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Experimental Contribution to the Phenomena of Methanisation by Co-digestion of Organic Waste from the Residence of the Cheikh Anta Diop University in Dakar

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Abstract In this work we undertook a series of experiments to evaluate the biogas potential of the waste from the UCAD university residence. The first experiment revealed several types of waste at room temperature in a 1.5-litre canister equipped with an empty inflatable balloon used to recover biogas, which was our bio-digester. A shaking is done on each digester once a day. The pH was measured at the beginning and end of each experiment. The production of biogas appeared after two days. The second experiment consisted in allowing a temperature of 40°C (mesophilic temperature) and continued at room temperature by shaking the reactor once a day. For this experiment, we found that some bio-digesters started to produce after two hours of time. The inflatable balloon increased in volume every hour until 24 hours before remaining constant or continued to produce throughout the experiment. Then it was a question of co-digesting waste with the best biogas potential. It appears that the co-digestion composed of cow dung and UCAD sewage sludge gives the best production. In the last experiment, the assembly of a two-liter bio-digester equipped with a manual mixing and grinding system and a gasometer made it possible to produce biogas under the influence of temperature and agitation, which took place almost three times a day. The objective of this work is to propose a new biogas production technique that will allow better management of organic waste, the production of flammable gas and open up a new alternative to the development of the rural world because biogas production in the rural world cannot have the same temperature conditions as the industrial one, so our research will provide part of the solution to this problem. Finally, we solve an environmental problem and contribute to the edifice of sustainable development.

Keywords: *methanisation, bio-digester, organic waste, environmental problem, sustainable development, rural world*

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1. Introduction

An anaerobic digester (also called a bioreactor or fermenter) is essentially a closed, airtight tank, preferably thermally isolated from the outside, in which different bacterial species take turns to degrade organic waste or effluent compounds and produce biogas [1,2], composed mainly of methane but also carbon dioxide[3], while reducing by half the rate of organic matter represented by biodegradable by-products [4,5]. This oxygen-free environment must respect several parameters in order to lead to different optimized and controlled reactions to produce biogas that can be recovered in different forms [6,7]. With a methane content ranging from 45 to more than 75%, biogas is one of the best exploited forms of renewable energy for years and is also suitable for replacing fossil fuels [8,9]. The low energy supply rate of rural populations in developing countries is a major handicap for their socio-economic and environmental development. Biogas can address a number of specific problems in the fields of energy, health and agriculture [10]. It is recognized as one of the most energy-efficient and environmentally friendly [11] and allows the local level to produce energy at a lower cost for cooking, heating, lighting and organic fertilizers for better fertilization of the soil for crops [12,13]. Nowadays the biogas use policy is widely disseminated through government institutions involved in subsidy programs, planning, design and implementation, construction, operation and maintenance of systems. As a result, several countries in Asia and Africa, including China, India, Nepal, Bangladesh, Cambodia, Vietnam, Kenya, Rwanda, Tanzania, Burkina Faso and Senegal are launching massive campaigns to promote biogas technology [14,15]. For a good diversification of energy resources from biomass, the management and valorization of waste from organic materials of various origins such as animal manure, household waste, vegetable and organic materials, by-products of the agri-food industry, in particular slaughterhouse waste, station sludge, etc. by anaerobic fermentation is a path to sustainable development [16,17,18]. With growing interest, renewable energies from biomass are constantly being undertaken to cope with the highly fluctuating energy value situation and significantly reduce local pollution and the greenhouse effect [19,20,21,22]. The assembly or design of the bio digester is not difficult. Nowadays they are built on site or prefabricated with different materials, such as brick, concrete and plastics [23] and thus it is possible to produce a widely available, inexpensive and non-polluting renewable energy that can be converted into almost any form of useful energy [24,25]. One of the secondary objectives of this study is directed towards the need of the rural world to satisfy its energy needs while recovering its own waste and thus considerably reducing the rate of use of fossil fuels, which are sometimes even scarce. As a reminder, the energy value of one cubic meter of biogas corresponds to 0.42 kg of liquefied petroleum gas; 4.34 kg of dry wood; 0.6 liters of petroleum and 5 to 6 kWh of thermal energy; but also the destruction of many pathogens, the elimination of odors from animal waste and human excreta, the protection of runoff and underground water. In addition, one cubic meter of effluent corresponds to 10kg of ammonium sulphate, 4.5kg of super phosphate, 10kg of potassium sulphate and other fertilizing elements [10,26,27]. The other objective is to contribute or propose a new biogas production technique because we have found that several bio digesters built in Dakar do not produce biogas efficiently or at all. This observation allowed us to conduct a series of experiments and propose a co-digestion substrate with good methanisable potential and a rather endogenous technique for biogas production. Better still, from this research, we can define the concepts of sustainable development [28] because anaerobic digestion represents one of the major actors of sustainable development and the circular economy in the concept of "waste to energy". Given the great diversity of organic waste, its development requires the optimization of co-digestion. Hence the need to develop simple tools to characterize substrates and predict digester performance in order to optimize their operation [29]. In the face of a growing population, the consumption of energy from biogas can also contribute to the particular problem of women's poverty [30], especially in rural areas, where people prefer to cook by cutting down trees, thus promoting the advance of the desert. Traditional cooking with firewood causes a faster depletion of biomass resources and increases women's time and labor burden because they need this time to collect firewood. In addition, the energy use of wood has a negative impact on women's health due to the smoke released during cooking. The use of biogas helps to significantly reduce women's time and work, which could be used for other productive purposes, and to improve their health conditions [31]. At the same time, more than 60% of total wood in developing countries is used as firewood in the form of either charcoal, mainly in urban areas, or firewood, mainly in rural areas. By 2040, the world is expected to have between 9 and 10 billion inhabitants and must be supplied with energy and materials. This will result in depleting forests at a faster rate than they can be replaced. Biogas is well positioned for the next generation to replace wood as an energy source in developing countries[32] Although human excrement and other waste can be used to produce biogas energy, which is beneficial to people, negative connotations are attached. Some people can see the biogas produced separately. Some people may see biogas produced from human excrement as dirty and unfit for use, especially for cooking [33]. Nevertheless, the new uses of biomass benefit from the advantages of modern biomass conversion technologies (combustion, pyrolysis, gasification, fermentation, anaerobic digestion) for the production of heat and electricity, as well as transportation fuel, etc. [34].

2. Materials and Method

The experiments were carried out at the Cheikh Anta Diop University in Dakar in the physics and application laboratory. We used the resources in terms of substrate and equipment on site. As for the bio digester, which no longer produces biogas, the one in the animal biology department served as an example of work. The installation of a simple bio digester for biogas production has been completed and the expectation of the expected results has been satisfactory.

2.1. Substrate

Your Our substrates are made up of sewage sludge from the residence of Sheikh Anta Diop University in Dakar, cow dung from the UCAD Animal Reproduction Biology Laboratory, poultry droppings from a local farm, and waste from the UCAD restaurant of two types: vegetables and fruit.

2.2. Methodology

The We conducted three types of experiments:

In the first experiment: we put each substrate in a 1.5-litre canister (digester) equipped with empty inflatable balloons and sealed them tightly while following the behavior of the inflatable balloon. The purpose of this experiment is to work at room temperature and see how long it is possible to produce biogas. In the second part, it is a question of mixing the different wastes in different proportions and following the process always at room temperature.

