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Research Article

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Technical study of biogas production by an experimental bioreactor

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ABSTRACT

In the current global context, the use of biomass is both an environmental necessity and an economic opportunity. Indeed, it opens new avenues for sustainable development: create jobs, reduce energetic and environmental constraints on the economy. The studies which our laboratory has done at the University City were able to show the socioeconomic importance of energy recovery from fermentation of organic waste collected locally. Indeed, we have able to assess a returns exceeding 500 litters of biogas per kilogram of organic matter and a potential of organic waste of more than one tonne per day. The energy produced can cover 100% of the energy needs of the kitchen and about 30% of energy needs for domestic hot water in the university residence of Oujda, which would reduce the cost of energy expenditure approximately 300000 Dirhams per year.

Keywords: organic waste, bioreactor, fermentation, biogas, Methane.

INTRODUCTION

Every day, domestic and industrial activities produce millions of tons of waste. In Morocco, for example, more than 20 million tons of waste is generated per day [1]. For several years the scientific community has sounded the alarm and encourages countries to take appropriate measures to minimize the risk of pollution and this particular through several evaluation studies of organic waste management techniques, and developing of new upgrading Technology.

Biogas as energy source, thus that the other renewable energy sources have again become very attractive in recent years, due to fact that reserves of fossil energy resources are in continual regressions and global energy demand, especially for electricity continues to rise. In addition, price increase that have experienced the fossil fuels those recent years are a major handicap to development especially for emerging countries, which imports most of their energy. The Morocco, for example, is experiencing a growth in electricity demand of 8% per year [2].

Conscious these challenges, the Moroccan authorities have undertaken for more than a decade a number of regulatory and institutional approaches to address the environmental challenges in general and the sound management of waste in particular. Thus, several studies have been launched to do inventory and propose regulatory and technical measures that are needed.

The promulgation in Morocco in 2006 of the 28-00 law on waste management and disposal is in this context a major turning point in terms of strengthening the legal framework for waste management in general, and hazardous waste in particular.

However, waste management follows several steps including the storage, disposal, reducing the amount or recovery such as incineration, composting and the controlled landfills or anaerobic digestion. The latter technique was introduced in Morocco in the early 80s, without success, mainly because to the non adaptation of technology to the Moroccan context and the lack of involvement of academic researchers in monitoring and evaluation [3].

Anaerobic digestion is an organic waste upgrading process that provides a renewable energy (biogas) in the absence of oxygen with the transformation and degradation of organic matter by the combined action of several communities of microorganisms.

This reaction is accompanied by the production of biogas, composed of 55-70% methane (natural gas) and a digestate that can be used as an agricultural amendment. In fact, the scrap or waste "digested" from anaerobic digestion are recommended for soil enrichment [4].

Most of the biogas thus produced by methanogenic microorganisms contains the methane of formula CH_4, this is a hydrocarbon of the alkanes family.

In this study, we show that anaerobic digesters or bioreactors can be made for the recovery of organic waste of the university canteen Oujda, with a very favourable energetic and economic interest.

EXPERIMENTAL SECTION

The technical study includes a survey and the data collection followed by laboratory analysis for the assessment and in the end comes out with recommendations. The following data were collected from the university restaurant staff in accord with their hierarchy:
✎ Determination of energetic expenditures (Energetic needs in MWh/year)
✎ The number of meals taken away and served on site.
✎ The waste generated from meals preparation and those abandoned by the students are collected throughout the week, then placed in labelled plastic bags, and stored in the laboratory freezer to perform the following analyzes :
- Fraction fermentable / non-fermentable,
- Density (D),
- Moisture content (% Rh),
- Dry Matter (DM),
- Mineral Matter (MM),
- Organic Matter (OM) or dry matter volatile (DMV),
- The total organic carbon (TOC),
- Microbiological characteristics,
- Potential of biogas in ml/g (or m^3/T).

