Evaluation of formulas to calculate biogas production under Moroccan conditions

This paper presents different formulas for calculating biogas production and evaluates them for use in the Moroccan context.

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Abstract

A biodigester was installed in Dayet Ifrah and connected to a farmer's toilet and to a barn in June 2010. This is the first pilot unit built in Morocco used to produce biogas from anaerobic treatment of human excreta and animal slurries. The biogas produced is used as energy in cooking food and heating water. The entire biogas system works normally and operates properly. But, after one year, the only problem we met is that the biogas production is low. The purpose of our study is to check if the weakness of the biogas volume is due to the dimensions of the biogas system. Our study confirms why biogas production is low. So, five other dimensioning formulas are evaluated and compared to the formula used by GIZ. All formulas are compared and ranked by the ELECTRE III method and then by the sensitivity analysis. Results indicate that under Moroccan conditions Vedrenne's formula (Vedrenne, 2007) is the most appropriate equation to calculate the biogas production in Moroccan context. In addition, the formula used in Dayet Ifrah over-estimated the volume and the Vedrenne's formula should be used.

Introduction

Anaerobic digestion is a biological process of degradation of organic input materials. In the anaerobic digestion process, micro-organisms convert complex organic matter to biogas, which consists of methane (CH^4) and carbon dioxide (CO^2) saturated with water. It seems to be an efficient way of wastewater treatment and renewable energy production. De La Farge (1995) provides an overview of biogas production and its environmental issues. A biogas plant can not only solve environmental problems, but also produce renewable energy or green energy.

In Morocco, biogas is not yet well developed for the following main reasons:

- Limited financial aids
- Technical problems (corrosion, sealing, …)
- No continuous training for managers and technicians
- No after-sales service
- Conventional energies (wood, butane, etc…) competitive and subsidized
- Little interest of people : wood is free and butane is prestige
- No integration of the private sector as manufacturer, repairer…

Key Messages:

- The biodigester is designed for 17 inhabitants, 5 cows, 3 calves, one mare, 2 donkeys, one mule and about 50 sheep and lambs.
- The biodigester's volume is about 40 m^3
- Organic load per person is 50 g COD per day in Moroccan rural areas.
- Total organic load of the farmer COD_{tot} = 30,61 kg COD per day.
- Dry matter in the manure is 20%.
- The blackwater and the manure are treated in the biodigester.
- Agriculture based economy.
- Water source – ground water

‘Douar’ (nomad village) Development Project, pilot project to reinforce local capacities in Dayet Ifrah (population 1500) with a participative approach. Activities include training, improvement of conditions for access to drinking water and sanitation, and creation of income generating activities (reuse of wastewater etc. on-going activities).

Dayet Ifrah village was selected as rural Moroccan area in order to test the experimentation of producing and recovering biogas for domestic or public uses. This place, with latitude of 33°34‘N and a longitude of 4°55‘W, is a wetland and a water resource for drinking water. It’s recognized as a biological and ecological interest site to be preserved in Morocco. It’s characterized by a sub-humid climate with cold winters and cool summers, with an annual rainfall of 1118 mm.

The project of Dayet Ifrah village is supported by GIZ within the AGIRE programme „Support to the Integrated Management of Water Resources program in Morocco“. It is the first pilot project in Morocco in term of experimentation and research in this field.

The purpose of our study is to compare different formulas used for counting biogas productions and then to choose the best one for the Moroccan context using a Principal Component Analysis. Our study shall allow better design of the future biodigesters planned in Dayet Ifrah by GIZ. It seems that the one built in June 2010 produces less biogas than expected.

Materials and Methods

Design and description of the biodigester

This digester is a continuous type with fixed dome, built entirely underground. As its name indicates, this type of digester has a fixed collection gas dome. It’s built using bricks and mortar as it’s shown in the Figure 1.

The users of biogas in the Dayet Ifrah village used a filtering individual pit to collect its domestic wastewater. But, this way of wastewater collection is inadequate and out standards of Moroccan laws. Since June 2010, the wastewater has been collected in a biodigester, which also receives the slurry of cattle.

Organic wastes from cattle slurry and domestic wastewater are mixed and treated continuously in our digester type psychrophilic fermentation because the temperature varies between 12°C and 17°C (Benhassane, 2011). The biogas produced is stored in the gasometer capping digester (Figure 2). It is used as fuel in the farmer home, and the heat generated is used for heating and cooking (Figure 3). As it is shown in Figure 4, the objective is of the digester is threefold: i) to reduce the pollution load, ii) to enhance fertilising elements and iii) produce biogas.

