

Quantitative and qualitative characterization of the energy productivity of pilot digesters of animal manure

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Abstract. In the optics of the control of the conditions of the fermentaire medium for a better energy valorization of biogas, this study proposes, like main aim, the follow-up and the evaluation on the one hand, of the quantitative productivity of the biogas produced on an experimental scale starting from avicolous droppings, and starting from bovine dejections, and on the other hand, of the gas qualitative productivity (gas composition and calorific value) on the level of the whole of digesters (experimental avicolous, rural bovine and industrial avicolous).

Such a work made it possible to arise the principal observations hereafter:

- The combined effect of the mode of food and the nature of the substrate on the quantitative energy performances of the experimental biogas product which is in favor of the digesters supplied uninterrupted with the avicolous droppings.
- The performance of a digester from gas production point of view primarily depends on the nature of the matters to ferment, the agitation of the substrate, the temperature maintained during digestion and also of the adjustment of the pH and the DM introduced.
- Rural or industrial biogas, undergoing a stage of post processing, present of better energy potentialities especially at the industrial scale in which the increase in the LCV can reach 25%. The qualitative energy performances of the rural digester are relatively limited compared to those of the industrial digester. This is with the least effectiveness of the systems of production and conditioning of the biogases employed by this last.

Keywords: *Animal biomass, pilot digesters, gas quantitative productivity, gas composition, calorific value.*

1. Introduction

Face to the very fluctuating economic situation of the energy-generating prices of products and to appreciably reduce local pollution and the greenhouse effect [1, 2] the prospection and the development of the new sources of energy were for a long time undertaken [3]. Thus, renewable energies arouse a growing interest in particular those resulting from the biomass, and particularly, biogas coming from the Biomethanisation of the agricultural effluents [4, 5, 6, 7, 8, 9].

Several research studies have been conducted on the biogas from bovine faeces alone [10, 11, 12, 13, 14, 15, 16, 17] or in Co-digestion [18, 19] thus as on poultry biomass [4, 20, 13, 21, 16, 22, 9].

The anaerobic fermentation is the bioenergetic die with the most promising prospects [23, 24]. In Tunisia, technologies of Biomethanisation are relatively new [4]. In the agricultural sector, we speak about the die of valorization of produced animal manure (Case of the rural digester of Sidi Thabet and the industrialist digester of Hammam Sousse, Tunisia).

The degradation of OM by anaerobic way is recognized more and more like fundamental method of an advanced technology allowing environmental protection and the conservation of the resources [25, 26].

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The good performance (depollution, energy potentiality) of this kind of process is conditioned largely by the physicochemical conditions of the substrate put in fermentation (pH, DM ...).

In the optics of the control of the conditions of the fermentation medium for a better energy valorization of produced biogas, this study proposes, like main aim, the follow-up and the evaluation on the one hand, of the quantitative productivity of the biogas produced on an experimental scale

starting from the poultry droppings (digesters I and II) and of the bovine dejections (digesters III and IV), and on the other hand, of the qualitative gas productivity (composition and calorific value) on the level of various types of digesters implemented (experimental, rural and industrial).

2. Material an method

2.1.1. Various experimental devices

2.1.2. Pilot digesters of laboratory

The experimental device, installed on the level of the laboratory “Biogas” of the Agricultural Professional Training Center in Bovine Breeding (A.P.T.C.B.B.) of Sidi Thabet (Tunisia), consists of four pilot digesters.

Two digesters I and II (mode de digestion uninterrupted) differ only by their concentrations in DM which is about 6% on the level of the first and 8% in the second. The follow-up of these experimental digesters stressed especially on the effect of the variation of the rate of DM of the substrates treated by anaerobic digestion on quantitative and qualitative productivities starting from the avicolous biomass.

The two experimental digesters III and IV (mode de digestion discontinuous) differ from physicochemical parameters point of view. They were useful for the follow-up of the quantitative gas productivity starting from the bovine biomass. Table 1 shows some general data on these two digesters tested.

Table 1. Criteria of differentiation enters the two experimental digesters III and IV

Digesters	Nature of the bovine dungs	Temperature (°C)	Agitation
Experimental III	Fresh and Black dungs	25	Without
Experimental IV	Fresh dungs	35	Along with

2.1.3. Rural pilot digester

It is a buried pilot digester, installed with the farm attached to the APTCBB. This rural digester is characterized by a very weak investment and a great simplicity, since it is, mainly, auto-builds and not using sophisticated equipment. This is a digester with manual uninterrupted feed.