In the second series of experiments we used the same processes as the first but at mesophilic temperature for the beginning of the operation and continued at room temperature; the objective is to propose the same conditions to the rural digester. During these experiments, the reactors were agitated only once a day. The third experiment takes into account the best result of the second experiment and will be submitted in a two-liter digester under the same operating temperature conditions, with more agitation. Three series of agitation per day were performed for this experiment.

2.2.1. Experimental Device

The For the first experiment at room temperature, we used 7 digesters with a capacity of 1.5 liters. Of which 4 digesters with only one type of substrate and 3 compound substrate digesters with the UCAD sewage sludge as the base substrate.

For the second experiment, we used 7 other mesophilic temperature digesters. The 4 digesters had only one substrate each and the other 3 digesters were co-digested with the sewage sludge as the main substrate.

The choice of our experiments follows the methods of Arnaiz et al. 2006, S. Kalloum et al. 2006, Lastella et al. 2002, S. Sambo et al. 1995, which used 1l, and 16g of dry matter.

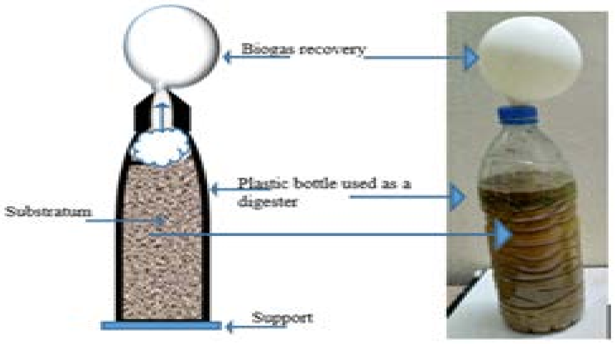

Figure 1. Diagram and photo of the digester

The proportions of each digester are as follows

Table 1. Summaries of the different digesters for the experiment n° 1

Ambient temperature 27°C	
R1 : Sludge from Dakar Cheikh Anta Diop University (BvU)	R5 : BvU + FV
R2 : Poultry droppings (FV)	R6 : BvU + DRc
R3 : Catering waste (kitchen waste)(DRc)	R7 : BvU + BV
R4 : Cow dung (BV)	

Table 2. Summaries of the different digester for the experiment n°2

Mesophilic temperature 40°C	
R8: (BvU)	R12 : BvU + FV
R9 : Poultry droppings (FV)	R13 : BvU + DRc
R10 : Catering waste (kitchen waste) (DRc)	R14 : BvU + BV
R11 : Cow dung (BV)	

To verify and confirm the experiments, each process was reproduced 3 times, i.e. 42 samples, allowing us to have the average and justify the results.

2.2.2. Assembly of Bio-digester

We have assembled a bio-digester composed of: A reactor used as a digester: it has a capacity of 2000ml and a total height of 10.50 cm and a diameter of 20.5cm. It is equipped with a manual mixing and grinding device adjustable on different parts. The introduction of the substrate is planned by the upper part of the reactor. A glass gasometer equipped with a valve to pass the biogas. The link between the digester and the gasometer is made through a Pvc tube with a pvc elbow also, connecting it to the gasometer. At the head of the gasometer there is a valve to release the biogas produced in order to burn it or to analyze it (the sampling is done with a syringe.)

In all experiments, the reactors were hermetically sealed to ensure total anaerobiosis. We measured the biogas produced by the displaced liquid method. The biogas produced in the glass exerts a certain pressure on the water by discharging it to the outside. The water is collected in a graduated container in order to know the quantity expelled from the bottle to know the quantity of biogas produced.

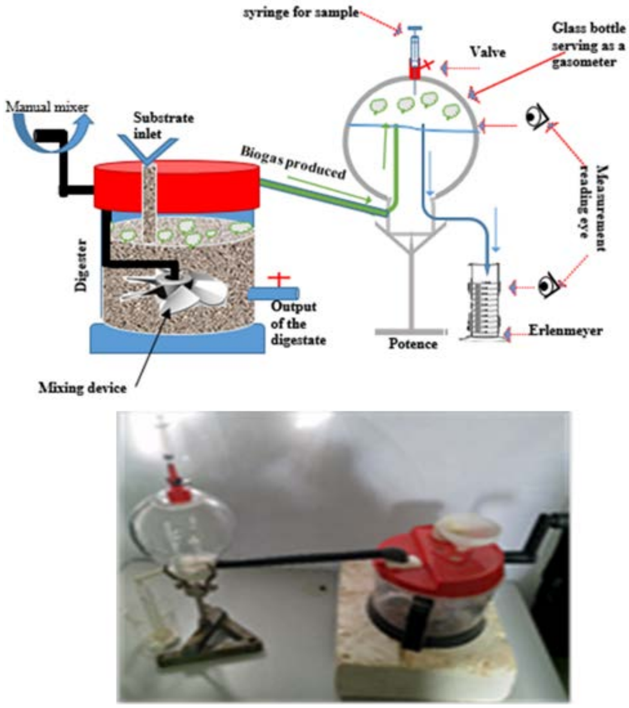

Figure 2. Diagram and photo of the reactor designed in the laboratory for the production of biogas

3. Results and Discussions

Biogas production depends on the nature and composition of the substrate. Several technological and process methods can be chosen to design an appropriate waste management system, so that an objective comparison of the different solutions could be made [35]. However, the design of a bio digester must take into account the characteristic of the present quantity of the substrate, the definition of a specific residence time according to a temperature range more or less optimized to its advantage. The substrate must be free of inhibiting material to prevent the natural production of biogas under conditions of more or less adjusted pH. The choice of our substrates as well as the methodological approach is taken for their importance in biogas production described by [12,36] and [37,38,39] for the restaurant's waste.

For cow dung [40,41,42,43,44] and poultry droppings we referred to the work of [13,45-49] and finally for sewage sludge the work of [50-54] allowed us to justify our choices.

After sampling, each waste was used directly in the laboratory in 1.5 L airtight containers equipped with an inflatable balloon as shown in Figure 1, the ambient temperature in the laboratory was 27°C before use. We performed a first series of experiments at room temperature and a second series of experiments at mesophilic temperature for the mixture before continuing at room temperature respectively Table 1 and Table 2. In order to minimize the risk of biological contamination, particularly with glass material that could break (cutting and introduction of microbiological germs), all the containers used for the first and second experiments were made of plastic. Unlike glass containers, plastic containers have a micro porosity of the surface that reduces their cleaning efficiency [55]. For the third experiment the mixing was done in a perfectly agitated reactor under a first mesophilic temperature of 40°C and continue at room temperature with agitation three times a day.

3.1. Biogas Production

Organic matter consists mainly of protein, carbohydrate and lipids. This complex source is first hydrolyzed into a single molecule (amino acids, sugars and fatty acids). These intermediate products are then transformed into organic acids, such as propionic acid, butyric acid, etc. Alcohols, hydrogen, carbon dioxide and water are also formed. This is the stage of acidogenesis.

The acetog enesis step allows the transformation of previously formed compounds into precursors of methane, acetic acid, carbon dioxide and hydrogen. Methanogenesis is then carried out by two routes.

- From hydrogen and CO_2 using hydrogenotrophic bacteria.
- And from acetate with acetotrophic bacteria.

