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(Research Article)

Experimentation of a better methanogenic potential by co-digestion of urban waste: Contribution to the challenges of sustainable development in the Sahel zone

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Abstract

It is clear that a high population density combined with the ecological fragility of the places where refugees settle are primary factors in the risk of environmental degradation. In the Sahel region, we can see a number of cases where refugees exploited the resources of their environment without worrying about their preservation; The study of existing documents provides some evidence of medium- and long-term ecological deterioration in areas affected by refugee movements. Changes in the vegetation cover of a host area are undoubtedly the most visible result of the presence of refugees, and this for several reasons.

First of all, as soon as they arrive in a new place, refugees need a large quantity of fuel and building materials and, in most of black Africa, this demand is most often met by local wood resources, thereby promoting the excessive cutting of trees and therefore the possibility of opening up a desert area over time. In order to provide a solution, we undertook to carry out tests on different types of urban waste in order to produce a good quality biogas which will be used for cooking food, but could also be used as alternative energy for electricity. After having carried out all the experiments, the best substrate considered is a co-digestion of fresh cow dung and poultry droppings. And secondly the combination of human waste mixed with poultry droppings and fresh cow dung. In third place we have human waste plus dry cow dung and poultry droppings. We have also studied case by case the structural composition of a digester. This work was carried out to contribute to the impact on the environment caused by displaced people in the Sahel zone in order to be able to contribute to the challenges of sustainable development in this area.

Keywords: Waste; Recovery; Biogas; Sustainable development; Sahel

1. Introduction

The deterioration of the socio-political situation in some countries has led to the departure of a significant number of the population and livestock, with the largest contingent finding refuge in the Sahel region. However, in this region, ecosystems are already weakened by the deterioration of climatic conditions and the intensification of extensive agricultural and pastoral activities. The relationship between forced population displacement and environmental changes is a growing concern for the international community, as evidenced by the recent proliferation of publications and reports [1-3]. It was especially following the Rio Summit on Environment and Development in 1992 that the Office of the United Nations High Commissioner for Refugees (UNHCR) began to give increased importance to environmental issues in planning refugee assistance programs [4].

Such concern about the negative impact of refugees on the environment is not new [5]. For example, in its Food Aid Review, the World Food Programme (WFP) describes the potential impact of refugees on local environments as "enormous," citing in particular deforestation around refugee settlements in Pakistan and Malawi. At the same time,

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organizations such as the International Federation of Red Cross and Red Crescent Societies (IFRC), CARE International, and the German Agency for Technical Cooperation (GTZ) have devoted increasing attention to environmental issues in refugee-affected areas [6-9]. Three types of potential environmental changes can be considered: changes in flora and fauna (expanding the earlier discussion on deforestation), land degradation, and, finally, the quality and quantity of water resources. As demand for fuelwood increases, markets are created and increasingly remote forests are affected; barter sites also emerge for other natural resources such as water or thatch; Firewood is sold or exchanged for food rations during times of food insecurity, i.e. during "scarcity seasons" after harvests, when food reserves are exhausted." [3]

In such a context, the arrival and settlement of refugees with large livestock populations constitutes a new source of additional pressure on environmental components.

The purpose of this research is to examine the plausible consequences of this influx of refugees on the Sahel environment and to propose a sustainable solution.

The solution we propose is linked to the presence of waste generated by animals and populations on the move; it involves the transformation of all the different types of putrescible organic waste into biogas and biofertilizer [10-13]. First of all, it is important to know that the different types of urban waste as well as household waste are generally disposed of in open landfills affecting environmental sustainability by the release of contaminants such as leachates and GHGs, generated by the high quantities of putrescible waste that increase the pollution potential of the sites[11]. The recovery of waste into biogas inevitably takes place in hermetically sealed enclosures called biodigesters[12]. The experiment we conducted consisted of highlighting several types of waste (about thirty combinations) under mesophilic temperature (35°C±2°C) in a 1.5l can equipped with an empty inflatable balloon used for the recovery of biogas, which constituted our biodigester[13]. The goal is to see the waste with the best biogas potential. We found that some biodigesters began to produce after two hours, the inflatable balloon increased in volume every hour up to 24 hours before remaining constant. Our approach could be implemented on a refugee site in the Sahel zone for the recovery of their organic waste into biogas for cooking and lighting and into biofertilizer for healthy agriculture. This could also answer questions of sustainable development.

2. Material and method

We used two types of temperature for our experiment, one ambient and the second mesophilic. Our digester has a capacity of 1.5 liters. Several tests were made and the best substrate considered was a co-digestion of cow dung and poultry droppings. And secondly the combination of human waste mixed with poultry droppings. 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 who used 1l and 16g of dry matter.

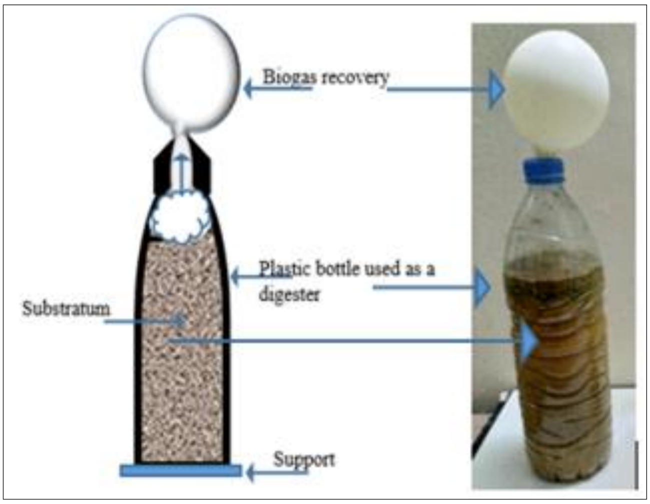


Figure 1 Biogas production device in the laboratory

After being collected, each waste was used directly in the laboratory in 1.5 L airtight cans equipped with an inflatable balloon as in Figure 1, the ambient temperature in the laboratory was 27 °C before their use. We did a first series of experiments at room temperature and a second series of experiments at mesophilic temperature [14-16].