2.1.4. Industrial pilot digester

It is a pilot digester with cylindrical form, installed in a poultry farm in Hammam Sousse (Tunisia) since the year 2000. The installation is designed to treat four tons of fresh dejections daily, representing the day laborer production of an industrial avicolous breeding around 20000 layers [4]. The unit of Biomethanisation installed has an environmental objective which consist in reducing the pollution generated by the avicolous droppings and an energy objective which consists to feed the generators and to thus satisfy the needs for the farm and the station in produced electrical energy. This is a digester with mechanical uninterrupted feed.

Table 2 summarizes some characteristics relative to the various digesters implemented.

Table 2. Summary of the general characteristics of the used digesters

Type of digester		Experimental		Rural	Industrial
		I and II	III and IV		
Nature of the substrate	Substrate	Avicolous dropping	Fresh bovine dungs		Avicolous dropping
	Inoculum	Black bovine dungs			-
Capacity of the digester		500 ml		6 m ³	300 m ³
DM (%)	Substrate	20.9	31.5	31.5	20.9
	Inoculum	4.0	9.4	9.4	-
pH	Substrate	8.7	6.5	6.5	8.7
	Inoculum	7.2	7.2	7.2	-

Table 3. Quantification of the inputs

Type of the digester	Substrate (l)	Inoculum (l)	Water (l)
Experimental I	0.12	0.15	0.23
Experimental II	0.17	0.15	0.18
Experimental III	0.60	0.30	0.18
Experimental IV	0.10	-	0.20
Rural	2000 in the start + 50/day	1000	0 in the start + 25/day
Industrial	3.33 m ³	-	6.66 m ³

The quantities of each raw material introduced into the digesters considered are mentioned in Table 3. Knowing that a thicker consistency slows digestion of faeces, the dilution rate of organic material intervenes to have "creamy" consistency [27] and to promote the speed of digestion.

2.1.5. Evaluation of the energy performance of produced biogas

The quantitative and qualitative follow-up of produced biogas is a paramount stage for a true characterization of the principal by-product of the Biomethanisation, for an optimal valorization.

The quantitative analysis was carried out at the laboratory "Biogas" of the APTCBB, whereas the qualitative analysis has made at the laboratory of the Tunisian Company of Industries of Refining (T.C.I.R.), located in Bizerte. This analysis understands a determination of the composition of biogas produces and its CV.

Concerning the quantification, we had a vat filled with water (Fig.1) in which, we installed beakers graduated to recover gas produced (the gas will drive out water and take its place, from where; we can directly read the quantity produced starting from the graduations).



Fig.1 Adopted system of quantification of experimental biogas

The taking away of biogas was carried out by calling upon a simple system based on bladders of balloon.

For the analysis of the gas composition, we had recourse to the technique of Gas chromatography (Fig. 2). This technique is suitable for the compounds gas or likely to be vaporized by heating without decomposition. The components determined by this method are the following: % CH₄, % CO₂ and % H₂S.

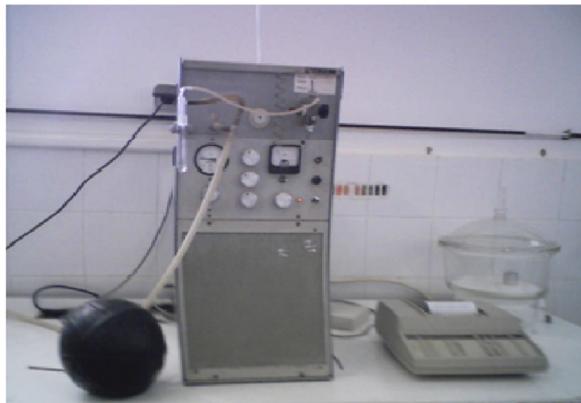


Fig. 2 The chromatography for the estimation of the composition of gas



Fig. 3 The chromatography for the estimation of the calorific values

Moreover, we were also interested in the natural energy (Figure 3), by considering the values lower and higher of the calorific value (LCV and HCV), expressed in kWh/m³, kcal/m³ or kcal/kg and which are linked by expression (1) following:

$$\text{HCV} = \text{LCV} + \text{Heat of Vaporization} \quad (1)$$

3. Results and discussion

3.1.1. Results of the quantitative evaluation of the gas productivity

In the studied case, when we speak about quantitative productivity of the biogas produced starting from the animal biomass in digesters of laboratory, there are two different scales: Large scales which correspond to the productivity recorded for the case of the avicolous droppings (Fig. 4) and the smaller second correspondent with the case of bovine dungs (Fig. 5). What makes it possible to conclude that the productivity of biogas depends on the type of OM methanized and the technology on power supply (or mode of digestion) of the digester. It is higher in the case of the avicolous biomass treated in a digester supplied uninterruptedly.

