Energetic Valorization of Adrar City Step Sludge by Batch Solar Digester

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Abstract-- **This work studies a novel digester using only solar energy, which presents a good environment and economic solution, especially in remote Saharan areas of ALGERIA. The produced batch solar digester treats the purification plant sludge of ADRAR natural lagoon located in western south of ALGERIA (1500 km from the capital of' ALGERIA). The solar collector incorporated in the digester converts the collected solar energy into thermal energy; this last is used to warm the digester. The period of experimentation was done during the months of autumn and winter when it was cold ambient temperatures. The temperature interval ensured by the solar collector supports a maximum methanization during an important delay of the day inside the digester. This methanization starts the flammable biogas production from the 20th day. Then, the digestate can be used also as fertilizer for the Saharan arable lands poor in organic matter.**

Index Term-- **Biomass, Solar energy, solar collector, Sludge, Methanization, Biogas**

1. INTRODUCTION

Currently, the cost of energy is increasing and the requirements energy are multipling with the world population growing and industrial processes, witch leades to dangerous envirenment pollution problems and provokes global warming. Many researchers are still trying to master the different renewable energy technologies, among these last we find the anaerobic digestion that alows to benefit a clean energy source (biogas) and an enriched fertilizer at time. These two benefits class the anaerobic digestion which is a decentralized energy as a suitable source for remote rural areas. [1]

It should be noted that most digesters are heated by conventional energy sources which makes their use expensive. In the work of Young et al. [2], the outer wall of the digester was coiled with an electrical heating material. The experimental tests carried out by [3], the hydrothermal treatment was carried out in a stainless steel digester was heated electrically. A thermostatic bath was used during the heating procedure of four anaerobic used reactors in the tests carried out by [4]. In order to stay within range mesophilic, Vincenzo et al [5], the required heat was provided by an electrical resistor of 15 m.

To improve the yield and reduce the cost of its digesters, several researchers have developed heat transfer models of anaerobic digesters heated by passive means such as solar energy. Among these researchers, Fleming (2002a,b) [6], Axaopoulos et al. (2001) [7], Kumar et al. (1988) [8], and Sodha et al. (1989) [9] have modeled heat transfer of anaerobic digesters with passive heating systems, but some of these models lack experimental validation.

Amro A.M. Hassaneina et al studyied the impact of solar energy use, specifically the use of the greenhouse to heated the digester, by modelisation, similation and validation. Forthermore, they did an economic analysis showed that the installation of their greenhouses system could increase revenue from biogas by US$ 1,29 per year, which could cover the greenhouses system cost only within 14 months of operation. [10]

Vergil C. Weatherford and Zhiqiang (John) Zhai studied the thermal performance of solar-assisted biogas digesters for cold climate through the calibration and verification of a modified thermal model, the result of this research shown that a one-dimensional thermal model can predict diurnal temperature fluctuations in slurry temperatures and overall temperature of the slurry within reasonable magnitude of temperature swings. [11]

Zhenjie Ren et al have done a similar job to our work (using solar energy instead of energy convenssionnelle) unless they have a solar water heater used to heat the digester, for our job we heat the digester by a solar collector incorporated into the digester. [12]

This work based on the use of the solar energy for the warming of digester (the batch type) via a double glazing solar collector coupled to the digester. The theoretical and experimental study (solar digester reduced scale of 11 liters and 14 liters) enabled us to carry out this digester and to have very encouraging results with the realization of a solar digester having a capacity of 200 liters. The experimentation consists in directing our full southern digester and with an inclination of 27.88° for a maximum reception of the solar rays. The digester is filled by sludge obtained from the purification plant by natural lagoon and we let it digest; the substrate is homogenized by manual agitation.

The follow-up of the internal energy assessment of the digester is ensured by thermocouple established inside the digester. Another anaerobic digestion follow-up (methanization) is elaborated by different physicochemical analyzes, as well as that of the biogas production.

The objective of this research is to determine the performance of solar digester and the agricultural yield digestate. In this study we followed the evolution of the different parameters pollutions, the temperature inside the digester, the volume of biogas produced as well as the mmicrobiological analyzes.

2. THEORETICAL STUDY

Thermal assessment of the double glazing solar collector

Simplifying assumptions:

The temperature of each element of the digester is uniform.

The solar quantity of radiation absorbed by the glazing is neglected.