It is estimated that 70% of methane production comes from acetates. The first two steps of fermentation are done by anaerobic and aerobic bacteria. Methanogenesis, on the other hand, is strictly anaerobic. Temperature affects the rate of decomposition of matter: the higher it is in the digester, the faster the biological process of methanisation takes place [56,57,58].

3.2. Observation of the pH

During our experiments, we did not change the pH during the process but we took it at the beginning and end of each experiment.

The pH is a very interesting indicator in the stabilization and proper functioning of anaerobic digestion. In our bibliographical study we note several ph. values varying from 5.5 to 8.5, with an optimum around 7-8 [61,62,63,64] or 8.5 [65,66]. As anaerobic digestion processes are strongly influenced by pH, they can however take place optimally in the vicinity of pH = 7 neutrality and between 6.5 and 7.5 giving a good yield but also beyond this range, bacteria could then be inhibited [67]. Under normal operating conditions, the pH reduction caused by acid-producing bacteria can be buffered by the hydrogen carbonates produced by methane-generating bacteria [69]. In our experiments we did not measure the pH every day but we took it at the beginning and end of each operation. The observation we made at the end of the reactions is the fact that for some digesters that have produced biogas, the pH was either very low at around 4.5 or very high up to 8, but for each digester we were able to produce biogas. The results showed that on the second series of experiments performed on mesophilic conditions, most of the pH measurements were within the standards elucidated in the literature. At the end of this series of experiments, the pH measured was always in the best production intervals. Except for the case observed in the R11 digester composed of catering waste.

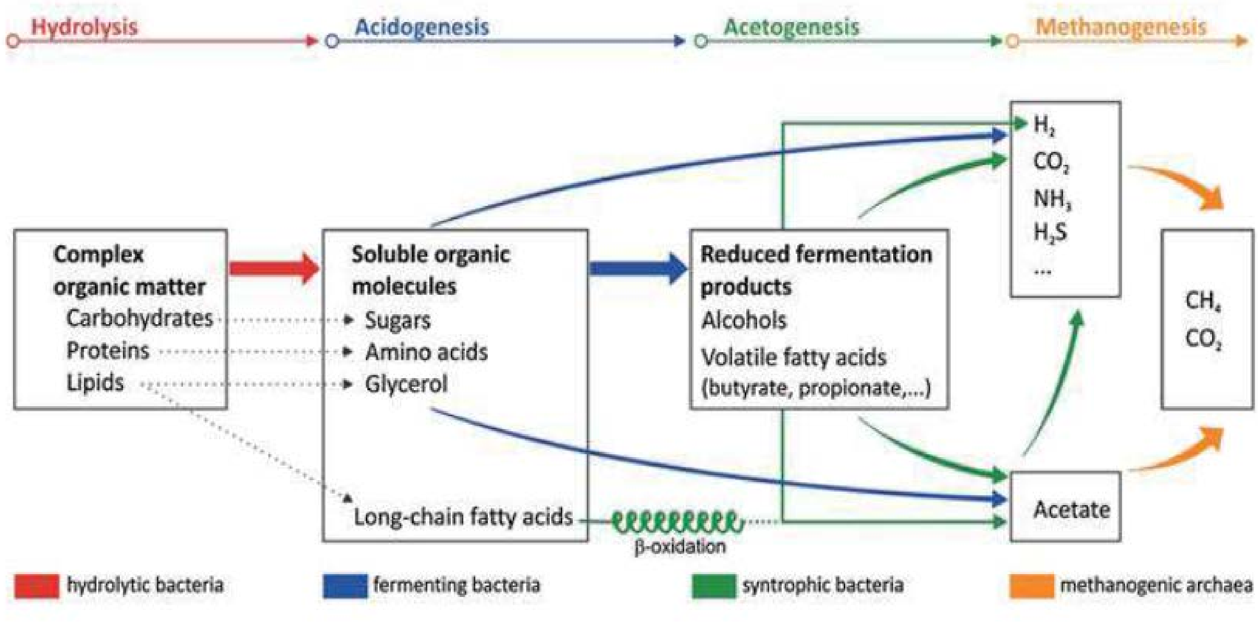

Figure 3. Stage of biological mechanisms of anaerobic digestion According to [59] in the thesis of [60]

Table 3. pH observation at the beginning and at the end of each operation.

Reactor	pH measured at the beginning of the experiment at room temperature	pH measured at the end of the room temperature experiment
R1 : BvU	6	7
R2 : FV	7	7,2
R3 : BV	5,50	5
R4 : DRc	5,6	6
R5 : BvU+FV	7,2	7.6
R6 : BvU+BV	7	7.5
R7 : BvU+DRc	6	6.5
	pH measured at the beginning of the mesophilic temperature experiment	**pH measured at the end of the ambient temperature experiment**
R8 : BvU	6,9	7
R9 : FV	7,2	7,8
R10 : BV	6,50	5,5
R11 : DRc	5	4,5
R12 : BvU+FV	7,1	7,8
R13 : BvU+BV	7	8
R14 : BvU+DRc	6,5	6

3.3. First Series of Experiments

From the second to the fifth day we observed the swelling of the biogas recovery balloon. The balloon increased in volume during the fifteen-day experiment. The temperature for this series of experiments was the ambient temperature in the laboratory, which was in the range of 27 to 28.5°C. The only intervention in the various digesters was the agitation that was carried out once a day every morning at 10am. Later we noticed that the balloon tended to increase in volume after the action of agitation for some time during the day before decreasing in volume.

The Figure 4 below shows the appearance of the curves of biogas production by our different substrates over time.

In Figure 4, it can be seen that the R1 reactor composed of the UCAD sludge (color Black BvU) produces biogas from the second day with a slight increase until the fourth day before decreasing in volume in the preceding days.

The curve of biogas production from poultry manure (R2. FV blue color) began to increase between the second and fourth day with a drop in production on the sixth day. There was a slight increase in the volume of the recuperator balloon on the tenth day and a fall two days later that continued until the end of the experiment. The production of biogas from cow dung (R3 BV orange) started almost from the third day. Its volume increased slightly the following day before decreasing from the seventh day. The smallest production was observed on the balloon of reactor R4 composed of UCAD restoration waste (DRc Couleur verte). The balloon started almost between the fourth and fifth day of the experiment and continued until the eighth day before losing its volume.

3.3.1. Experiment on Co-digestion at Room Temperature with One Agitation per Day

The series of this experiment is done using the first substrates in co-digestion. Faecal sludge was chosen as the main substrate for mixing. The experience lasted thirty days. The production of biogas from the different Co digestion is different from the first series of experiments because the volume observed in this phase is slightly higher and the production time is also better than that of a single substrate. Shaking is done once a day every day from 12pm. The codigest ion of UCAD sludge plus poultry droppings in the R5 reactor (R5 BvU+FV blue) began to produce on the second day by slightly increasing its volume on the third day until the thirteenth day before gradually falling until the last days of the experiment. Between the third and fifteenth day there is a change in the fall and increase in the volume of biogas produced, probably due to the action of the agitation that took place once a day every 12 hours.

The second production was observed in the R6 digester composed of UCAD sludge plus cow dung (R6 BvU+BV red and white) on the third day with an increase from that day to almost twenty days before falling the rest of the time of the experiment. The production interval from the first day to the twentieth day is subjected to the action of agitation, which shows the sinusoidal line on Figure 5.