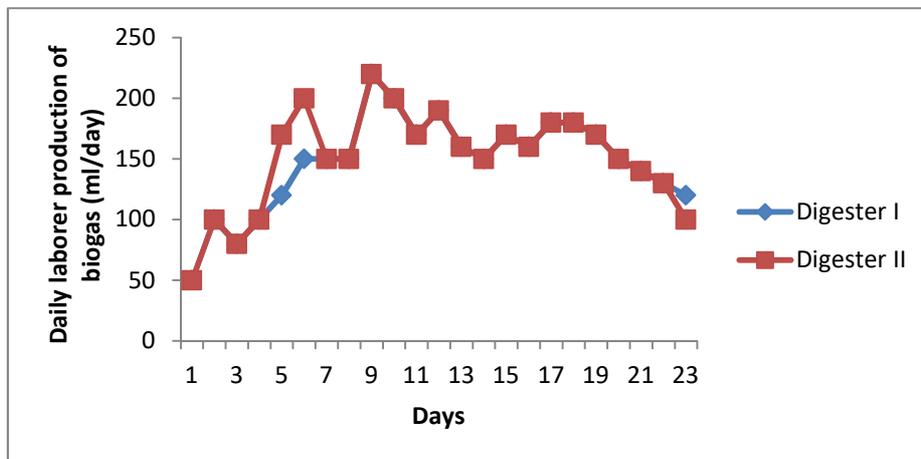


Fig. 4 Evolution of the avicolous volume of biogas produced

The daily laborer production of avicolous biogas is not constant. It fluctuated around an average value of day laborer, which is about 142 ml for the case of digester I (6% DM), and around 147 ml for the case of digester II (8% DM).

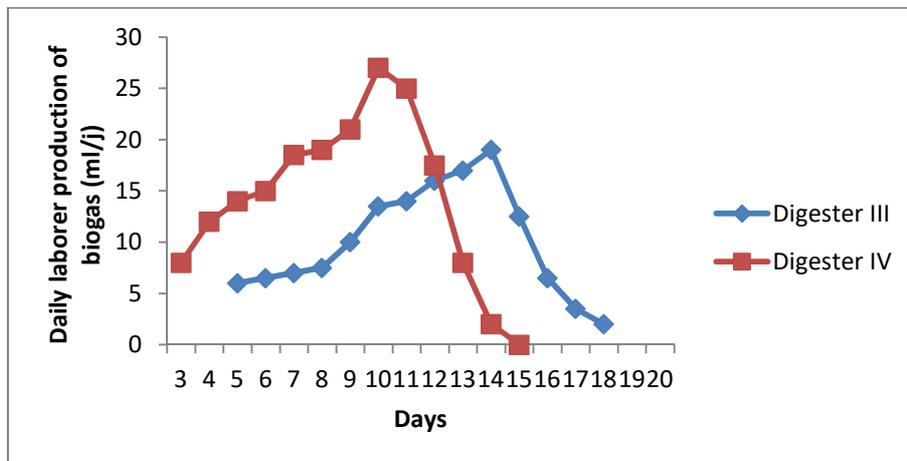


Fig. 5 Evolution of the volume of bovine biogas produced

The results obtained for two digesters I and II are in conformity with the bibliography which indicates an increase in the production of biogas with the increase in the concentration of DM [28]. According to the same author, the concentration in DM of the poultry droppings in a digester should not exceed 10%. Beyond this value, the matter is dense and causes the quickly arrested of methane fermentation.

The presence of various peaks could be explained by the existence of the fresh matters which do not arrive regularly at the level of the bacteria and their evacuation which is done before their complete decomposition.

The considerable combined effect of the temperature and agitation on the productivity of bovine biogas is more remarkable than the effect of the addition of the inoculum, from point of view speed and quantity of production.