The cylinder is compared to a parallelepiped.

Thermal exchange between the substrate layers is done only by conduction.

The heat transfer by convection is in laminar mode.

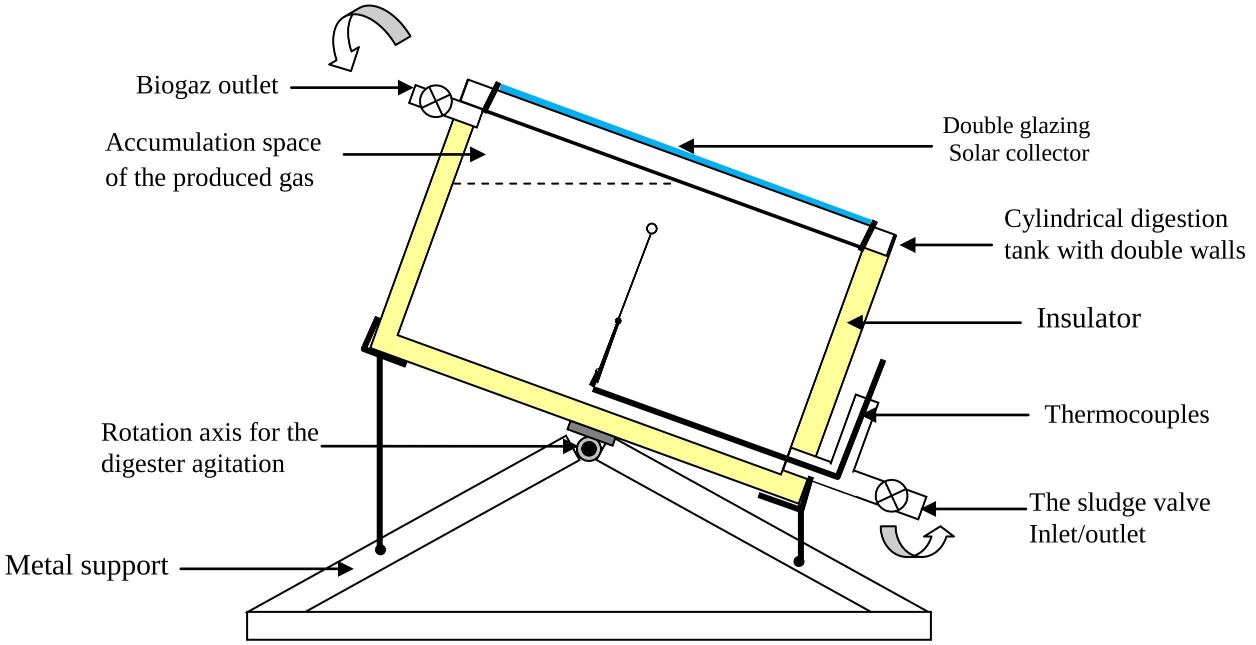

Fig. 1. Solar digester analytical scheme (the batch type) of a capacity of 200 litters equipped with a double glazing solar collector

2.1 Energy assessment of the solar digester:

- On the level of the external glazing:

$$M_v Cp_v \frac{dT_{vex}}{dt} = (hc_{vin-vex} + hr_{vin-vex}) A_v (T_{vin} - T_{vex}) - hr_{vex-sk} A_v (T_{vex} - T_{sk}) - hwA_v (T_{vex} - Ta) \qquad (1)$$

- On the level of the interior glazing:

$$M_v Cp_v \frac{dT_{vin}}{dt} = hc_{p-vin} A_p (T_p - T_{vin}) + hr_{p-vin} A_p (T_p - T_{vin}) - (hc_{vin-vex} + hr_{vin-vex}) A_v (T_{vin} - T_{vex}) \qquad (2)$$

- On the level of the absorption plate:

$$M_p Cp_p \frac{dT_p}{dt} = (\tau_v \alpha_p) Is A_p - hc_{p-vin} A_p (T_p - T_{vin}) - hr_{p-vin} A_p (T_p - T_{vin}) - hpA_p (T_p - T_{sub1}) \tag{3}$$

- On the level of the substrate upper layer:

$$\frac{M_{sub}}{3} Cp_{sub} \frac{dT_{sub1}}{dt} = hpA_p (Tp - T_{sub1}) - hsubA_{sub} (T_{sub1} - T_{sub2}) - hlatA_{lat} (T_{sub1} - Ta) \tag{4}$$