The third co-digestion is composed of UCAD sewage sludge plus restaurant waste in the R7 digester (BvU+DRc green colour). Production is done on the fifth day with a production higher than R6 but which does not last long enough. The drop in production was observed on the tenth day until the twenty-second day.

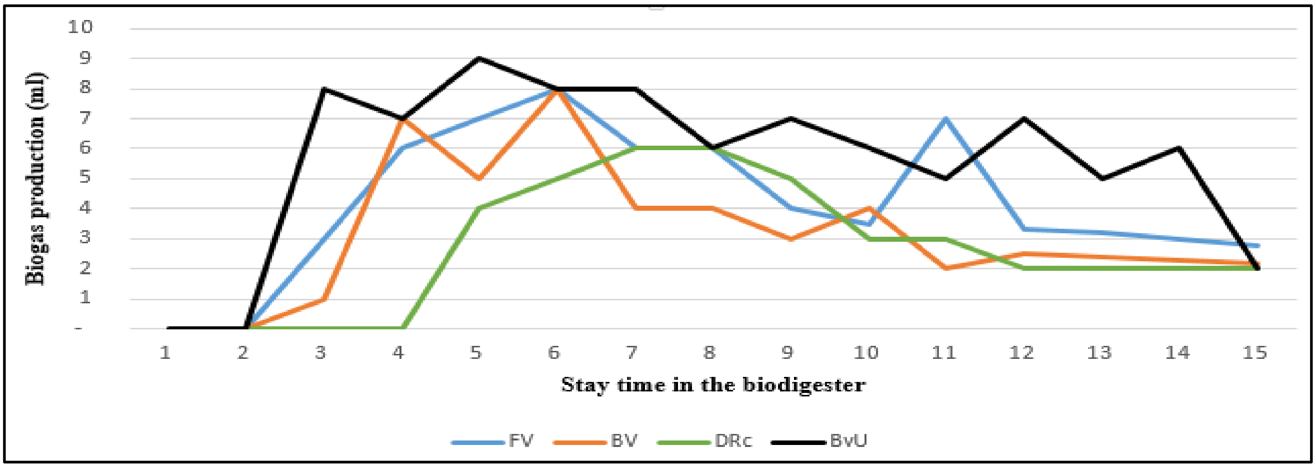

Figure 4. Production of biogas from a single substrate with stirring per day at room temperature (27 ° C)

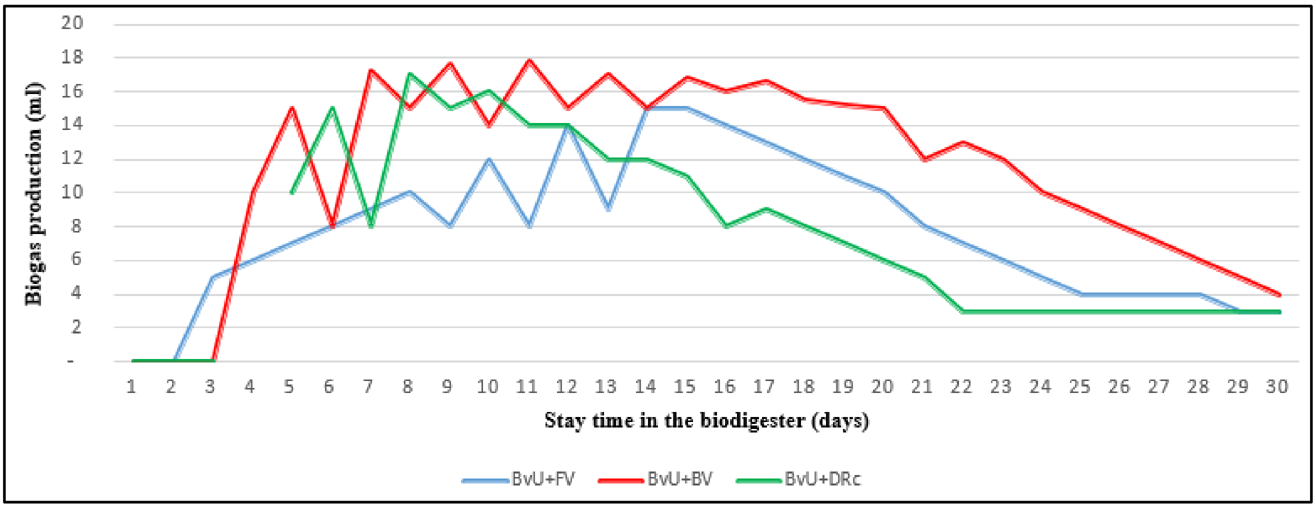

Figure 5. Production of biogas from co-digestion by shaking daily and at room temperature (27°C)

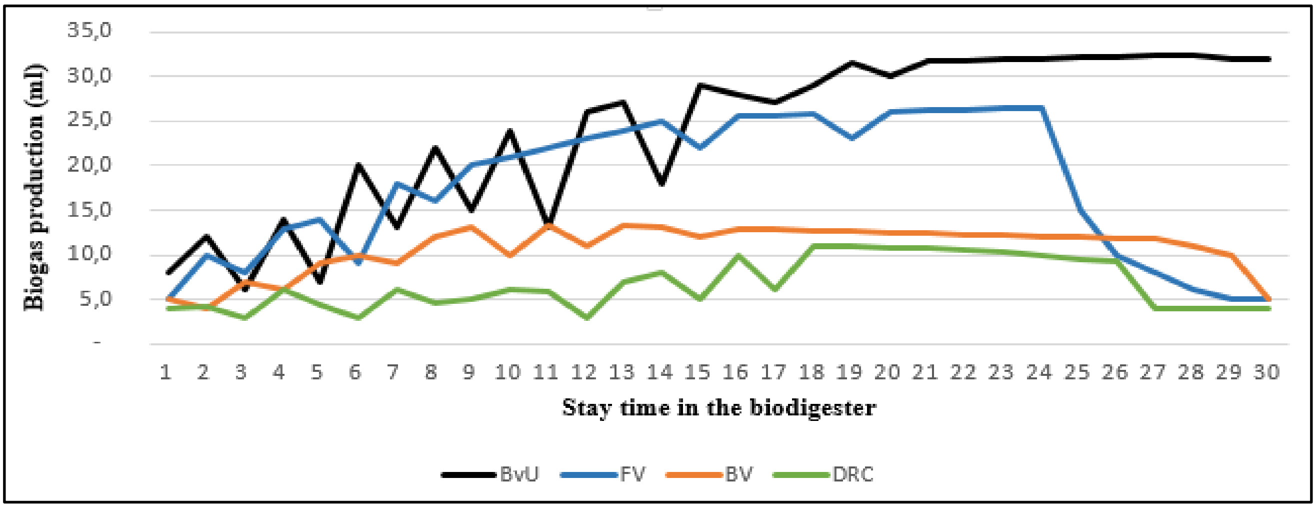

Figure 6. Production of biogas from a single substrate under stirring per day at mesophilic temperature (40°C)

3.3.2. Second Series of Experiments with a Single Substrate under Mesophilic Temperature

In J. HESS' thesis work, he states that temperature can affect biochemical reactions through bacterial kinetics. Karakashev et al (2005) studied the effect of temperature on the complexity of the methanogenic ecosystem. They were able to show that mesophilic reactors had a higher bacterial diversity than thermophilic reactors [8,69].