3. Results and Discussion

Biogas is a renewable combustible gas resulting from the degradation of animal or plant organic matter by microorganisms under anaerobic conditions. This gas is mainly composed of methane (CH4) and carbon dioxide (CO2) and to a lesser extent hydrogen sulfide (H2S), nitrogen (N2), or even dihydrogen (H2), metals and volatile compounds. The energy potential of biogas results from its methane content. For pure methane, the calorific value is 9.94 kWh/Nm-3 to 12.67 kWh.m−3. The PCI (lower calorific value) of biogas is proportional to its methane content, for example for a biogas with 70% methane at 15°C and normal atmospheric pressure, the PCI is equal to 9.42 × 0.7 = 6.59 kWh/m3. Our first goal was to have fire for cooking to replace coal and wood that promoted deforestation. The digester was exposed to receive solar radiation during the day and a tarpaulin was used to cover the digester during the night in order to maintain a certain temperature inside that was favorable for the microorganism to continue producing.

3.1. Results of the different experiments at ambient temperature

The table below shows the average of the ambient temperature variations of the digesters

Table 1 Ambient temperatures of the five different digesters

	BVF+FV		BVS+ FV		DP+ BVF		DP+ BVS		BVF +DP+ BVF	
	T en °C à 8h	T en °C à 15h	T en °C à 8h	T en °C à 15h	T en °C à 8h	T en °C à 15h	T en °C à 8h	T en °C à 15h	T en °C à 8h	T en °C à 15h
J- C 1	29	30	29,3	32	31	34	29,3	40	30	41
J- C 2	29,1	31	28,9	39,1	29,4	37	29,2	38,9	29,6	40
J- C 3	29	32	29,6	32,3	29,4	32,7	29	32,3	29,2	33
J- C 4	30	33	30,3	33,1	29,9	33	29,9	33,5	30,2	33
J- C 5	30,3	32,6	30,6	32,7	30	32,7	30,2	32,6	30,2	32
J- C 6	31,1	33,5	30,8	33,6	30,9	34	30,8	33,6	31,1	34
J- C 7	34,6	33	31,1	33,2	30,6	33,3	30,8	32	30,6	32

J- C = Combined days (totaling the average of five 5 days)

The graph below is the representation of the variation of ambient temperatures of the five digesters

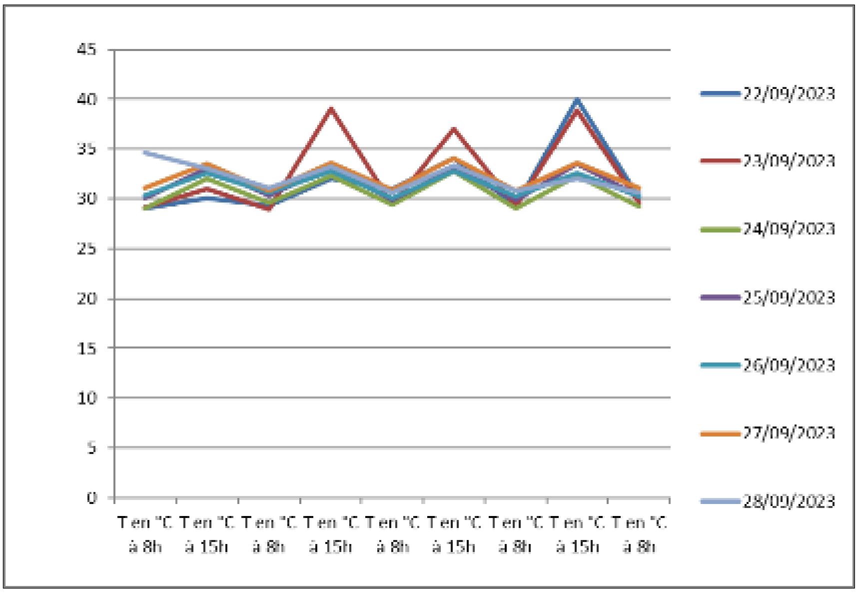


Figure 2 Graphical representations of the average ambient temperature variations

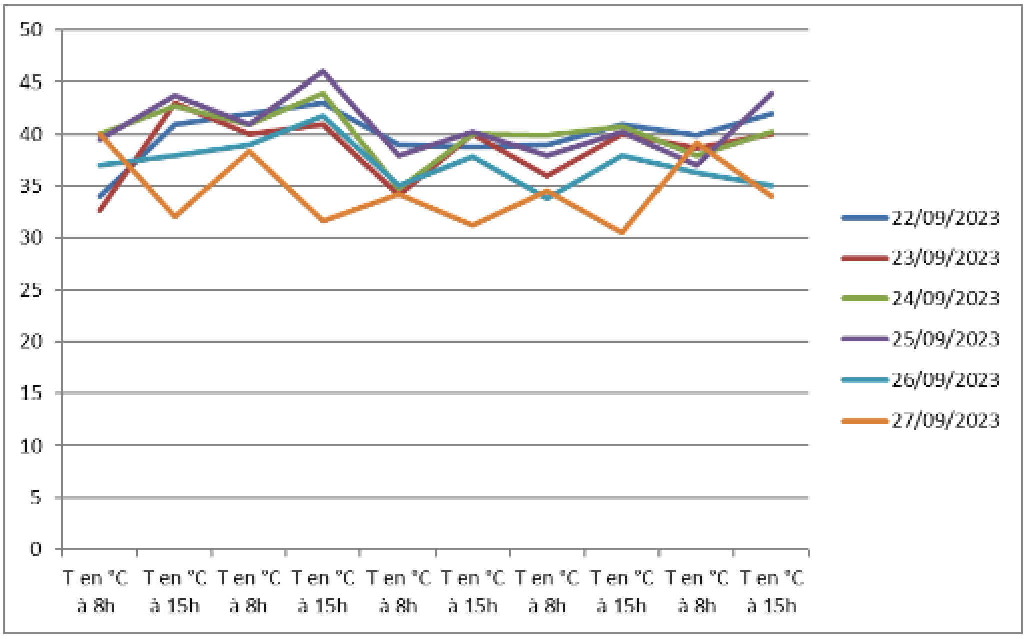
3.2. Results of the different mesophilic temperature experiments