The study of the methane fermentation was carried out in different conditions, in 12 bioreactors, depending on the parameters listed in the following table 1

Test	1	2	3	4	5	6	7	8	9	10	11	12
Temperature (°C)	17	35	45	55	35	35	35	35	35	35	35	45
Rate of fresh substrate (%)	10	10	10	10	1	10	30	10	10	10	10	10
Ferment rate (%)	50	50	50	50	50	50	50	0	25	50	100	50
Total volume (ml)	100	100	100	100	100	100	100	100	100	100	100	250

RESULTS AND DISCUSSION

3.1. The campus energy needs:

The annual energy requirement, other than electricity, of the university campus of Oujda are estimated at around 2033 MWh/year, this which costs about 723 200 Dh/year. The majority of this energy is supplied by coal (81.93%) and diesel (18%) to heat water of the pavilions and of the kitchen. In addition, energy use of the kitchen (in propane) is 1.36 MWh.

While the energy currently used in the university restaurant Oujda are polluting and are expensive (propane 176.47 dh/kWh, coal 0.156 dh/kWh, diesel 0.61dh/kWh), biogas appears the best alternative because it is clean and is produced by organic waste produced by the cafeteria itself.

Tab 2. Energy requirements other than electricity

	Consumption (Ton/year)	Density (kg/L)	LHV (KWh/L or KWh/Kg)	Consumption (MWh /year)	Consumption (Dh/year)	Energy (%)	Cost (%)
Gasoil	30	820 000	10	365.85	223 200	18	31
Propane	120	0.5812	6.59	1.36	240 000	0.07	33
Coal	200	-	8.33	1666	260 000	81.9	36
Total	-	-	-	2033	723 200	-	-

3.2. The biomass potential:
The results in Table 3 show that the potato residues are the major organic waste, this substrate being very fermentable is encouraging for the installation of biogas's bioreactors. The rest of the waste (meat and vegetables) are also fermentable and present no problem for anaerobic digestion.

So the amount of waste generated is of the order of:

6988 Kg/week hence a potential of about 1t/day

The wastes produced by the cafeteria are about 1 ton/day, mainly composed by remnants generated during meal preparation (97.11%). The rest comes from the remains of meals served to students (2.89%), this small percentage is due to made the majority of prepared meals are carried away outside of the restaurant (95.5%). And less than 5% of students consume their meals on site. This seems to be related according to administration to the fact that the majority of students reside outside the university campus.

Tab 3. The waste of meal preparation

Food	Food Quantity (Kg/Week)	Waste (%)	Waste Quantity (Kg/Week)
Potato	30000	15	4500
Beef	4783	35	1674
Cabbage	1000	15	150
Chicken	2500	5	131.5
Sheep	1000	13	130
Carrot	2000	5	100
Cucumber	2000	2	40
Onion	1000	3	30
Tomato	1500	2	30
Fish	2000	0	0
Total	-	-	6785.5

3.3. The fermentable fraction and non-fermentable fraction:
The table 4 below give some information about the menu of meals for each day of the week:

Tab. 4. The weight and the percentage of the fermentable fraction (FF) and non-fermentable fraction (NFF) according the menus of each day

Days	weight FF (Kg)	weight NFF (Kg)	Percentage FF (%)	Percentage NFF (%)
Monday	1692.79	244.54	87.38	12.62
Tuesday	1542.58	40.81	97.42	2.58
Wednesday	714.12	208.18	77.43	22.57
Thursday	891.27	103.09	89.63	10.37
Friday	1627.39	210.59	88.54	11.46
Saturday	823.39	83.19	90.82	9.18
Sunday	0	0	0	0
Total	-	-	88.54	11.46

The waste of the university restaurant contain on average a fraction non-fermentable of 11% (plastic, yoghurt pot ...) and 89% of fermentable and it is this that is interesting for the production of biogas.

3.4. Density:

The evaluation of the density is necessary in order to determine the volume occupied by the waste. This parameter was measured using the following procedure: between 1 and 10 g of fresh substrate is weighed into a volumetric flask of appropriate volume (50 to 250 ml) previously weighed. A sufficient quantity of water to drown the material is added and the mixture is slightly stirred and allowed to stand a few tens of minutes so that the material be properly soaked. The water is then added to the mark. The total volume of added water, determined by weighing, allows the determination of the sample volume. The density is calculated from the ratio of the dry waste mass introduced on the volume occupied by the waste. The density is of 0.76kg/l, this is comparable to the values observed on site 0.6-0.9 kg / l [5]. The table 5 summarizes the results of the determination of the density; the experiment was repeated 3 times.