During this series of experiments, we mixed the substrate with hot water and heated it to 40°C for one hour while stirring the solution. Each reactor was agitated only once a day from 2pm. Each agitation lasted about 30 minutes. As for the first series of experiments at room temperature with one agitation per day, biogas production was observed on each digester, each consisting of a substrate. The figure below shows us the appearance of the biogas production curves under mixing temperature under the mesophilic range. At mesophilic temperature, the digester R8 containing the UCAD sludge (R8: BvU black colour) started to produce in the first few hours after the experiment was carried out. This resulted in an increase in the volume of the balloon every day due to agitation and bacteria influenced by the first mixture under the mesophilic heat, probably. However, the curve of the latter remains sinusoidal throughout the experiment until the twenty-first day and stabilizes to produce normally after the twenty-second day until the end of the experiment.

The R9 reactor composed of poultry manure (R9 FV blue) has about the same production rate as the R8. For this substrate also, with a temperature of 40°C the production is good because the pH was in good intervals.

As for the R10 digester composed of cow dung taken from the UCAD Animal Biology Department (R10: (BV) orange colour), the biogas production was not very encouraging because it had not exceeded the 14ml production bar but it produced throughout the experiment.

The last one to be produced in this series is the R11 digester composed of catering waste (R11: DRc green colour). Influenced by a very low pH, this digester produced a small amount of biogas.

3.3.3. Second Series of Experiments in Co-digestion under Mesophilic Temperature with One Agitation per Day

The production results of the series with a single substrate at mesophilic temperature with one agitation per day were satisfactory to propose a co-digestion of the different wastes. Three mixes were made with the UCAD's sewage sludge as the main mixing medium.

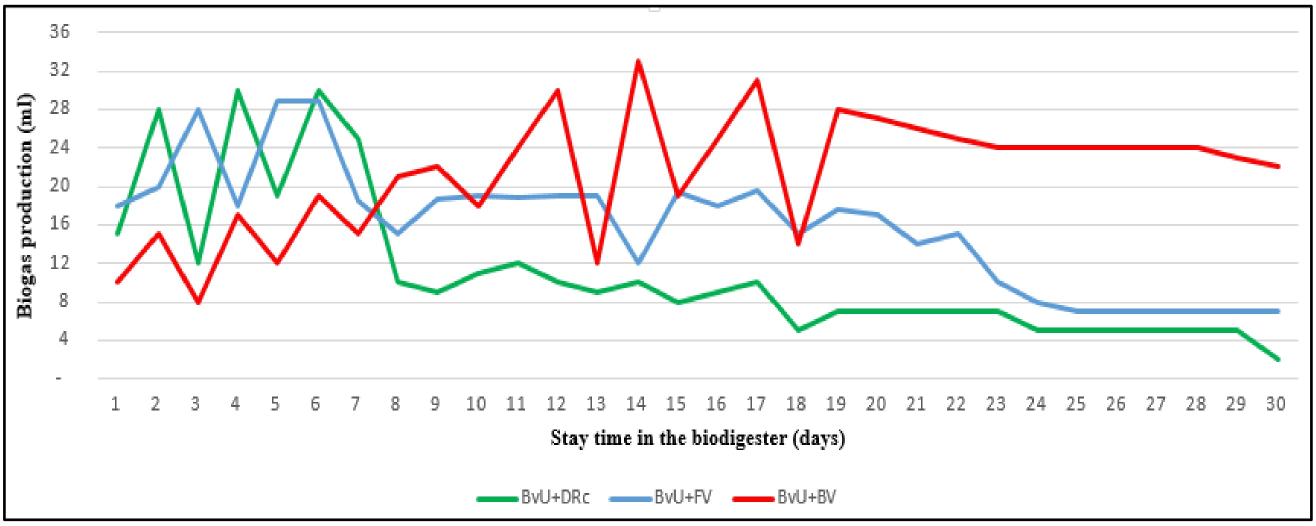

Figure 7. Biogas production by co-digestion under stirring per day at mesophilic temperature (40°C)

Biogas production from this co-digestion is better than the other series with a peak production of around 33ml observed on day 14 on the R13 digester. The Figure 7 shows the production of biogas from the different co-digestions in the three reactors.

The R12 digester, which consists of the emptying dung plus poultry droppings (R12 BvU+FV blue in colour), produced gas from the very first hours. The increase in the volume of the recovery balloon was greater than the others for about a week before decreasing on the eighth day with a more or less the same volume on the seventeenth day. The rest of the experience the volume has almost halved.

For the production of the digester R13 composed of emptying dung and cow dung (R13: BvU+BV red colour) the production although starting in the early hours, it only gives its best yield between the eleventh and fourteenth days of the experiment and on the nineteenth day the production was constant for the rest of the experiment.

In this experiment the last digester R14 with a co-digestion composed of UCAD sewage sludge and restaurant waste (R14 BvU+DRc) started to produce the fastest of all the other digesters for 7 days, but on the eighth day the production decreased until the end of the experiment.

3.3.4. Third Experiment: Agitation of the Reactor Composed of UCAD Sewage Sludge and Cow Dung Several Times a Day

For a better improvement of gas production, it is essential to have a suitable temperature for the functioning of the bacteria and specially to ensure agitation allowing a homogeneous distribution of methanogenic bacteria within the digester. The production of biogas with agitation three times a day gives an increasing curve. We have chosen from all previous experiences the one that gave the best performance in different series. The choice of co-digestion composed of sewage sludge and cow dung is the best of all. The action of agitation in our bio digester has allowed us to give the best growing yield.

In this experiment, the pH measured at the beginning of the experiment was 7.2. At the end of the experiment the pH was 7 and the mixing temperature was 40°C. The action of the agitation was repeated three times a day in the morning at 8am in the evening at 4pm and at night at 10pm. Each agitation lasted about thirty minutes.

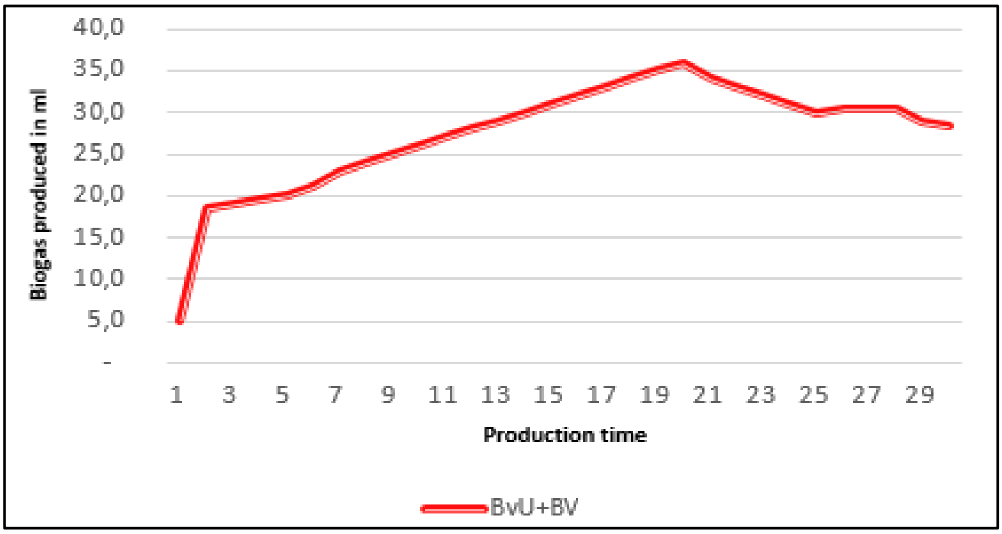

Figure 8. Biogas production by codigestion under the influence of agitation and at mesophilic temperature (40 ° C)

The observation of pH is within the standards of better productions as pointed out by several authors. The production curve does not have a sinusoidal line like the other curves of the previous experiments. The curve is increasing from the first to the twentieth day. The rest of the experience the production decreased but the yield was better than all the other productions.