The table below shows the mesophilic temperature variation of the different digesters in the water bath during the seven days of the week.

Table 2 Mesophilic temperature variation in one week

	BVF+FV		**BVS+ FV**		**DP+ BVF**		**DP+ BVS**		**BVF +DP+ BVF**	
	T en °C à 8h	**T en °C à 15h**	**T en °C à 8h**	**T en °C à 15h**	**T en °C à 8h**	**T en °C à 15h**	**T en °C à 8h**	**T en °C à 15h**	**T en °C à 8h**	**T en °C à 15h**
J-C 1	34	41	42	43	39	38,8	39	41	39,9	42
J-C 2	32,7	43	40	41	34,1	40	36	40	38,7	40
J-C 3	40	42,7	41	44	34,7	40	39,9	40,7	38	40,2
J-C 4	39,5	43,7	41	46	38	40,2	38	40,2	37	44
J-C 5	37	38	39	41,8	35	37,8	33,8	38	36,3	35
J-C 6	40	32	38,4	31,6	34,2	31,2	34,5	30,5	39,2	34
J-C 7	38,1	36	41	40	37	38	39,3	37,5	38	36

The graphical representation below shows the average mesophilic temperature variations



BVS + FV: dry cow dung + poultry droppings; BVF + FV: Fresh Cow Dung + poultry droppings; DP: Human Waste; BVS + DP: dry cow dung + human waste; BVF + DP: fresh cow dung + human waste; BVF + DP+ BVF fresh cow dung + human waste + dry cow dung

Figure 3 The average of the mesophilic temperature variations of five digesters

After performing all the experiments, the best substrate considered is a co-digestion of fresh cow dung and poultry droppings. And secondly the combination of human waste mixed with poultry droppings and fresh cow dung. In third place we have human waste plus dry cow dung and poultry droppings. The figure below gives us an overview of the responses of the experiments submitted.

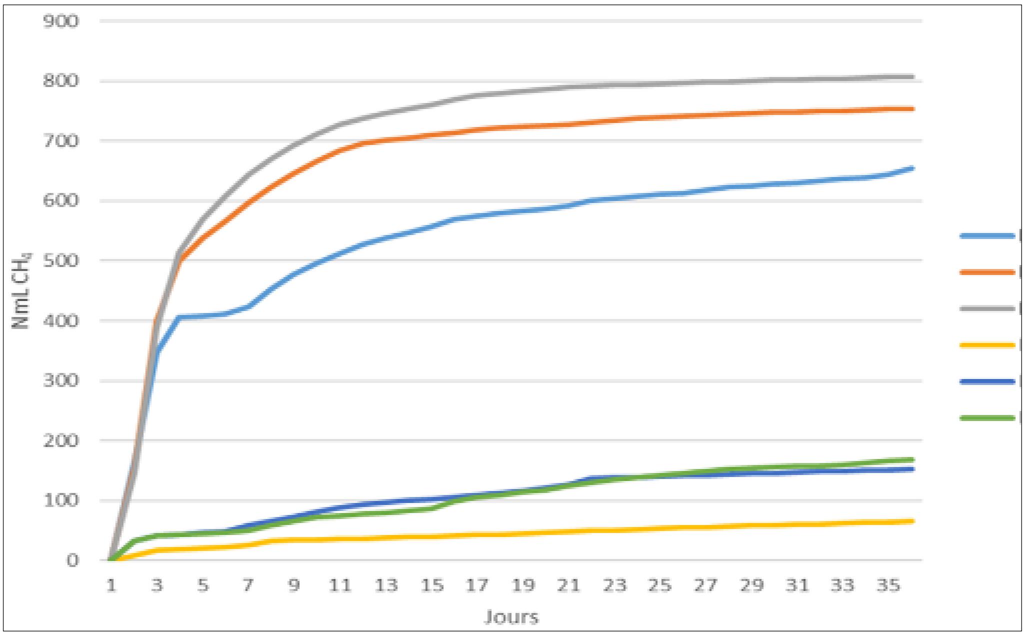


Figure 4 Average Biogas Production from Six Digesters

3.3. Proposal and Technical Contribution Related to Sustainable Development Challenges in the Sahel

3.3.1. Types of Anaerobic Digesters

Anaerobic digestion is the biological process for converting organic matter into rich methane called biogas [17-19]. It is a well-established technology for treating the organic fraction of various wastes [20-23]. The dry matter (DM) content of the available substrate and, conversely, the water content generally determines the choice of methanization processes and the type of anaerobic digester. Arbitrarily, anaerobic digestion is called "wet" in the case of treating waste with a dry matter (DM) content of between 5 and 20%. It is called "dry" for waste with a DM percentage of between 20 and 50%. Below 5% DM, anaerobic digestion of liquid effluents occurs, while above 55% DM, the substrate is difficult to treat by anaerobic digestion. Anaerobic digestion concerns biodegradable organic matter in airtight reactors, commonly called digesters, and generates two main products, namely biogas and digestate [24-25].