Figure 2: Gasometer capping Dayet Ifrah biodigester (Photo: GIZ, 2011)

Figure 3: Biogas cooker at the farmer’s kitchen in Dayet Ifrah (Photo : ABARGHAZ, 2011)

Figure 1 : Biogas plant during construction in Dayet Ifrah village, Morocco (Photos : ABARGHAZ, 2010)

The study considered manures and slurries produced by the farm and human excreta produced by all members of the family which is composed of 17 people and has until eight cattle (five cows and three calves), about 50 sheep and lambs, one mare, two donkeys and a mule that are used for transportation.

The daily input into digester is 124 kg of slurries and 42 kg of human waste. According to Amahrouch and Jlaidi (1995) the manure should be mixed with water at a ratio 1:1, therefore 124 liters of water and/or urine are added to dilute slurries. The hydraulic retention time chosen is 150 days. The volume of the biodigester was chosen as follows: (124 x 2 x 150)/0.95 = 40 m^3. The volume of biogas produced per day varies from 0.7 to 5 m^3 (Abarghaz, 2009).

Calculation of biogas production

a: Formula used in Dayet Ifrah:

For the biodigester built in Dayet Ifrah village, GIZ used the following model „Formula used in Dayet Ifrah" to dimension the production volume of biogas.

According to the study done by GIZ in 2009 in designing the existing biodigester in Dayet Ifrah village, the biogas production in summer can reach 35 liters per kg of fresh matters (Wauthelet et al., 1996). In winter, production can be reduced to 5 liters per kg (Wauthelet et al., 1996). This production is dependent on the hydraulic retention time of matters in the biodigester, on the temperature and on the quality of organic matters. The substrates should be collected as often as possible (once or twice a day) and be the freshest possible.

The daily quantity of biogas produced by the slurries alone and if the toilet is also connected to the biodigester is shown in Table 1. When adding faeces, biogas production will be increased by 190 liters per day.

We also need to estimate total chemical oxygen demand that could be converted to biogas :

- COD_total = COD_human + COD_manure
- The percentage of dry matter (DM) in the slurry represents 20 %, corresponding to 200 g DM/kg
- COD_manure = (DM + 20 % . DM) x 124 = 240 x 124 = 29'760 g/d
- COD_human = 50 * 17 = 850 g/d
- COD_total = 29.76 + 0.85 = 30.61 kg/d

It is assumed that half of COD_total was converted to 4.53 m^3 of biogas at 20°C and to 0.81 m^3 at 10°C.

So, the equation used in the Dayet Ifrah project to calculate the produced biogas Q_biogas (m^3/d) was:

$$Q\_biogas = 0.3 \times COD\_total \quad (1)$$

b: Other formulas:

In the following, 5 other formulas for calculating the volume of the produced biogas which seem to be applicable in the case of continuous fermentations of completely mixed animal and human substrates are explained below:

i: Formula according to Boursier (2003) :

$$Vg = Ps \times COD\_reduced \quad (2)$$

where:

- Vg : the quantity of biogas produced (m^3)
- Ps : the specific gas production (Figure 5)
- COD_reduced/d: Chemical Oxygen Demand removed per day (kg COD/d)

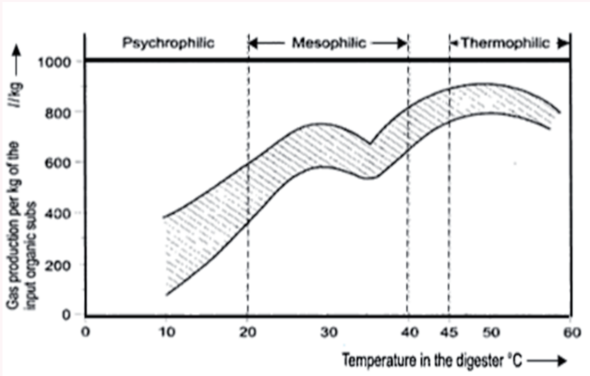

Figure 5 : Temperature effect on gas production (Nijaguna, 2002)

ii: Formula according to Bouille and Dubois (2004):

$$Q = Bo.Mo \quad (3)$$

where:

- Q: The amount of biogas produced (m^3)
- Bo: the potential of biogas production (Figure 5)
- Mo: oxidisable matter.

Table 1 : Biogas production per day (Slurries and faeces)

Quality of Biogas production					
Slurry (kg/d)	Faeces (kg/d)	Summer (20°C)		Winter (10°C)	
		(l/kg)	(l/d)	(l/kg)	(l/d)
124	-	35	4340	5	620
124	42	-	4530	-	810

Mo could be expressed in relation of COD by using the empirical relationship of Mo according to BOD_5 and COD, i.e. Mo = (BOD_5 + 2 COD) / 3. Additionally, we know that COD/BOD_5 = 2.5 and therefore Mo = 0.6 COD.

iii: Model Hashimoto according to Nijaguna (2002) (equation n° 3).

$$Q\_m\ (m^3/d) = VVJ.V \quad (4)$$

where:

- VVJ : Technological efficiency
- V : Biodigester volume (m 3)

$$VVJ = B.(Mo/HRT) \quad (5)$$

where:

- B: Biological efficiency
- Mo: matter oxidizable
- HRT: hydraulic retention time.

$$B\ (m^3\ CH_4/\ kg\ Mo) = Bo.\ [1 - (K/(Mm.HRT) + K - 1)] \quad (6)$$

where:

- K: Constant of inhibition
- Mm : kinetic coefficient
- Bo : Production potential of methane = 0,35 /kg Mo

$$Mm = 0.013 * T - 0.129 \quad (7)$$

$$K = 0.6 + 0.021.10^{0.05}\ .Mo \quad (8)$$

iv: Formula according to Vedrenne (2007) :

$$QCH_4 = Bo\ .\ Mo\ .\ MCF\ .\ Sg \quad (9)$$

where:

- Bo : potential production of methane per kg of matter oxidizable ,
- Mo: matter oxidizable
- Sg : Part of faeces directed towards anaerobic system,
- MCF : Methane conversion factor (Table 2)

v: Formula according to Executive Board-CDM (2008):

$$QCH_4 = S_y\ .\ COD\ .\ FCM\ .\ COD_f\ .\ F\ .\ 16/12 \quad (10)$$

where:

- S_y: Volume of wastes feeding the biodigester
- COD: Fraction of degradable organic matter
- FCM: Methane conversion factor,
- COD_f: Fraction of COD converted to biogas
- F: Fraction of methane in gas (0.5, IPCC, 2006).
- 16/12: Conversion factor carbon to methane.

Evaluation of the formulas

Before implementing the pilot project, GIZ recommended Eq. 1, the „Formula used in Dayet Ifrah“ for estimating the biogas production. However, this equation may is not adapted to the Moroccan context. Therefore n this paper we wanted to answer the following question: Which equation should be used to estimate the biogas quantity in Dayet Ifrah?

In this paper, for comparing the equations described above we chose principal component analysis (PCA, Le Moal, 2002). The results of the PCA are then compared and ranked using the ELECTRE III multi-criteria method, and then a sensitivity analysis will be applied in order to check the stability of the ranked formula.

PCA is one of the most known methods and flexible for data analysis; it's a descriptive method that aims at describing and graphing the similarities between individuals from all variables. The implementation of PCA can be used according to the Factor Analysis procedure of SPSS (Statistical Package for the Social Sciences) software. Factor Analysis is based on the calculation of averages, variances and correlation coefficients. It's a multivariate data analysis technique whose main purpose is to reduce the dimension of the observations and thus simplify the analysis and interpretation of data, as well as facilitate the construction of predictive models. PCA is a linear dimensionality reduction technique, which identifies orthogonal directions of maximum variance in the original data, and projects the data into a lower-dimensionality space formed of a sub-set of the highest-variance components.

ELECTRE (ELimination and Choice Expressing REality) is a family of multi-criteria decision analysis methods. ELECTRE III was developed by Roy (1968, 1991) in response to deficiencies of existing decision making solution methods. It is a mathematical method of decision aid, typically used in the field of waste management, its principle is based on the ranking of the different proposed actions to choose the most appropriate (Saaty, 1980). We chose ELECTRE III method

Table 2 : Methane conversion factor (MCF) for storage of cattle slurry for different temperatures and retention times.

Retention time (Days)	Temperature (°C)			
	10	15	20	30
30	0	0	0,02	0,34
100	0	0	0,31	0,63
180	0,15	0,27	0,41	0,77

because it was applied with success during the last two decades on a broad range of real-life applications in ranking problematic.

Results and Discussions

According to the measurements at the biogas system in Dayet Ifrah carried out from April 2011 to July 2011 by Benhassane (Benhassane, 2011), the results are summarized as follows:

- As it is shown in the Table 3, the ratio acidity on alkalinity found is around 0.5, which shows that there is no accumulation of volatile fatty-acids (propenoic acid, acetic acid, butyric acid) which certainly disturb the anaerobic digestion process and consequently the production of biogas.

Table 3: Measurements of $CaCO_3$ and fatty-acids concentrations

	Alkalinity (g $CaCO_3$)	Acidity (g)	Acidity/ Alkalinity
June 13, 2011	11	3	0,27
June 16, 2011	14	6,75	0,48
June 23, 2011	10,45	4,76	0,46
June 27, 2011	12,23	5,66	0, 46

- The measured pH value in the influent of the digester was 7.4 (N = 17, standard deviation = 0.2) and in the outlet 8.1 (N = 17, standard deviation = 0.2). The higher value of the pH in the effluent corresponds to the results of a search carried out by Kupper and Fuchs (2007).

- According to the BOD_5 analysis the performance of the digester was 82 % (Table 4). On May 18, 2011, we observed COD to BOD_5 ratio of 1.35 showing high biodegradability of the substrate.