Tab 5. Density occupied by the waste

	Volume (L) of Beaker	Weight (Kg) of Beaker	Weight (Kg) (Beaker +Waste)	Weight (Kg) of Waste	Density (Kg/L)
Large Beaker	1.2140	0.0859	1.1362	1.0503	0.87
Medium Beaker	0.3100	0.1074	0.3212	0.2137	0.69
Small Beaker	0.1840	0.0230	0.1542	0.1313	0.71
Average	-	-	-	-	0.76

3.5. Waste composition used:

As summarized in Figure 1 below, the waste from Oujda university restaurant have a high percentage of humidity (hum) (80%), this is a very important parameter for the development of the microbial flora. The organic matter (Mo) is 17%, this is the fraction which is transformed into biogas. Mineral matter (Mm) is from 3%, it remains intact after fermentation.

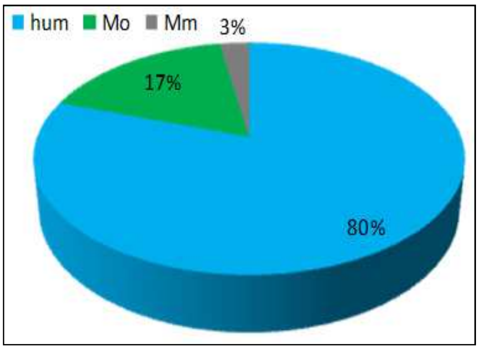

Figure1: Composition of waste from the university restaurant Oujda

3.6. Biogas potential :

3.6.1. Temperature optimization :

Biogas production at room temperature (17 ° C) is practically zero, even after 22 days. Indeed, at these relatively low temperatures, metabolism and activity of methanogenic microorganisms appear reduced and therefore require several weeks of incubation.

The higher production of biogas is observed at 45 ° C with a value of 643.5 ml, for 19 days, this is probably due to the acceleration of the hydrolysis stage releasing substrates for methanogens, the same remark was advanced by other authors [6].

By cons at a temperature of 55 ° C, the genesis of biogas seems fast and productive, 572ml in 3 days. Theoretically, increasing the temperature causes an increase in the efficiency of the anaerobic digestion. Although, this growth is not linear but is reproducible in the mesophilic and thermophilic temperature range (35°C - 55°C)[7]. Thus, maintenance of the temperature in this range is essential for the efficiency of the process [8].

Temperature (°C)	0	35	45	55
Biogas product (mL)	0	131.9	643.5	572

Fig. 2. Total production (ml) of biogas according to the temperature (for 10% substrate)

3.6.2. Rate of organic load and the biogas yield:

Biogas production is proportional to the organic load. This production reaches its optimum at 8% of the dry matter [9]. It represents the volume of biogas produced from a mass of waste:

Biogas yield = Biogas volume / quantity of waste

After optimization, we have 2.129 L of biogas from 25g of waste. Either Biogas yield is 85.14 l/Kg of fresh waste (FW).

Knowing that: Dry matter DM = 20% FW and Organic matter OM = 17% FW

So 85.14 l/kg FW Equivalent to 85.14 l / 0.20 Kg DM = 425.7 l/kg DM

Thus 85.14L / Kg FW Equivalent to 85.14 l / 0.17 Kg OM = 500,82 l / Kg OM

So, the biogases yield:

Biogas yield = 85.14 l/Kg (FW) = 425.7 l/Kg DM = 500.82 l/Kg OM

From 889 kg/day of waste, we have 75.70 m^3/day of biogas (with 52% of methane). Therefore, we have 39.94 m^3 of methane, equivalent to 387.418 kWh/day (1m^3 of methane product 9.7 kWh).

