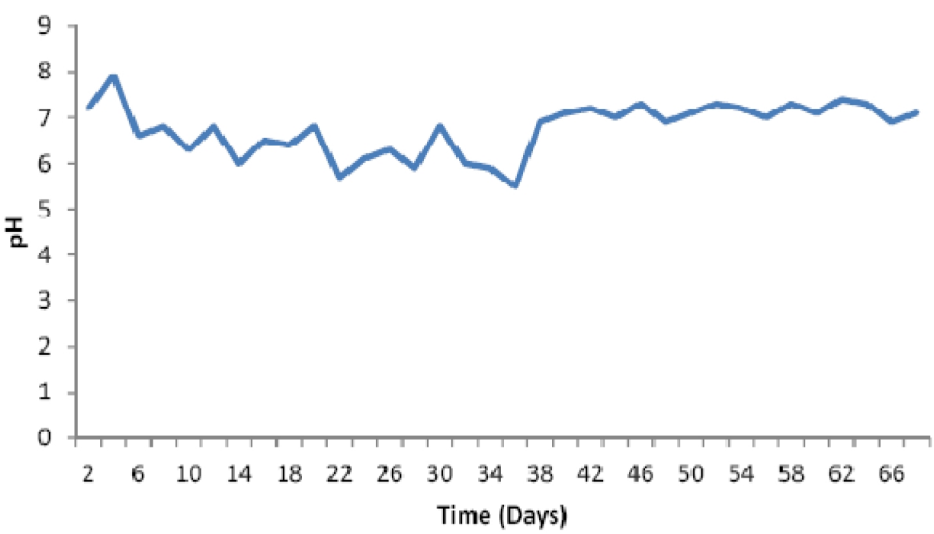


Fig. 7. Evolution of the pH

3.1.2 Quality of biogas produced

The biogas which is produced could be a source of energy in various processes (production of heat, electricity production) and consequently must be richer in methane. Table 1 presents the biogas composition obtained by chromatography.

Table 1. Biogas composition

Sample number	Analysis date	Main constituents	Quantities (%)
01	17th day of production	N_2	6.62
		CO_2	35.4
		CH_4	56.4
02	34th day of production	N_2	1.46
		CO_2	36.02
		CH_4	61.51
03	51th day of production	N_2	4.63
		CO_2	33.6
		CH_4	59.6

The biogas produced by the combined unit is essentially constituted of methane (60.17%) and carbon dioxide (36.72%). The following composition of the biogas indicated in previous studies. The average composition of produced biogas contains 61% of methane and 35.65% of Carbone dioxide [28], 59.8% of CH_4 and 35.8% of CO_2 in the reference [29]. The maximum differences between the results obtained and those of other researches/studies are lower than 5%, indicating our system is viable. However, ameliorations such as the inclusions of a less energy consuming heating system for the digester, a controlled ration for cows/animals are necessary.

3.2 Fish Drying

The study of drying entails the determination of the relative humidity loss curves. Fig. 8 presents the evolutions of the relative humidity loss.

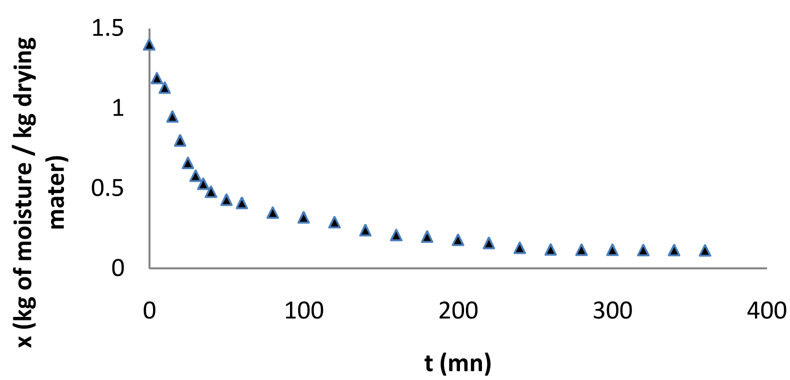


Fig. 8. Curve showing the trend of the fish's water content during its drying

Affirmations of water loss are made after observing the relative humidity loss curve, implying there is evaporation and consequently mass transfer. Two phases are observed in the water loss curve. These are, the rapid migration phase and the decreasing phase. A light fluctuation is observed on the relative humidity loss curve and this can be explained by infiltrations resulting from systems' air tightness imperfections. Fig. 9 shows the evolution of moisture content of the fish during drying when multi-purpose dryer is used.