3.4. Effect of Agitation on Biogas Production

To achieve high levels of biogas production, close contact between bacteria and substrate is required, which is usually achieved with an effective mixture in the digestion tank [70]. If there is no good mixture in the digester, after a while the contents are demixed and layers are formed. This is due to differences in the density of the various components of the substrate as well as vertical thrust due to gas formation. In this case, due to its higher density, most of the bacterial mass accumulates in the lower layer while the substrate to be decomposed often accumulates in the upper layer.

The contact zone is then located in the intermediate zone between these two layers and the degradation phenomenon is then very limited. In addition, solids rise to the surface to form a layer of foam that slows the release of gas [71]. It is therefore important to promote contact between the microorganisms and the substrate by mixing the contents of the digestion tank. However, excessive mixing should be avoided. Thus, acetic acid-producing bacteria (acetogenesis) and archaea (methanogenesis) constitute a close biotic community that is enormously important for the undisturbed continuation of the biogas formation process. If excessive shear forces destroy this biotic community as a result of intensive agitation, this can have negative consequences for anaerobic decomposition. It is therefore important to find a compromise that satisfies both conditions.

Monitoring the impact of agitation on the progress of the biogas production process is comparable to the effect of adding inoculum in terms of the speed of the production process. The considerable effect of agitation in a digester is due to the fact that agitation releases gas bubbles from the deep layers, maintains temperature homogeneity at different levels and prevents consolidation of the crust on the surface of the digester. In addition, it promotes the supply of nutrients to bacteria and their transport.

4. Conclusion

The use of biogas as energy is one of the healthiest and most environmentally friendly ways to generate renewable energy [72]. Our study on the experimental contribution to the phenomena of methanisation by co-digestion of organic waste from the residence of the Cheikh Anta Diop University in Dakar has enabled us to understand and propose a parameter for the production of biogas from waste used as co-substrate. The testing and assembly of a biodigester in the laboratory allowed us to produce biogas. The results of the experiments carried out in this study show that the performance of a digester, whatever its experimental or rural nature, from a gas production point of view depends essentially on the nature of the materials to be fermented, the temperature and agitation.

In the environment, the use of biogas emits seven times less carbon dioxide than firewood. This study justifies the production of biogas by co-digestion of household, toilet and small livestock waste in homes as the main domestic energy for cooking and lighting. Rural residents living around schools and universities and wishing to have energy will be able to exploit waste directly from the school, the market or any other place used for a community of people or animals. This research will be a good manual for any school located in a rural area of Senegal to be able to exploit its waste [73]. Our work, as for many other researchers, clearly indicates that the co-digestion of organic waste is one of the most effective biological treatments, and thus by a simple process, allows the treatment of a wide variety of solid organic waste and sludge for biogas production [74]. Thus, improving the ever-growing standard of living is a serious challenge for the energy sector, as the contribution of energy from biogas can in part meet the needs of the rural education system [75].

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References

[1] Florence CHARNAY. “Compostage des déchets urbains dans es Pays en Développement: élaboration d’une démarche méthodologique pour une production pérenne de compost”. Thèse pour obtenir le grade de docteur de l’université de LIMOGES Année : 2005.

[2] R. Moletta. Caractérisation de la diversité microbienne aéroportée des biogaz. 2005. Thèse doctorat, Université Montpellier II Sciences et Techniques du Languedoc.

[3] Kalloum.S,Boubdessalem.H, Touzi.A et Iddou.A. La digestion anaérobie des boues des stations d’épuration: une opportunité énergétique et environnementale. Mémoire de Magister. Ecole Nationale Supérieure des Enseignements Technique Oran. 2006.

[4] Document, ‘L’Incinération des Déchets et la Santé Publique: Bilan des Connaissances Récentes et Evaluation du Risque’, ADEME, 1999.

[5] J. Rodier. L’analyse de l’eau eaux naturelles, eaux résiduaires et eau de mer. 1984 8eme édition.

[6] A. OHANNESSIAN, “Composés Organiques Volatils du Silicium. Un frein à la valorisation énergétique de biogaz”, Thèse de doctorat, École doctorale de Chimie de Lyon, (2008) 305 p.

[7] M. E. AFILAL, A. BAKX, N. BELAKHDAR, Y. MEMBREZ, “Evaluation of the biogas potential of organic waste in the northern provinces of Morocco“. Rev. Energ. Ren., 13 (2) (2010) 249-255.

[8] J. HESS, “Modélisation de la qualité du biogaz produit par un fermenteur méthanogène et stratégie de régulation en vue de sa valorisation”, Thèse de Doctorat dissertation, Université Nice Sophia Antipolis, (2007) 229 p.

[9] Y. M’SADAK, A. B. M’BAREK, “Valorisations environnementale, énergétique et agronomique de la biométhanisation industrielle appliquée à la biomasse avicole récupérée en Tunisie“, Rev. Mar. Sci. Agron. Vét., 3 (3) (2015) 54-66.

[10] Dr Mamadou Lamarana DIALLO. Les énergies renouvelables entant que facteur d'atténuation des GES – cas de la Guinée. Evaluation environnemental et énergie. Québec 9 /2008.

[11] Surendra, K.C.; Takara, D.; Hashimoto, A.G.; Khanal, S.K. Biogas as a sustainable energy source for developing countries: Opportunities and challenges. Renew. Sustain. Energy Rev. 2014, 31, 846-859.

[12] M. E. AFILAL, N. BELKHADIR, H. DAOUDI, O. ELASRI, ''Fermentation méthanique des différents substrats organiques'', J. Mater. Environ. Sci., 4 (1) (2013) 11- 16.

[13] N. DOUAG-TIRICHINE, A. BENKHELIFA ET K. BOUSDIRA, ''Production de biogaz à partir des déjections bovines en milieu aride: cas du M'Zab (Algérie)'', Revue des Energies Renouvelables, 17 (3) (2014) 419-426

[14] Kossmann, W.; Pönitz, U.; Habermehl, S.; Hoerz, T.; Krämer, P.; Klingler, B.; Kellner, C.; Wittur, T.; Klopotek, F.V.; Krieg, A.; et al. Biogas Digest; Biogas Basics: Eschborn, Germany, 1988; Volume I, pp. 1-46.

[15] RAPPORT FINAL : ETUDE D'ETABLISSEMENT D'UNE BASE DE REFERENCE POUR LE PROJET BIOGAZ. Programme de Structuration du Marché des Boues de Vidange en faveur des ménages démunis de Pikine et Guédiawaye (PSMBV). OFFICE NATIONAL DE L'ASSAINISSEMENT DU SENEGAL. Novembre 2013.