In industrialized countries, anaerobic digesters are generally grouped into 3 main categories, depending on their feeding modes and frequencies, as well as their degrees of sophistication:

- Single-stage discontinuous or batch digesters;
- Single-stage continuous feeding systems;
- Multi-stage continuous reactors, in which the hydrolysis and acidogenesis phase is separated from acetogenesis and methanogenesis, to improve process stability [26]. These systems are generally adapted to both wet and dry anaerobic digestion processes.

Anaerobic digesters in developing countries (DCs) are usually operated wet to facilitate the handling of material entering and leaving the digester. They can also be grouped into 3 main categories, taking into account only their feeding frequency [27]:

- Discontinuous digesters (or batch), loaded only once, until the substrate is exhausted and the methanogenic process is complete;
- Continuous digesters, whose contents are partly renewed regularly;
- Semi-continuous digesters, corresponding to rather rustic or unconventional continuous processes.

3.3.2. Structure and layout of the anaerobic digester.

The structural composition of a digester includes, as a main component, a container or tank that contains the waste. It must be hermetically sealed to create anaerobic conditions and allow the biogas production process. There are no significant limitations on the construction materials, its shape and size [28]. It must include a method of filling the substrate as well as biogas extraction.

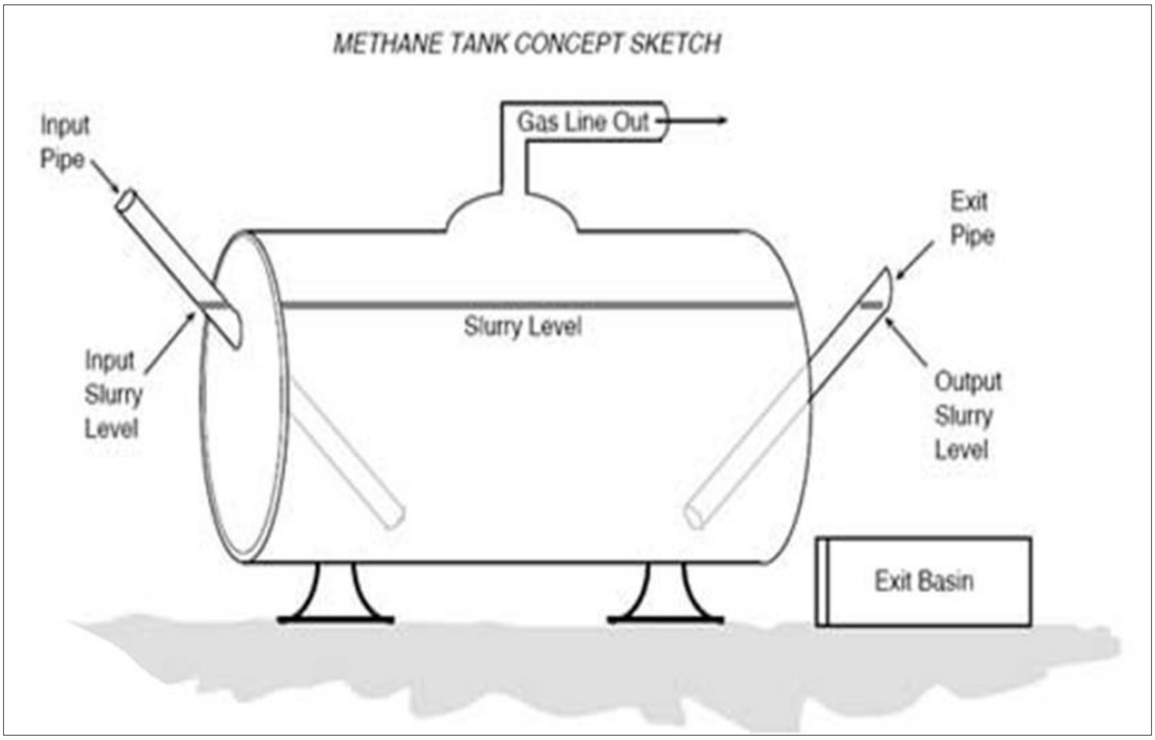


Figure 5 Continuous flow biodigester configuration

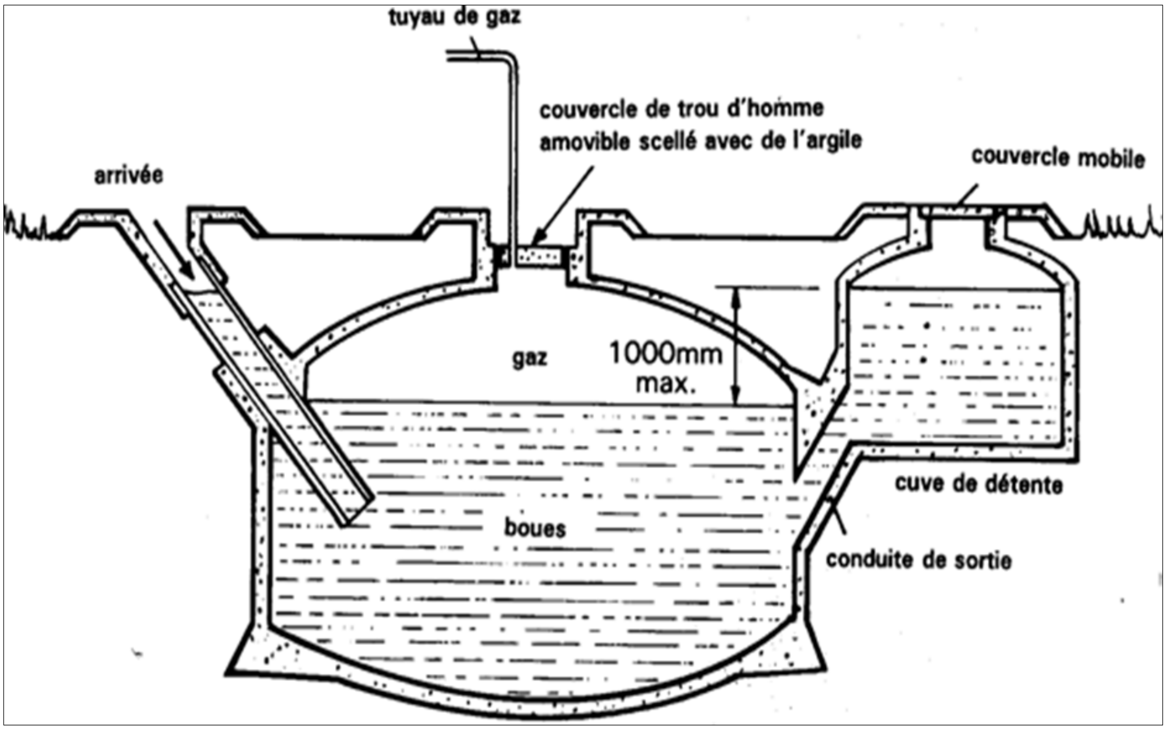


Figure 6 Fixed dome biodigester configuration

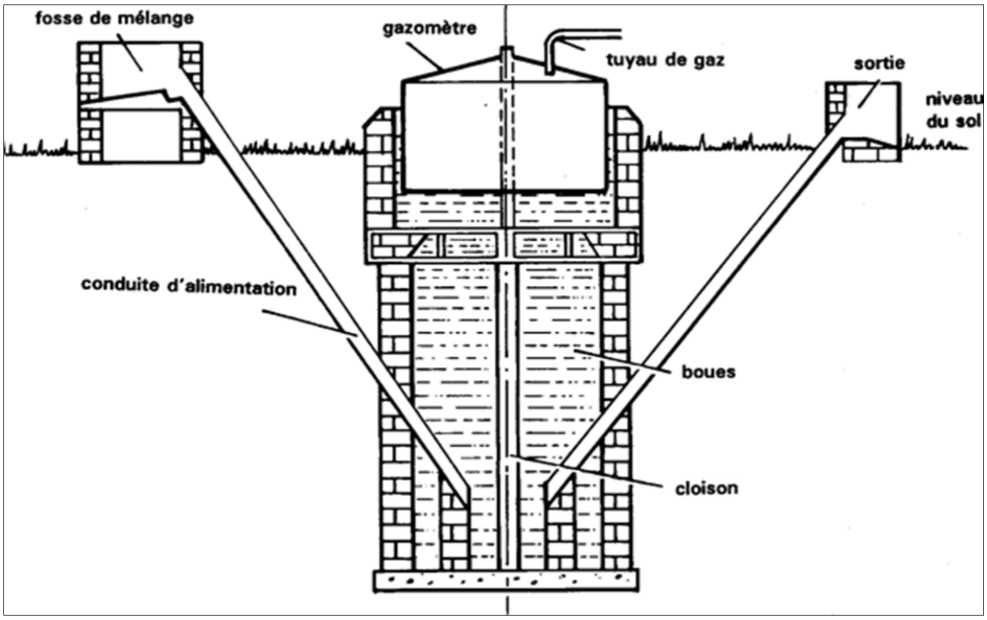


Figure 7 Floating drum biodigester configuration

In developing regions, biodigesters are the new solutions showing benefits for basic livelihood indicators as well as development [29].

Nowadays, they are built on site or prefabricated [30] with different materials, such as brick, concrete and plastics.

Figures 5, 6 and 6 show three main types of household biodigesters commonly used in developing countries [31-35]. Even though the method and design of biodigesters are different, the digestion steps and the biogas production process is the same [36].

The following figure schematically presents 4 models of mixed digesters, with different agitation devices.

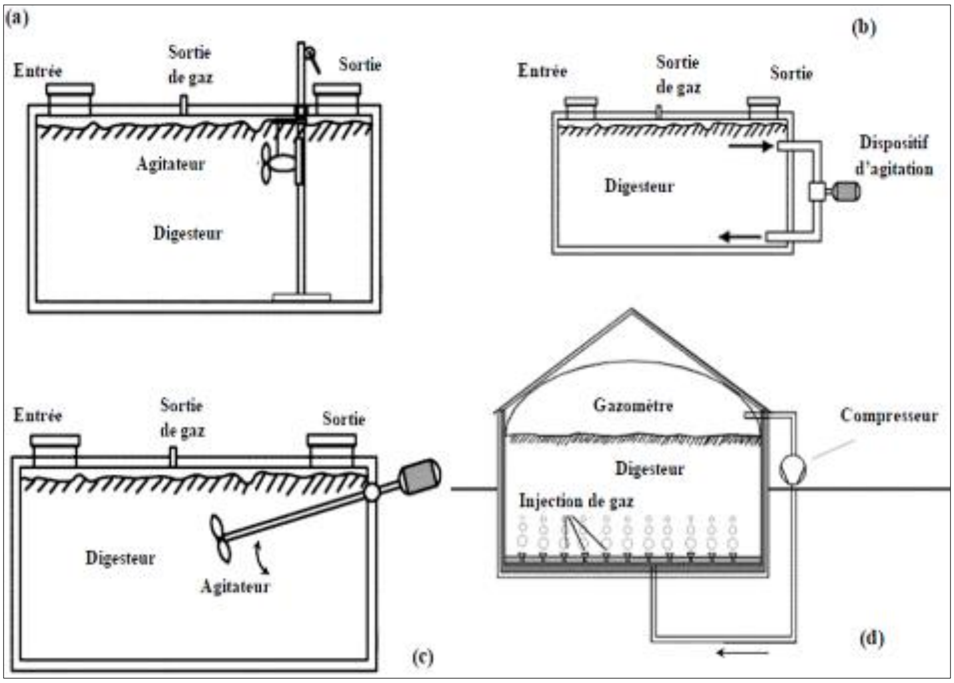


Figure 8 Schematic sections of infinitely mixed digesters, using: (a) a mechanical rotor immersed in the digester, (b) a hydraulic agitation device, (c) an agitation paddle placed on the side, a biogas injection agitation device (Source: [37])