In this respect, let us announce that agitation makes it possible to release the gas bubbles starting from the deep layers, to maintain the homogeneity of the temperature at various levels and to avoid the consolidation of the crust on the surface of the digester. It supports, moreover, the provisioning of the bacteria of nutritive substances and their transport with the fresh substrate, lately introduced, from where a clear improvement of the produced quantity.

In terms of productivity, digester IV presented a total production about 187 ml with a peak of production corresponding to 27 ml/day. For the case of digester III, it recorded a total equal to 141 ml of biogas produced with a maximum of order of 19 ml/day.

The Biomethanisation of animal waste can be an alternative to the production of biogas. The use of an adequate dilution ratio makes it possible to improve the quantitative gaseous productivity. The results of the study, carried out by Aboubakar et al. [29], on the biogas potential assessment of animal waste from experimental biogas units in the laboratory of the Maroua Zootechnique Center (Cameroon), revealed that one kilogram of the cow dung substrate at a 1/3 dose yields 100 l of biogas, being 2% and 6% higher than those of the cow dung substrates at the rate of 1/4 and 1/2 respectively. Similarly, avicolous droppings at the 1/5 dose provide 130 l of biogas, 2% and 8% higher than those at the 1/4 and 1/3 dose respectively. Crude production of biogas by avicolous droppings remains 12% higher than that of bovine dung, ie 130 l/kg compared to 100 l/kg.

3.1.2. Results of the qualitative evaluation of the gas productivity

The biogas produced by the rural digester underwent a conditioning (filtration, reduction of moisture...), in the same way, industrial biogas underwent a treatment by purification by calling upon a desulphurization with the iron hematite. Purification consists in eliminating not only of the elements traces like the steam, the hydrogen sulfide and the halogenous compounds, but also the carbonic gas, in order to enrich the concentration by methane biogas.

Concerning experimental biogas, no conditioning was implemented, in the same way, the qualitative follow-up was limited to the biogas produced on the level of the experimental digesters I and II.

3.1.3. Gas composition

The results of the analyzes relating to the composition in major elements of the experimental biogas produced by the digesters tested are given in Table 4. In real scale, the results of the analyzes relating to the digesters tested are given in Fig. 6.

The quality of biogas is evaluated primarily by the percentage of methane (CH₄) which it contains. A biogas is much better when its percentage of CH₄ is high [28]. For the case of the experimental digesters, % CH₄ generally produces increased with the increase in the concentration in DM (while passing from 6 to 8%). However, rise is negligible. It should be noted that the content CH₄ is also influenced by other not followed parameters (report C/N ...). In the same way, % CO₂ also rose with

the increase in the concentration in DM. This could be explained by the dissolution of ammonia, thus raising the value of the pH, whereas after post-processing of rural and industrial biogas, % of this element comes to decrease considerably.

Table 4. Expression of the results of the composition of produced experimental biogas

Type of digester	CH ₄ (%)	CO ₂ (%)	H ₂ S (%)
Experimental I	63.30	20.00	16.16
Experimental II	63.40	30.00	5.89

% H₂S decreased with the rise in the concentration in DM under the adopted experimental conditions. However, it is advisable to announce that this parameter is generally less low than that raised. Such a rate generates the phenomenon of corrosion and the purification of produced biogas proves strongly recommended before use.

The analysis of the results of the performance evaluation of post processing carried out makes it possible to release that % CH₄ after conditioning increased by 8% (case of the rural digester) and by 15% (case of the industrial digester), which respectively gives outputs of purification of 13.8% and 25.0%.

The results obtained show a certain effectiveness of the post-processing of the biogas which ensures a reduction in polluting elements more (CO₂, H₂S ...) as well as intensification in concentration of the CH₄.

The biomethane composition of the biogas produced in Burkina Faso is 48.5% on average for bovine substrates tested by Adeossi [30]. The results achieved in Tunisia are far better. Certainly, the digestion conditions (physico-chemical properties of the effluent, fermentation environment ...) influence the quality of the biogas produced.