[16] IRDA, "Déjection Animales : Mettre au Point des Techniques pour Réduire les Emissions dans l'Environnement", (2012) 2 p.

[17] T. H. ERGUDER, U. TEZEL, E. GUVEN, G.N. DEMIRER, ''Anaerobic biotransformation and methane generation potential of cheese whey in batch and UASB reactors'', Waste Manage., 21 (7), (2001) 643-650.

[18] Mbuligwe S.E., Kassenga G.R., 2004.- Feasibility and strategies for anaerobic digestion of solid waste for energy production in Dar es Salaam City, Tanzania. Resources, Conservation and Recycling (42), 2004, 183-203.

[19] Afilal M.E., Moncif M., Benyamna A., 2007.- Valorisation des déchets organiques par fermentation méthanique. Rev. Energ. Ren. : CER'07 Oujda: 9-12. www.cder.dz/download/cer07_2.pdf

[20] Schievano A., D'Imporzano G., Adani F., 2009.- Substituting energy crops with organic wastes and agro-industrial residues for biogas production. Journal of Environmental Management (90): 2537-2541.

[21] Afilal M.E., Belkhadir N., Merzak Z., 2013.- Biogas Production from Anaerobic Digestion of Manure Waste Moroccan Case. Global Journal of Science Frontier Research Biological Sciences, vol.XIII Issue I, 3 p.

[22] Afilal M.E., Elasri O., Merzak Z., 2014.- Caractérisations des déchets organiques et évaluation du potentiel Biogaz (Organic waste characterization and evaluation of its potential biogas). J. Mater. Environ. Sci., 5 (4): 1160-1169.

[23] Cheng, S.; Li, Z.; Mang, H.P.; Huba, E.M.; Gao, R.; Wang, X. Development and application of prefabricated biogas digesters in developing countries. Renew. Sustain. Energy Rev. 2014, 34, 387-400.

[24] Schievano A., Pognani M., D'Imporzano G, Adani F., 2008. Predicting anaerobic biogasification potential of ingestates and digestates of a full-scale biogas plant using chemical and biological parameters. Bioresource Technology 99 (17): 8112-8117.

[25] Holm-Nielsen J.B., Al Seadi T., Oleskowicz-Popiel P., 2009.- The future of anaerobic digestion and biogas utilization. Bioresource Technology 100 (22): 5478-5484.

[26] A, Demeyer, F. Jacob, M. Jay, G. Menguy et J. Perrier,' La Conversion bioénergétique du rayonnement solaire et les biotechnologies', Edition Tec & Doc, 1980, pp. 213-215.

[27] Méthanisation. Disposible sur: http ://www.methanisation.info/etapes.html.

[28] Saidi A., Abada B., 2007.- La biométhanisation: une solution pour un développement durable. Rev. Energ. Ren.: CER'07 Oujda: 31-35.

[29] Mokhles Kouas. Caractérisation cinétique de la biodégradation de substrats solides et application à l'optimisation et à la modélisation de la co-digestion. Autre. Université Montpellier, 2018. Français. <NNT : 2018MONTG021>. <tel-01908664>.

[30] Molla and Asmare, "Design of cylindrical fixed dome bio digester in the condominium houses for cooking purpose at Dibiza Site, East Gojjam Ethiopia," American Journal of Energy Engineering, p. 1, 2014.

[31] Amingun. B, Parawira and Musango. J, "Anaerobic Biogas Generation for Rural area Energy Provision in Afrcica," ISBN:978-, In Tech, 2012.

[32] Aremu, M .O.; Agarry, S. E.(2013). Enhanced Biogas Production From Poultry Droppings Using Corn-Cob And Waste Paper As Co-Substrate. International Journal of Engineering Science and Technology (IJEST), 5(02), 247-253.

[33] Sibisi, N.T.; Green, J.M. (2005) A floating dome biogas digester: perceptions of energizing a rural school in Maphephetheni. KwaZulu-Natal, Journal of Energy in Southern Africa, 16(3), 45-55.

[34] Moonmoon. H, "Bioenergy potential from crop residue biomass in India," Renewable, p. 5, 2015.

[35] Cremiato, R., Mastellone, M. L., Tagliaferri, C., Zaccariello, L., & Lettieri, P. (2018). Environmental impact of municipal solid waste management using Life Cycle Assessment: The effect of anaerobic digestion, materials recovery and secondary fuels production. Renewable Energy, 124, 180-188.

[36] M. Khelafi1, A. Tahri1, F. Salem1, K. Kaidi1, L. Bensmail3, O. Barako3, A. Kadri3, A. Amrouche3 Méthanisation des déchets organiques issus de la résidence universitaire de l'université Africaine de la ville d'Adrar Sud-Ouest de l'Algérie. J. Mater. Environ. Sci. 5 (S2) (2014) 2484-2488.

[37] Fuqing Xua, Yangyang Lia,b, Xumeng Gea,c, Liangcheng Yangd, Yebo Lia,c, Anaerobic digestion of food waste – Challenges and opportunities 0960-8524/ © 2017 Elsevier Ltd. All rights reserved.

[38] Hessami M.A., Christensen S., Gani R., 1996.- Anaerobic Digestion of Household Organic Waste to Produce Biogas. In: Proceedings of the World Renewable Energy Congress (WREC'96), 954-957.

[39] Bouallagui H., Lahdheb H., Ben Romdan E., Rachdi B., Hamdi M., 2009. Improvement of fruit and vegetable waste anaerobic digestion performance and stability with co-substrates addition. Journal of Environmental Management (90), 1844-1849.

[40] M'Sadak Y., Ben M'Barek A., Baraket S., 2012.- Suivis physico-chimique et énergétique de la Biométhanisation expérimentale appliquée à la biomasse bovine. Revue Nature & Technologie, n° 7, Juin 2012, 81-86.

[41] M'Sadak Y., Ben M'Barek A. 2013.- Energy, environmental and agronomic valorizations of the rural biomethanisation of the bovine biomass. International Journal of Innovation and Applied Studies (IJIAS), vol. 4, n° 2, 343-352.

[42] Jain M.K., Singh R., Tauro P., 1982.- Biochemical changes during anaerobic digestion of animal wastes. Journal Water Research, 16 (4), 411-415.

[43] Tou I., Igoud S., Touzi A., 2001.- Production de Biométhane à Partir des Déjections Animales. Rev. Energ. Ren.: Production et Valorisation-Biomasse: 103-108.

[44] M'SADAK Y. et BEN M'BAREK A. PERFORMANCES ENVIRONNEMENTALES ET ÉNERGÉTIQUES DE LA BIOMÉTHANISATION APPLIQUÉE AUX DÉJECTIONS BOVINES DANS LE CONTEXTE TUNISIEN .Algerian journal of arid environment 76 vol. 5, n° 1, Juin 2015: 76-91 Université de Sousse, Institut Supérieur Agronomique de Chott-Mariem, 4042, Tunisie.

[45] S. IGOUD, I. TOU, S. KEHAL, N. MANSOURI ET A. TOUZI, ''Première Approche de la Caractérisation du Biogaz Produit à Partir des Déjections Bovines'', Revue des Energies Renouvelables, (5) (2002) 123-128.