3.4. Ways of using anaerobic digestion products

- Solid fraction of the digestate

Chanakya et al., 2007 [38], Lacour et al., 2011 [39], present in their work the importance of the solid fraction of the digestate because if it does not contain undesirable materials (glass, plastics, etc.) or toxic substances, the digestate can be transformed into compost after aerobic maturation, or used as a substrate for the production of worm compost and edible mushrooms. According to Schulz and Eder, 2001 [40], Schröder et al., 2008 [41], an aerobic stabilization of solid digestate can be used as an organic amendment, subject to its safety, to fertilize and improve the structures of agricultural soils, while reducing the risks of agro-chemical pollution of surface and groundwater linked to the massive use of chemical fertilizers. For our experiments, we made an ecological charcoal. The solid digestate and a liquid part served as a basis for mixing with several other types of dry household waste. The whole is mixed under a given temperature and exposed to the sun. Once dry, the latter is again mixed with the digestate and covered under a shelter from the sun, once the moisture content is acceptable, they are passed through a pressure mold to have a shape and exposed to the sun to dry and be ready for use.

Figure 9 Valorization of digestate in the production of sustainable coal

- Liquid fraction of the digester

The liquid leaving the digester can have pesticidal properties and be used against sucking insects of annual crops. This liquid can also be used as a source of nutrients in aquaculture or as an inoculum for anaerobic digestion.

3.4.1. Digestate valorization

One of our objectives was also to valorize the digestates obtained during the different experiments and to use them for several purposes:

Figure 10 Production of a biofertilizer (homemade)

Using digestate to fertilize the soil: this recovery consisted of directly using the liquid digestate in crop plots by following the same process of watering the plants but by preparing the crop soil in advance with the liquid digestate.

Figure 11 Valorization of digestate in crops

3.4.2. Production of biogas and use for cooking

The biogas produced respects all the stages of the biological mechanisms of anaerobic digestion described by [42]. For a small homemade assembly from a biodigester, we have the following system:

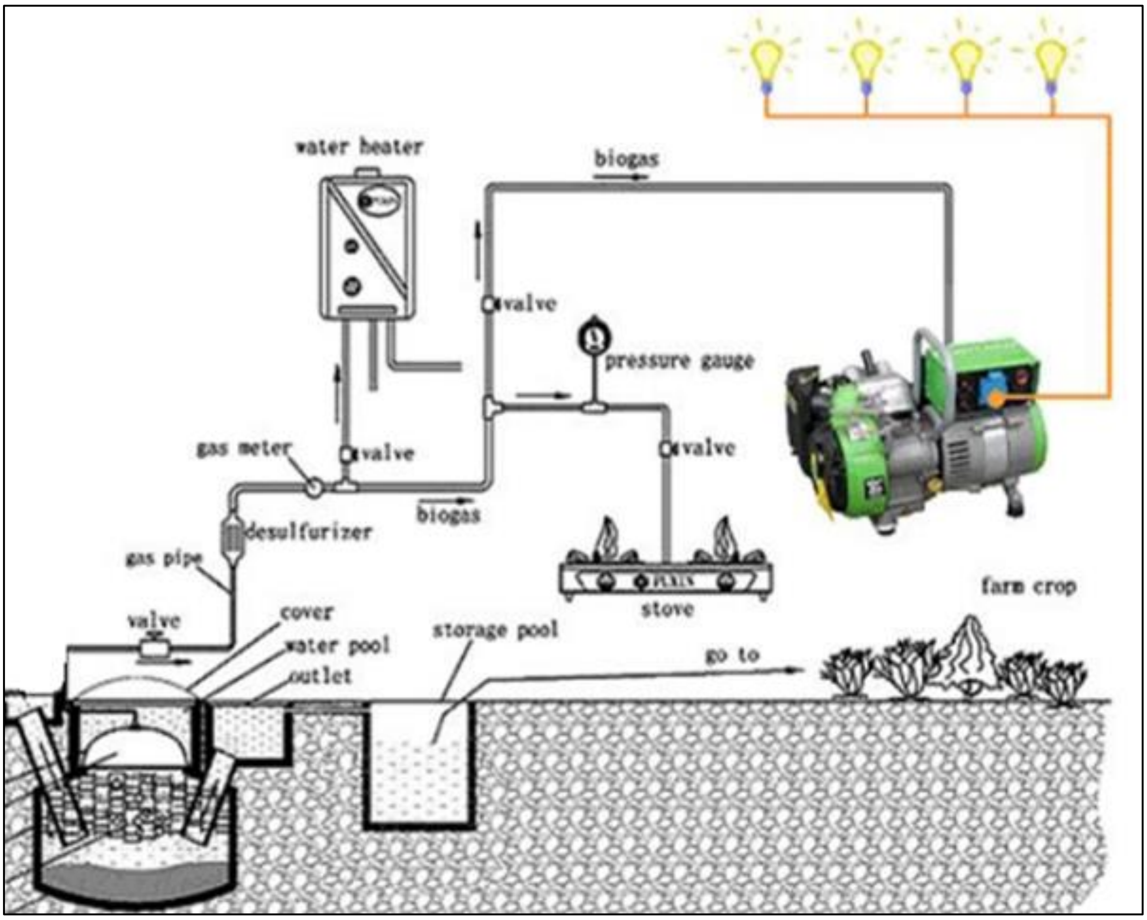


Figure 12 Assembly of a system for the production and recovery of biogas and organic fertilizer

A photograph of the different uses of biogas for cooking is given in the figure below.