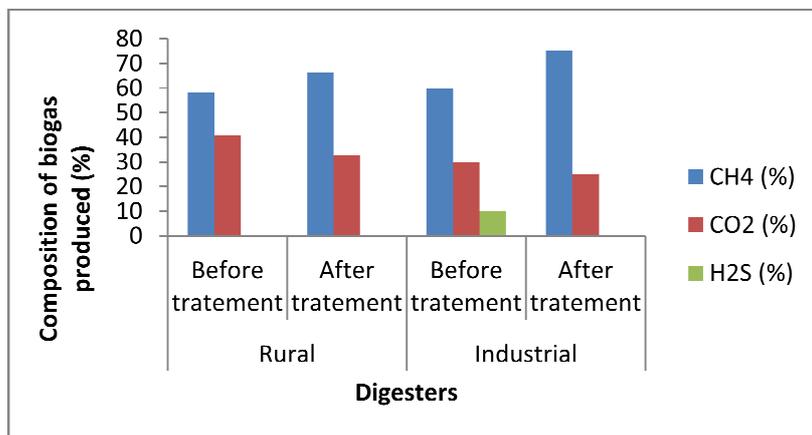


Fig. 6 Effect of the post-processing in the results of the composition of biogas

3.1.4. Calorific value

The energy results corresponding to the LCV, and thereafter, to the determination of the HCV on the level of the two experimental digesters considered, are given in Table 5.

Table 5. Results relating to the calorific values

Type of digesters	LCV (kcal/Nm ³)	HCV (kcal/Nm ³)
Experimental I	5394	6011
Experimental II	5429	6045

After purification, there is a light increase in the LCV according to the concentration in DM. In the case of the real scale (Fig. 7), contrary, there is an improvement of the calorific value especially in the case of the industrial digester presenting an output equal to 25%. We can say that industrial biogas produces present valid energy potentialities before and after purification. The output of purification of the rural digester is equal to 4.8%. This poor yield could be explained by the inefficiency of the process of conditioning implemented. Ultimately, it is advisable to more improve the output of purification of biogas to reach the theoretical maximum equal to 8500 kcal/Nm³ [31].

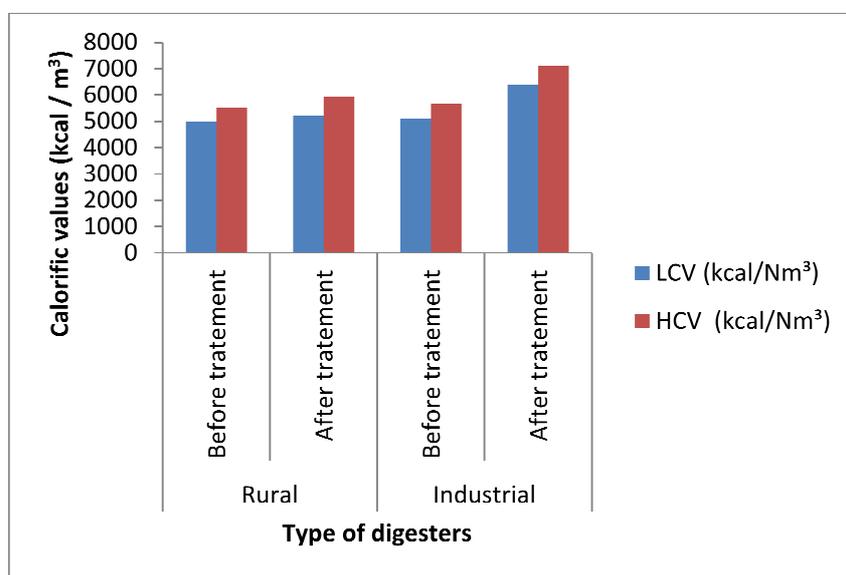


Fig. 7 Effect of the post-processing in the results relating to the calorific values

4. Conclusion

In the light of the results obtained at the time of this study referring to the energy valorization of the biogas produced starting from animal manure (avicolous droppings and bovine dungs) digested in various types of digesters (experimental, rural and industrial), we could draw some interesting observations on:

- The combined effect of the mode of digestion (uninterrupted or into discontinuous) and of the nature of the substrate (avicolous or bovine) on the quantitative energy performances of experimental biogas produced. The gas productivity is higher in the case of the digesters supplied uninterrupted with the avicolous droppings.
- The quantitative performance of experimental digesters depends on the nature of the matters to ferment, the agitation of the substrate, the temperature maintained during digestion and also of the adjustment of the pH and the DM introduced.