[46] Ansoumane SAKOUVOGUI et al. Évaluation du potentiel en biogaz de la bouse de vache, de la fiente de poule et en codigestion à Mamou, République de Guinée Afrique SCIENCE 14(5) (2018) 147-157.

[47] M'Sadak Y., Ben M'Barek A., Zoghlami R.I., 2013.- Diagnostics environnemental et énergétique des digesteurs anaérobies expérimentaux des fientes avicoles. Revue Nature et Technologie, n°. 8 (C): 19-26.

[48] Y. M'SADAK, et A. BEN M'BAREK, "Caractérisation quantitative du digestat solide de la biométhanisation industrielle des fientes avicoles et alternatives de son exploitation agronomique hors sol", Revue des Energies Renouvelables, 16 (1) (2013) 33-42.

[49] ABOUBAKAR, Z. BOLI et C. M. F. MBOFUNG, "Etude du potentiel biogaz des déjections animales : bouses de bovins et fientes de volailles d'un centre zootechnique à Maroua - Cameroun", Revue des Energies Renouvelables, 19 (3) (2016) 447-464.

[50] Wen-biao Han, Yu-zhu Zhao, Hao Chen*Study on Biogas Production of Joint Anaerobic Digestion with Excess Sludge and

Kitchen Waste International Conference on Solid Waste Management, 5IconSWM 2015.

[51] A. Donoso-Bravo and F. Fdz-Polanco Modeling of the anaerobic digestion of sewage sludge: Evaluation of several reactor configurations 11th International Symposium on Computer Applications in Biotechnology Leuven, Belgium, July 7-9, 2010.

[52] Document Installation Biogaz autoconstruite ou « Comment rouler avec du caca » -Version 1.5 du 01/06/2013 -http://forum.adabio-autoconstruction.org

[53] Ogouvidé Akpaki , Gnon Baba, Komi Edem Koledzi, Kwamivi N. Segbeaya Quantification et valorisation en biogaz des boues de vidange du site d'Attidjin à Lomé. Journal de la Société Ouest-Africaine de Chimie J. Soc. Ouest-Afr. Chim.(2016), 042 : 30-35 21èmeAnnée, Décembre 2016.

[54] S. O. Dahunsi1and U. S. Oranusi Co-digestion of Food Waste and Human Excreta for Biogas Production British Biotechnology Journal SCIENCEDOMAIN international 3(4): 485-499, 2013.

[55] David BASSARD Méthodologie de prédiction et d'optimisation du potentiel méthane de mélanges complexes en co-digestion T H È S E Université de Technologie de Compiègne École Doctorale de Compiègne février 2015.

[56] Nicolas Dupont. Valorisation du biogaz de fermentation: combustion catalytique. Autre. Université Claude Bernard - Lyon I, 2010. Français. <NNT : 2010LYO10081>. <tel-00816867>.

[57] Laura Sarperi. Développement d'une filière de production de bio-GNV à partir de biogaz agricole à l'echelle individuelle. Génie des procédés. Ecole des Mines de Nantes, 2014. Français. <NNT: 2014EMNA0169>. <tel-01077969>.

[58] MOLETTA, R. 2008. La méthanisation. p. 532, Tec&Doc, Lavoisier.

[59] Ceballos, G., Ehrlich, P.R., Barnosky, A.D., Garcia, A., Pringle, R.M., Palmer, T.M., 2015. Accelerated modern human-induced species losses: Entering the sixth mass extinction. Sci. Adv. 1,e1400253–e1400253.

[60] Wendy Laperrière. Évaluation des limites d'un digesteur biogaz pour une utilisation flexible dans un réseau local de production d'énergie. Sciences agricoles. Université Montpellier, 2017. Français. <NNT : 2017MONTT068>. <tel-01704573>].

[61] Gourdon R., Techniques de l'Ingénieur, 2060. Novembre (2012).

[62] Roque H., 1981. Fondements théoriques du traitement biologique des eaux. Chap. 3-6: Traitement anaérobie: 1476-1532.

[63] Al Saedi, T., Rutz, D., Prassl, H., Köttner, M., Finsterwalder, T., Volk, S. & Janssen, R. 2008 Biogas Handbook. University of Southern Denmark Esbjerg, Niels Bohrs Vej 9-10. DK-6700 Esbjerg, Denmark.

[64] Youssef Abarghaz, Khiyati Mohammed El Ghali, Mustapha Mahi, Christine Werner, Najib Bendaou, Mohammed Fekhaoui and Ben Houssa Abdelaziz Modelling of anaerobic digester biogas production: case study of a pilot project in Morocco. IWA Publishing 2013 Journal of Water Reuse and Desalination | 03.4 | 2013.

[65] Graieb, M. (1988). Étude et réalisation d'une installation de méthanisation avec chauffage. Mémoire de Spécialisation, Institut National Agronomique de Tunis, Tunisie.

[66] Gungor K, Karthikeyan KG. Influence of anaerobic digestion on dairy manure phosphorus extractability. Transac. ASABE. 2005; 48: 1497-1507.

[67] Roque, H. (1981). Fondements théoriques du traitement biologique des eaux. Chap. 3-6: Traitement anaérobie, 1476-1532.

[68] Jin Bai ZHANG :PROCEDE DE TRAITEMENT ANAEROBIE DES BOUES ET DE VALORISATION DU BIOGAZ THÈSE INSTITUT NATIONAL POLYTECHNIQUE DE LORRAINE École Nationale Supérieure des Industries Chimiques Laboratoire Réactions et Génie des Procédés École Doctorale RP2E 12 Décembre 2011.

[69] D. KARAKASHEV, D. J. BATSTONE & I. ANGELIDAKI, "Influence of Environmental Conditions on Methanogenic Compositions in Anaerobic Biogas Reactor", Applied and Environmental Microbiology, vol. 71, no 1, p. 331-338, 2005.

[70] Kaltschmitt, M.; Hartmann, H.; Hofbauer, H.: Energie aus Biomasse – Grundlagen, Techniken und Verfahren; Springer Verlag ; Berlin, Heidelberg, New York, 2001.

[71] Maurer, M.; Winkler, J-P., Biogas – Theoretische Grundlagen, Bau und Betrieb von Anlagen, Verlag C.F. Müller, Karlsruhe, 1980.

[72] Membere. E, "Biomechanization Potential of Organic Fraction of Municipal Solid Waste from Co-digestion of Pig and Cow dung," International Journal of Environmental Science, 2012.

[73] Marie Judith Kundwa, Constant Mahame, Pascaline Sanga, Theoneste Bigirimana. Contribution of Modern Biogas Plant to Energy Source and Environment Protection in Rwanda. Journal of Civil, Construction and Environmental Engineering. Vol. 3, No. 4, 2018, pp. 125-132.

[74] Alemayehu Gashaw. Anaerobic Co-Digestion of Biodegradable Municipal Solid Waste with Human Excreta for Biogas Production: A Review. American Journal of Applied Chemistry. Vol. 2, No. 4, 2014, pp. 55-62.

[75] Anupam. J, Mikul. B and P. Barua, "Biomass for Sustainable Development-Lessons for Decentralized Energy Delivery," Village Energy Security Programme. Document of the WorldBank, 2011.