Figure 13 Photograph of stoves using fire from biogas for cooking

4. Conclusion

The purpose of this work is to contribute to the challenges of sustainable development in the Sahel based on climatic, epidemic, security and humanitarian challenges. These natural and cultural hazards that occur recurrently in the Sahel contribute to slowing down and undermining social progress. The sudden increase in the population and livestock in the Sahel region, due to the arrival of refugees, promotes, as mentioned above, a growing impact on the environment. One of the solutions

Recognized as one of the most energy-efficient and environmentally friendly, anaerobic digestion technology can alleviate health problems related to the environment and human health, while representing a waste management solution. Result of the methanization or anaerobic digestion of fermentable waste in hermetically sealed enclosures called digesters, purified biogas is used as green energy and is presented as an alternative energy source to replace fossil fuel. It is an opportunity for diversification of energy resources and sustainable management of the environment in rural areas and in the Sahel zone. Anaerobic digestion represents one of the major players in sustainable development and the circular economy in the concept of "waste to energy".

Compliance with ethical standards

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Disclosure of conflict of interest

“The authors declare no conflicts of interest.”

References

[1] LASSAILLY-JACOB V., ZMOLEK M. (ED.) [1992], « ENVIRONMENTAL REFUGEES », REFUGE, 12 (1), SPECIAL EDITION.

[2] BLACK R. [1994 A], « FORCED MIGRATION AND ENVIRONMENTAL CHANGE : THE IMPACT OF REFUGEES ON HOST ENVIRONMENTS », JOURNAL OF ENVIRONMENTAL MANAGEMENT, 24 : 261-277.

[3] JACOBSEN K. [1994], THE IMPACT OF REFUGEES ON THE ENVIRONMENT : A REVIEW OF THE EVIDENCE, WASHINGTON, DC, REFUGEE POLICY GROUP. 49 P.

[4] HOERZ T. [1995], REFUGEES AND HOST ENVIRONMENTS : A REVIEW OF CURRENT AND RELATED LITERATURE, OXFORD, REPORT FOR DEUTSCHE GESELLSCHAFT FÜR TECHNISCHE ZUSAMMENARBEIT (GTZ), 121 P.

[5] IOM [1996], ENVIRONMENTALLY-INDUCED POPULATION DISPLACEMENTS AND ENVIRONMENTAL IMPACTS RESULTING FROM MASS MIGRATIONS. INTERNATIONAL SYMPOSIUM, GENEVE, 21-24 AVRIL 1996, INTERNATIONAL ORGANIZATION FOR MIGRATION, 128 P.

[6] SIMMACE A. [1987], « THE IMPACT OF LARGE-SCALE REFUGEE MOVEMENTS AND THE ROLE OF UNHCR », IN J. ROGGE (ED.), REFUGEES : A THIRD WORLD DILEMMA, TOTOWA, NEW JERSEY, ROWMAN & LITTLEFIELD : 9-14.

[7] VON BUCHWALD U. [1992], « MIGRATION AND ENVIRONMENT : LIMITS AND POSSIBILITIES OF DISASTER

[8] RELIEF », PAPER PRESENTED AT GERMAN RED CROSS SEMINAR ON MAN IN DISASTER : CAUSES, ASSISTANCE AND PREVENTION, BONN, 7 P.

[9] CARE-ODA [1994], REFUGEE INFLOW INTO NGARA AND KARAGWE DISTRICTS, KAGERA REGION, TANZANIA : ENVIRONMENTAL IMPACT ASSESSMENT, LONDRES, CARE INTERNATIONAL AND OVERSEAS DEVELOPMENT ADMINISTRATION, 73 P.

[10] Haroun Ali Adannou,et al. (2019) Valorization Capacity of Slaughterhouse Waste in Biogas by a Tarpaulin Digester in Dakar, Senegal. American Journal of Environmental Protection. Vol. 8, No. 1, 2019, pp. 22-30. doi: 10.11648/j.ajep.20190801.14

[11] Haroun Ali Adannou, et al, (2019) "Experimental Contribution to the Phenomena of Methanisation by Co-digestion of Organic Waste from the Residence of the Cheikh Anta Diop University in Dakar." Applied Ecology and Environmental Sciences, vol. 7, no. 2 (2019): 56-65. doi: 10.12691/aees-7-2-3.

[12] Haroun Ali Adannou.,et al. (2019) Influence of Climate Temperature on the Valorization of Dung-Wastewater Slaughterhouse Biogas in Two Regions: In Chad and Senegal. Natural Resources , 10, 81-95. https://doi.org/10.4236/nr.2019.104006

[13] Haroun Ali Adannou : Industrial production of biogas and energy recovery: Study of the tarpaulin digester using slaughterhouse waste. Doctoral thesis: Doctoral School of Physics, Chemistry, Earth, Universe and Engineering Sciences ED – PCSTUI : UNIVERSITE CHEIKH ANTA DIOP DE DAKAR

[14] 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. doi:10.1016/j.renene.2017.06.033

[15] M. Khelafi1, A. Tahri1, F. Salem1, K. Kaidi1, L. Bensmail3, O. Barako3, A. Kadri3, A. Amrouche3 Methanization of organic waste from the university residence of the African University of the city of Adrar, South-West Algeria. J. Mater. Environ. Sci. 5 (S2) (2014) 2484-2488 EDE4 Djaafri et al. ISSN: 2028-2508 CODEN: JMESCN 18 October 2014

[16] 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

[17] Cabbai, V.; De Bortoli, N.; Goi, D. Pilot plant experience on anaerobic codigestion of source selected OFMSW and sewage sludge. Waste Manag. 2016, 49, 47–54. [CrossRef] [PubMed]