- The effect of the concentration in DM on the qualitative energy performances (gas composition and calorific value) of produced experimental biogas. This provided observation is valid when the concentration in DM does not exceed 10%, which is confirmed by the results raised for the experimental digester II (8% DM) whose maximum day laborer production reaches a peak of 220 ml.

- The effect of the addition of a inoculum, temperature and agitation on the quantitative productivity. The latter is more important in the case of the bovine digester IV using the fresh bovine dungs like substrate and the black dungs like inoculum and functioning at a temperature equal to 35°C and under mechanical agitation.

- The post-processing of rural or industrial biogas makes it possible to more increase its energy potentialities on the plans % CH₄ and HCV of 25% in the case of the industrial digester.

Biomethanisation technology is part of the new and renewable, non-polluting, decentralized technologies, leading to the autonomous production of energy. As a result, this technology deserves special attention if we consider real development for current populations and future generations.

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6. References

- [1]. Mata-Alvarez, J. Macé, S. Llabres, P., 2000- Anaerobic digestion of organic solid wastes: An overview of research achievements and perspectives, *Bioresource Technology* 74, 3-16. www.sciencedirect.com/science/journal/.../74/1
- [2]. Holm-Nielsen, J.B., Seadi, T., Oleskowicz-Popiel, P., 2009- The future of anaerobic digestion and biogas utilization, *Bioresource Technology* 100, 5478-5484. top25.sciencedirect.com/.../bioresource-technology/...
- [3]. Amand, G., Bonnouvrier, A., Chevalier, D., Dezat, E., Nicolas, C., Ponchant, P., 2008- Les consommations d'énergie dans les bâtiments avicoles, Quelques repères sur les consommations d'énergie et propositions de pistes d'amélioration, *ITAVI* 1, 24 p. www.itavi.asso.fr/elevage/batiment/energie_aviculture_ademe.pdf
- [4]. ALCOR & AXENNE, 2003- Étude stratégique pour le développement des énergies renouvelables en Tunisie-Bilan des réalisations, Rapport final de l'Agence Nationale des Énergies Renouvelables, 148-157.
- [5]. Fuchs, J.G., 2008- Effets de composts et de digestats sur l'environnement, sur la fertilité du sol et sur la santé des plantes, Institut de Recherche en Agriculture Biologique (FiBL), *Revue UFA* 11, 44-55. <http://orgprints.org/13335/>
- [6]. 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. www.researchgate.net/.../Substituting_energy_crops...
- [7]. Karellas, S., Boukis, I., Kontopoulos, G., 2010- Development of an investment decision tool for biogas production from agricultural waste, *Renewable and Sustainable Energy Reviews* 14, 1273-1282. www.researchgate.net/.../222409692_Development_o...