Table 4: BOD_5 and COD analysis results

	BOD_5 inlet (mg/l)	BOD_5 outlet (mg/l)	COD inlet (mg/l)
May 18, 2011	8500	1550	-
May 27, 2011	9200	1200	-
June 13, 2011	-	1150	-
June 16, 2011	9550	1400	-
June 23, 2011	7600	1180	-
June 27, 2011	8500	1100	-

- The measurements regarding removal of bacteriological parameters are shown in Table 5

According to the results shown above, the Dayet Ifrah biogas system works normally and operates properly. So, the lower volume of biogas produced is only due to the equation used to dimension the production of biogas.

By using the evaluation methods described above, it was found that Vedrenne's formula (Eq. 9) is the most appropriate to estimate the production of biogas in the context of our biodigester. Vedrenne's formula was ranked first among all formulas when applying the ELECTRE III method.

When applying the different formulas to estimate biogas production, we calculated the quantity of biogas produced daily, corresponding to a rate of COD removed (varying from 10 to 100%) and under different temperature conditions (minimum =10.5°C and maximum =20°C). The formula used in Dayet Ifrah (Eq. 1) is over-estimating the biogas quantity compared to Vedrenne's formula (Eq. 9) especially in summer (Figure 6).

Conclusion

The decision to construct an UDDT also involved the The results of our study have shown that the quantity of biogas produced in the digester as estimated by the Formula used in Dayet Ifrah (Eq. 1) are overestimated especially in conditions of high production i.e. high temperature. Using principal component analysis, ELECTRE III method and sensitivity analysis, we obtain the most appropriate formula for calculating the amount of biogas produced in the digester existing in Dayet Ifrah under Moroccan rural conditions. Therefore, we can consider that the Vedrenne equation (Eq. 9) is the closest to the reality of the Moroccan context in estimating quantities of biogas produced.

The results can help with designing new biogas systems planned for Morocco. However, the biogas volume should in second step be measured in the area of this study to confirm that indeed the equation found is the closest to the reality of the produced biogas volume. The technology is new in Morocco and as such will need demonstration at other farms in the study area to further the information on these systems and confirm the study's conclusion.

The overall outcome of this study is the optimization costs investment, operating and maintenance. This attainment allowed us to correct the calculation methods for future sites with more efficiency and effectiveness. The biogas system works normally if operated properly and well designed.

Table 5 : Bacteriological analysis results

Date	Localisation	Total coliforms	Faecal coliforms	Faecal streptococci	Clostridium
June 14, 2011	Inlet	$3,2\ 10^5$	$4,2\ 10^4$	$3,9\ 10^3$	$4,2\ 10^4$
	Outlet	$4,2\ 10^2$	$2,1\ 10^2$	$3,1\ 10^2$	< 1
Elimination rate		99,87 %	99,5 %	92,05 %	> 99,998%
June 20, 2011	Inlet	$4,2\ 10^4$	$2,2\ 10^4$	$1,3\ 10^3$	$2,1\ 10^4$
	Outlet	$2,1\ 10^2$	$3,5\ 10^1$	$2\ 10^1$	< 1
Elimination rate		99,5 %	99,84 %	98,46 %	99,995 %
June 07, 2011	Inlet	$5,1\ 10^3$	$2,1\ 10^3$	$4,1\ 10^2$	$2,1\ 10^3$
	Outlet	$1,4\ 10^2$	2,1 101	$1,5\ 10^1$	< 1
Elimination rate		97,25 %	99%	96,34 %	> 99,95 %

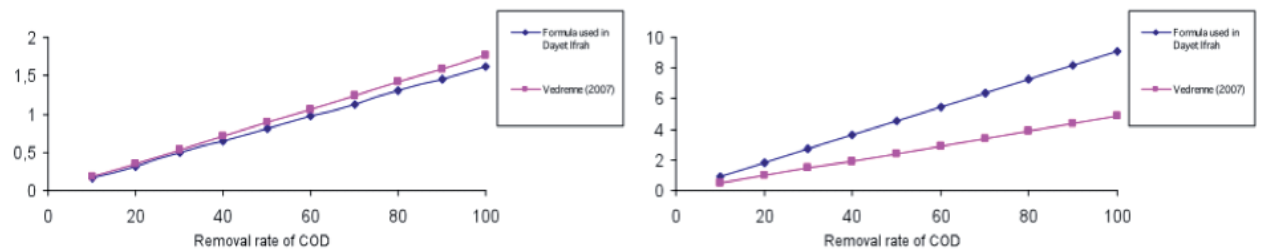

Figure 6 : Daily quantity of biogas produced (m^3) depending on the COD removal rate in winter (left) and summer (right) calculated using the Formula used in Dayet Ifrah (Eq. 1) and Vedrenne's formula (Eq. 9).

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