[18] Kothari, R.; Pandey, A.K.; Kumar, S.; Tyagi, V.V.; Tyagi, S.K. Different aspects of dry anaerobic digestion for bio-energy: An overview. Renew. Sustain. Energy Rev. 2014, 39, 174–195. [CrossRef]

[19] Bond, T.; Templeton, M.R. History and future of domestic biogas plants in the developing world. Energy Sustain. Dev. 2011, 15, 347–354. [CrossRef]

[20] Mudasar, R.; Kim,M.H. Experimental study of power generation utilizing human excreta. Energy Convers. Manag. 2017, 147, 86–99. [CrossRef]

[21] Colón, J.; Forbis-Stokes, A.A.; Deshusses, M.A. Anaerobic digestion of undiluted simulant human excreta for sanitation and energy recovery in less-developed countries. Energy Sustain. Dev. 2015, 29, 57–64. [CrossRef]

[22] Decrey, L.; Kohn, T. Virus inactivation in stored human urine, sludge and animal manure under typical conditions of storage or mesophilic anaerobic digestion. Environ. Sci. Water Res. Technol. 2017, 3, 492–501. [CrossRef]

[23] Singh, J.; Gu, S. Biomass conversion to energy in India-A critique. Renew. Sustain. Energy Rev. 2010, 14, 1367–1378. [CrossRef]

Cioablã, A.E.; Ionel, I.; Tri-Tordai, G. Experimental approach for biogas production from biowaste. Int. J.Energy Environ. 2011, 5, 402–409.

[24] Rao, P.V.; Baral, S.S.; Dey, R.; Mutnuri, S. Biogas generation potential by anaerobic digestion for sustainable energy development in India. Renew. Sustain. Energy Rev. 2010, 14, 2086–2094. [CrossRef]

[25] Owamah, H.I.; Dahunsi, S.O.; Oranusi, U.S.; Alfa, M.I. Fertilizer and sanitary quality of digestate biofertilizer from the co-digestion of food waste and human excreta.Waste Manag. 2014, 34, 747–752. [CrossRef] [PubMed]

[26] Vögeli, Y.; Riu, C.; Gallardo, A.; Diener, S.; Zurbrügg, C. Anaerobic Digestion of Biowaste in Developing Countries, Pratical Information and Case Studies; Eawag-Sandec: Zürich, Switzerland, 2014.

[27] Jatinder Singh, K.; Singh Sooch, S. Comparative study of economics of different models of family size biogas plants for state of Punjab, India. Energy Convers. Manag. 2004, 45, 1329–1341. [CrossRef]

[28] Aggarangsi, P.; Tippayawong, N.; Moran, J.C.; Rerkkriangkrai, P. Overview of livestock biogas technology development and implementation in Thailand. Energy Sustain. Dev. 2013, 17, 371–377. [CrossRef]

[29] Ghimire, P.C. SNV supported domestic biogas programmes in Asia and Africa. Renew. Energy 2013, 49, 90–94. [CrossRef]

[30] 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. [CrossRef]

[31] 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.

[32] Mao, C.; Feng, Y.;Wang, X.; Ren, G. Review on research achievements of biogas from anaerobic digestion. Renew. Sustain. Energy Rev. 2015, 45, 540–555. [CrossRef]

[33] Lou, X.F.; Nair, J.; Ho, G. Energy for Sustainable Development Field performance of small scale anaerobic digesters treating food waste. Energy Sustain. Dev. 2012, 16, 509–514. [CrossRef]

[34] Ferrer, I.; Garfí, M.; Uggetti, E.; Ferrer-Martí, L.; Calderon, A.; Velo, E. Biogas production in low-cost household digesters at the Peruvian Andes. Biomass Bioenergy 2011, 35, 1668–1674. [CrossRef]

[35] Martí-Herrero, J.; Chipana, M.; Cuevas, C.; Paco, G.; Serrano, V.; Zymla, B.; Heising, K.; Sologuren, J.; Gamarra, A. Low cost tubular digesters as appropriate technology for widespread application: Results andlessons learned from Bolivia. Renew. Energy 2014, 71, 156–165. [CrossRef]

[36] Marchaim, U. Biogas Processes for Sustainable Development;MIGAL Galilee Technological Center: Kirtat Shmona, Israel; FAO: Rome, Italy, 1996.

[37] Build a biogas Plant. Natural and Renewable. Available online: http://www.build-a-biogas-plant. com/methane-and-biogas/ (accessed on 24 Janvier 2019).

[38] Chanakya H. N., Ramachandra T. V., Guruprasad M., Devi V. Micro-treatment options for components of organic fraction of MSW in residential areas. Environ Monit Assess, 2007, vol. 135, pp. 129-139.

[39] Lacour J., Bayard R., Emmanuel E., Gourdon R. Evaluation of the potential for recovery by anaerobic digestion of deposits of organic waste of agricultural origin and similar in Haiti. Waste - Francophone Review of Industrial Ecology,2011, vol. 60, pp.

[40] Schulz H., Eder B. Biogas in practice. Fundamentals, projections, facility construction, examples. 2. ed. rev. and enl. ; Biogas-Praxis. Grundlagen, Planung, Anlagenbau, Beispiele, ISBN 3-922964-59-1 ; TRN : DE01G9766. 2001. 165 pages

[41] SChröder P., Herzig R., BOjinov B., Ruttens A., Nehnevajova E., Stamatiadis S., Memon A., Vassilev A. Bioenergy to save the world producing novel energy plants for growth on abandoned land. Env Sci Pollut Res, 2008, vol. 3, n° 15, pp. 196-204.

[42] 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. doi:10.1126/sciadv.1400253