By calculating on 1 year, knowing that the university restaurant only work 285 days/year, we get:

387.418Wh/day x 285day/year = 110.4 MWh/year

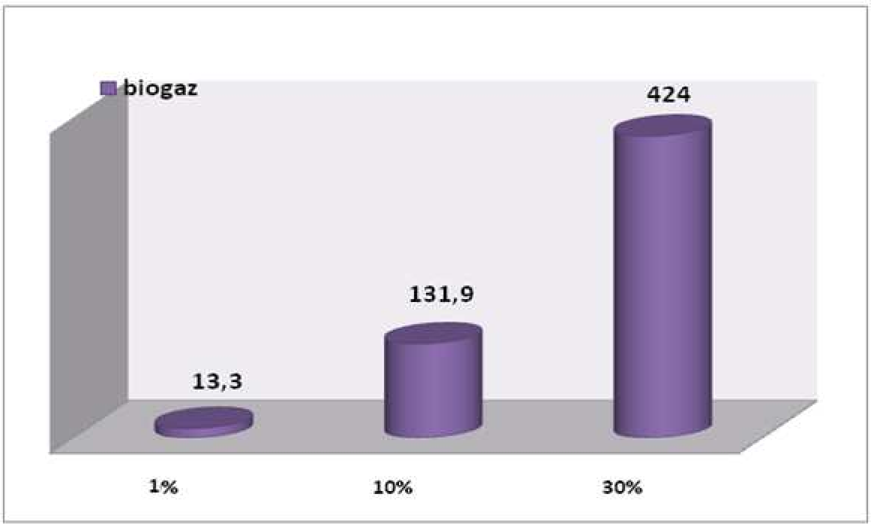

Fig 3. Production of biogas depending in the organic filler (fresh matter)

3.7. Sizing of bioreactor proposed for the university restaurant of Oujda:
For system in continuous, this is the quantity of periodic contribution until total replacement of the substrate volume in the bioreactor.

3.7.1. Calculating the volume of the bioreactor:
For calculating the volume of the bioreactor, we use the following equation:

$$V_{bioreactor} = V_{useful} + 0.15\ V_{useful}$$

With $V_{useful} = V_{daily} \times THR$

THR is the time of the hydraulic retention.

We have a production of about 890 Kg of organic waste/day.

Knowing that the density of the waste is about 0.8 kg/l,

While the volume of waste is: 890/0.8 ≈ 1.1 m^3/day.

Since the percentage of the organic material is 17%, we need to dilute the waste twice to achieve humidification of 8.5%.

Therefore, the volume of water to be added is equivalent to 1.1 m^3.

The daily volume (Vd) ≈ 2 m^3/day.

The time of hydraulic retention THR ≈ 30 days

Therefore, the useful volume Vu = Vd * THR

Whether, Vu = 2 * 30 = 60 m^3

Therefore, V bioréactor = 60 + (0.15 * 60) ≈ 70 m^3.

3.7.2. The bioreactors proposed:
We propose two types of digesters: The first proposal is a single cylindrical bioreactor having a volume of 70$m^3$and the second proposal is three cylindrical bioreactors connected in series with a volume of 23m^3 each.