- [8]. Douag-Tirichine, N., Benkhelifa, A., Bousdira K., 2013- Production de Biogaz à Partir des Déjections Bovines en Milieu Aride : Cas du M'Zab (Algérie), Conférence Internationale des Energies Renouvelables (CIER'13), Sousse, Tunisie, 4 p.
- [9]. Afilal, M.E., Elasri, O., Merzak, Z., 2014- Caractérisations des déchets organiques et évaluation du potentiel Biogaz, J. Mater. Environ. Sci., 5 (4), 2014, 1160-1169.
- [10]. Tou, I., Igoud, S., Touzi, A., 2001- Production de biométhane à partir des déjections animales, Revue des Energies Renouvelables, N° Spécial : Biomasse, production et valorisation, 103-108. www.cder.dz/download/bio_17.pdf
- [11]. Igoud, S., Tou, I., Kehal, S., Mansouri N., Touzi, A., 2002- Première Approche de la Caractérisation du Biogaz Produit à Partir des Déjections Bovines, Revue des Energies Renouvelables, Vol.5, pp 123-128. www.cder.dz/download/Art5-2_4.pdf
- [12]. Dejiang, L., Guili, G., Yanmei, Z., Yan, L., Zhiquan, Y., 2005- The comparison experiment of biogas fermentation with pig dung, cow dung, sheep dung, J.Tarim Univ. Vol. 17, N° 2, 3-11.
- [13] Afilal, M.E., Bakx, A., Belakhdar, N., Membrez, Y., 2010- Evaluation of the biogas potential of organic waste in the northern provinces of Morocco, Revue des Energies Renouvelables, Vol. 13 N°2, 249-255. www.cder.dz/download/Art13-2_5.pdf
- [14]. Ounnar, A., Benhabyles, L., Igoud, S., 2012- Energetic Valorization of Biomethane Produced from Cow-Dung, Procedia Engineering, Vol. 33, 330-334, 2012. www.sciencedirect.com/science/.../S18777058120124...
- [15]. 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, décembre 2012, N°7, 81-86. http://www.univ-chlef.dz/revuenatec/Art_07_10.pdf
- [16]. 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, 2013, 3 p.
- [17]. 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, 4 (2), oct. 2013, 343-352. www.issrjournals.org/ijias/fr/authid.php?id=612
- [18]. TchouateHéteu, P., Martin, J., 2003- Conversion biochimique de la biomasse : Aspects technologiques et environnementaux. Université Catholique de Louvain, 27 p.
- [19]. Zhou, S., Zhang Dong Y., 2012- Pretreatment for biogas production by Anaerobic fermentation of mixed corn stover and cow dung, Energy, Vol. 46, 644-648. <https://ideas.repec.org/.../energy/v46y2012i1p644-64>
- [20]. Afilal, M.E., Moncif, M., Benyamna, A., 2007- Valorisation des déchets organiques par fermentation méthanique, Revue des Energies Renouvelables CER'07 Oujda (2007) : 9-12.
- [21]. M'Sadak, Y., Zoghliami, R.I., 2012- Caractérisations physico-chimique, environnementale et énergétique de la Biométhanisation industrielle avicole en Tunisie semi-aride, Algerian Journal of Arid Environment, 2 (2), décembre 2012, 16-27. www.univouargla.dz/Pagesweb/PressUniversitaire/doc/.../E020202.pdf
- [22]. M'Sadak, Y., Ben M'Barek, A., Zoghliami, R.I., 2013- Diagnostics environnemental et énergétique des digesteurs anaérobies expérimentaux des fientes avicoles, Revue Nature & Technologie, janvier 2013, Numéro 8 (C), 19-26. www.univ-chlef.dz/revuenatec/Art_08_C_03.pdf
- [23]. 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 (2008) 8112-8117. www.researchgate.net/.../5411213_Predicting_anaero
- [24]. Moletta, R., 2009- La méthanisation. Édition TEC & DOC Lavoisier, Paris, France, 532 p.

- [25]. Satyanarayana, Sh., Murkutea, P., Ramakant, X., 2008- Biogas production enhancement by Brassica compostries amendment in cattle dung digesters, *Biomass and Bioenergy* 32, 210-215. www.sciencedirect.com/science/journal/.../32/3
- [26]. Karagiannidis, A., Perkoulidis, G., 2009- Multi-criteria ranking of different technologies for the anaerobic digestion for energy recovery of the organic fraction of municipal solid wastes, *Bioresource Technology* 100, 2355-2360. www.sciencedirect.com/science/journal/.../100/8
- [27]. Lagrange, B., 1979- EDISUD, Biométhane Tome 2 : Principes, techniques et utilisations, 246 p.
- [28]. Akrouit, J., 1992- Étude énergétique de la fermentation méthanique des fientes de volailles: optimisation des facteurs influant et modélisation du système, Doctorat de spécialisation, École Nationale des Ingénieurs de Tunis, Tunisie, 143 p.
- [29]. Aboubakar, A.D., Boli, Z., Mbofung, C.M.F., 2016- Étude du potentiel biogaz des déjections animales : bouses de bovins et fientes de volailles d'un centre zootechnique à Maroua - Cameroun, *Revue des Energies Renouvelables* Vol. 19 N°3 (2016), 447-464. http://www.cder.dz/download/Art19-3_11.pdf
- [30]. Adeossi, F.G.F., 2013- Caractérisation du biogaz produit à partir des substrats bovins et porcins dans la région du Centre du Burkina Faso, Mémoire Mastère, Institut International d'Ingénierie de l'Eau et de l'Environnement (Fondation 2iE), Ouagadougou, Burkina Faso, 56 p. http://documentation.2ie-edu.org/cdi2ie/opac_css/doc_num.php?explnum_id=1824
- [31]. Monzambe, M., 2002- La problématique de la Biométhanisation en République Démocratique du Congo, Kinshasa, Académie Nationale des Sciences du Développement, Bulletin de l'ANSD, Vol. 3, 7-34.