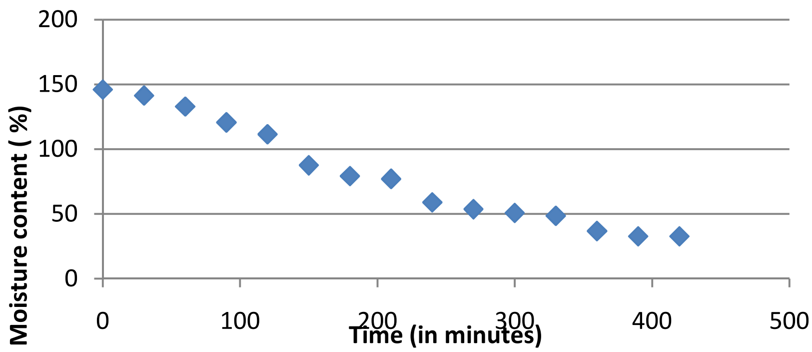


Fig. 9. Evolution of moisture content during drying

The initial water content in the fish is 70%, by the end of drying, its value drops to 20%.The average speed of water removal is of 0.49 kg of water/h with the combined system and 0.56 kg of water/h when the multipurpose dryer is used. At the beginning of drying, the drying rate is low and shows a light withering. After, the phase of decreasing drying speed occurs when the fish's surface is dried; water reaches the surface at the liquid state after channelling into the fish's capillary network and entirely leaves the surface at the vapour state. The success of the drying process is indicated by the existence of different drying phases. During the drying, we observe that fishes displayed on the third grid got dried faster than others, also there were permutations of grids every three hours in other to homogenise the fish drying. Fig. 10 shows the evolution of temperature in the dryer. Operating temperature varies from 30 to 95ºC.

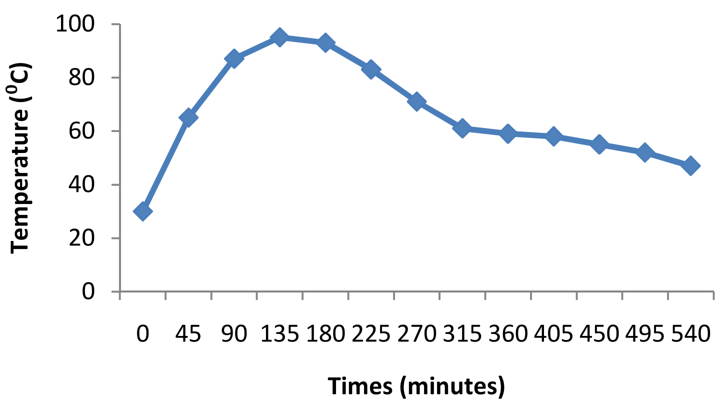


Fig. 10. Temperature evolution in the dryer

Results of many studies and experimentations on drying of alimentary staples are presented in the literatures. In the reference [25], drying of 2.5kg of fish was carried out in 6 hours, the temperature in the dryer varied between 32ºC and 120ºC, the speed of removal of water was 0.19kg of water/hr. The drying phases observed were similar to those obtained by the combined module. In the reference [11], beef samples of thickness 0.015cm were dried within 15hrs in a heat pump dryer of the LATE, the ventilation speed being 212m^3/hr. The results obtained showed the existence of different drying phases. Similar results were obtained in the reference [31-33]. In the reference [34], the author makes a comparative study of many types of dryers (heat pump, direct air opened solar dryer, electric dryer, multipurpose dryer of the LATE). The results of these studies show a convergence with those obtained by the combined dryer-smokehouse/cow dung based biogas production unit module, as far as the existence is concerned and look of the drying curves as well as the evolution of the temperatures in the dryer. Nevertheless, if the energetic performances, the texture and the state of the dried fish are almost identical with those of most dryers, our model has the advantage of being less costly and the dried products are safe. Table 2 shows the efficiencies parameters concerning the combined system set up and the multi-purpose dryer of LATE.

Table 2. Efficiency parameters of dryers

Parameters	**Combined dryer-smokehouse/ biogas production unit**	**Multi-purpose dryer (LATE)**
Type of fuel	Cow dung	Charcoal
Drying time	8 hrs	7 hrs
Overall efficiency of the system	1.7 kg of fish dried/ kg of cow dung input	1.35 kg of fish dried /kg of charcoal input
Fuel Unit cost	€ 0.045/ kg of cow dung	€1.05/ kg of charcoal
Manufacturing cost	€ 600	€ 229

Source: Author's experimentations and investigations

The average drying time of 4 kgs of fish (*salmo salar*) was 8 hours with the combined system and 7 hours with others traditional dryers, but the dried fishes are unblemished when the designed equipment is used. The overall efficiency of the designed system is 1.7 kg of fish dried/ kg of cow dung input, this range of value is appreciable.

4. CONCLUSION

The aim of this work was to set up a combined biogas production unit/drier-smokehouse module and to test it upon fish drying. After 66 days of digestion of 150 kgs of cow dung, 9.13m^3 of biogas was obtained. The production of biogas compared to the quantity of waste introduced into the digester of our combined unit is of 0.060m^3/kg cow dung input. Analysis of the produced biogas indicated that it is essentially constituted of methane (60.17%) and carbon dioxide (36.72%). The drying of 4 kgs of fishes was done in 8 hours, the texture of the dried fishes is appreciable and they are unblemished. The overall efficiency of the designed system is 1.7 kg of fish dried/ kg of cow dung input; consequently it will improve the drying conditions in Cameroon. The quality of dried fish is best when the designed system is used. Efforts should be centred on informing and sensitising the population on the benefits offered by biogas. In order to avoid environmental attacks, methods such as combustion by flaring or thermal cracking in view of producing hydrogen should be made popular. A financial and technical support should be allocated to the development of biogas valorisation models.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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