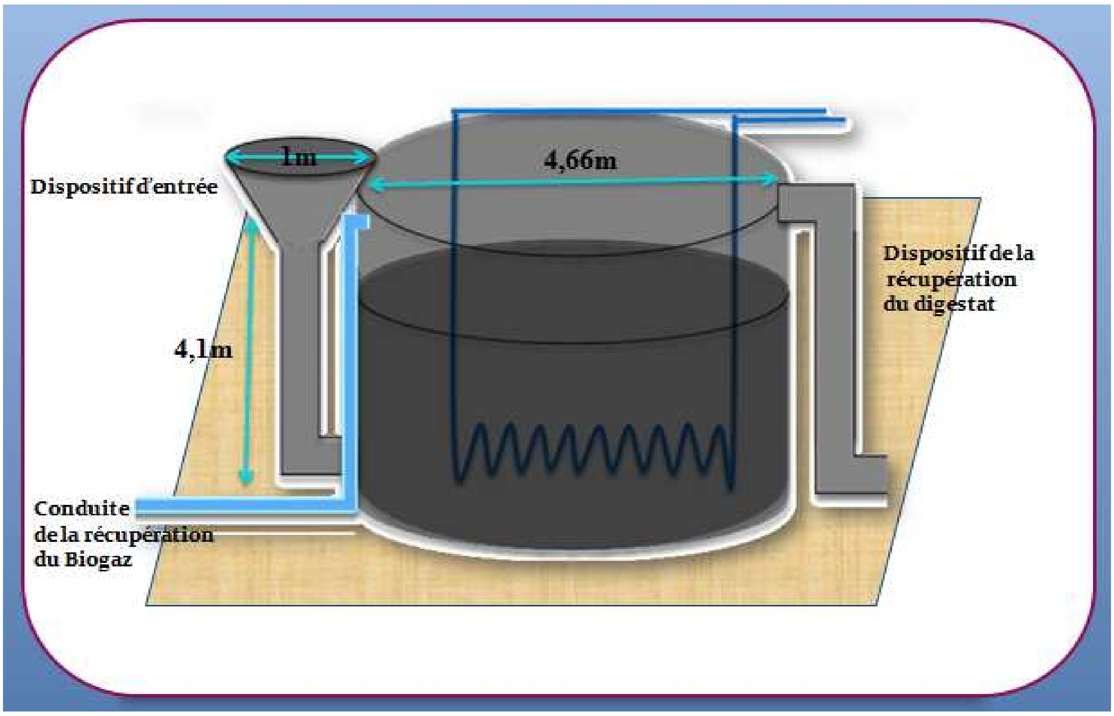

Fig.4. Schema of the first proposal of bioreactor

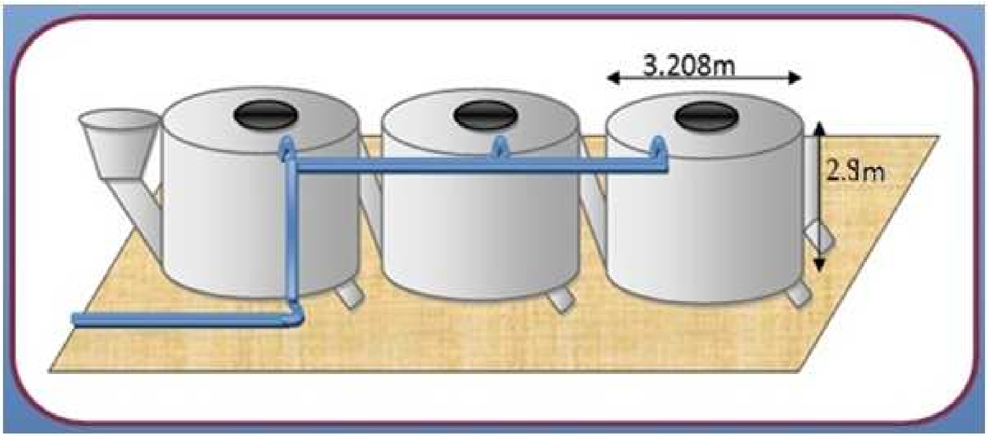

Fig.5. Scheme of the second proposal

3.7.3. Amortization of spending:

For our technical study, we estimate a biogas production of around 75.70m3/day with 39.95m3 methane/day, energy equivalence of 387.51kWh/day or 110.4MWh/year. This biogas can replace the consumption of 1.36 MWh/year of propane origin that costs 240 000 Dh/year (Table 2) and the rest, ie 110.4-1.36=109.04MWh, a portion of 365.85MWh/year (Table2) of oil origin a value of 66 524 Dh/year, making a total of 306 524Dh / year savings. This represents about 42% of energy expenditure of the university restaurant, without considering costs of maintenance and management of the installation.

3.7.4. Cost of construction of a bioreactor:

Whatever the model of bioreactor chosen, the specialized companies in their manufacturing in the industrial area of Oujda have estimated us an overall cost of about 600000Dh / installation. So the payback period is less than three years.

It is also important to know that it takes only 1 month for the manufacture of the bioreactor and 1 month for the start of production of biogas.

CONCLUSION

Based on our technical and practical study, methane fermentation of organic waste to the University City of Oujda, offers an alternative and effective solution to the waste it produces, since these have high rates of organic matter and humidity.

The installation of bioreactors in the university restaurant and in the great restaurants has several advantages:
- Encourage this biogas technology that is environmentally friendly.
- Recycle the waste produced by the university restaurant, by producing biogas for its own consumption.
- Reducing CO_2 emissions from coal combustion [10,11].
- Produce the fertilizer for soil fertilization: The digestate can effectively replace chemical fertilizer [1]
- Creating jobs for the fabrication of bioreactors, management and operation of biogas production, the maintenance of installation.

So, the gain will be on three areas: ecological, economic and social, we can say that waste management by the industry of biogas illustrates perfectly the concept of sustainable development.

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