- On the level of the second layer:

$$\frac{M_{sub}}{3} Cp_{sub} \frac{dT_{sub2}}{dt} = (hsub(T_{sub1} - T_{sub2}) - hsub(T_{sub2} - T_{sub3}))A_{sub} - hlatA_{lat} (T_{sub2} - Ta) \tag{5}$$

- On the level of the inferior layer:

$$\frac{M_{sub}}{3} Cp_{sub} \frac{dT_{sub}}{dt} = hsubA_{sub} (T_{sub2} - T_{sub3}) - (hlatA_{lat} + harA_{sub})(T_{sub3} - Ta) \tag{6}$$

The coefficient of radiative exchange between two bodies is given by the following relation [13]:

$$hr_{ij} = 0.9\sigma(T_i^2 + T_j^2)(T_i + T_j) \tag{7}$$

The coefficient of convective exchange due to the wind is written as follows [14]:

$$hw = 5.7 + 3.8V$$

V being the wind speed

The coefficient of convective exchange between the absorption plate and the glazing just as that between the interior and the outside glazing [14]:

$$hc_{p-vin} = 1.32(\Delta T / L)^{0.25}$$

The coefficient of convective exchange between the plate and the substrate free face [15]:

$$hc_{p-sub} = 0.66(\Delta T / L)^{0.25}$$

The coefficient of thermal transfer between two adjacent layers of the substrate:

$$hsub = \frac{\lambda_{sub}}{Ep_{sub} / 3}$$

The coefficient of heat transfer between the plate and the upper layer of the substrate:

$$hp = \frac{1}{\frac{ep}{\lambda_p} + \frac{1}{\frac{\lambda_{air}}{Lvid} + hr_{p-sub} + hc_{p-sub}}}$$

The coefficient of thermal losses through the lateral sides:

$$hlat = \frac{1}{\frac{2\times ep}{\lambda_p} + \frac{Ep_{is}}{\lambda_{is}} + \frac{1}{hw}}$$

The coefficient of thermal losses postpones is equal to the losses coefficient hlat:

$$har = hlat$$

The ambient temperature is given by [14]:

$$Ta = \frac{T\max + T\min}{2} - \frac{T\max - T\min}{2}\sin(15t - 120) \tag{8}$$

The temperature of the sky is:

$$T_{sk} = Ta - 11 \tag{9}$$

The solar radiation arriving on a plane receiver of β inclination is calculated by the following equation:

$$I = I_b \cos(\Theta) + I_d \frac{1+\cos(\beta)}{2} + (I_b \sin(h) + I_d)\rho \frac{1-\cos(\beta)}{2} \tag{10}$$

With:

$$I_b = 1330 \times f \times a \times e^{-\frac{b}{\sin(h)}}$$

$$I_d = 1330 \times f \times \sin(h) \times (0.271 - 0.2939 \times a \times e^{-\frac{b}{\sin(h)}})$$

Where:

$$f = 1.034 \times \cos(\frac{360}{365} \times (jn - 5))$$

The angles H and Θ are respectively the height of the sun and the incidence angle of the solar radiation. The albedo of the ground is indicated by ρ. It is taken equal to 30%. I_b and I_d respectively indicate the direct component and the diffuse component of the solar radiation.

The parameters **a** and **b** depend on the sky state. For a normal state of the sky, a= 0.88 and b= 0.26.

2.2 Digital assets:

(τv =0.95; αp=0.95; ρsub = 1000; λsub=0.58; Cpsub=4118; ρp=7850; λp=45; Cpp=465; ρv= 2707.11, Cpv=836.8; λair=0.58; λis=0.041, Eis=0.05; V=2; Ep=0.0015; Scap=0.8×0.3; Vsub=0.1; Lcuve=0.9; Vcuve=0.2; Tmax= 30°C, Tmin=13°C; mois= MARCH).

The numerical resolution of the system of differential equations was done by the explicit method of finished differences.

2.3 Nomenclature:

[A: surface (m ^{2}), λ: thermal conductivity (w/m°C), CP: heat capacity (J/kg°C), M: mass (kg), T: temperature, Your: ambient temperature (K), H: heat transfer coefficient (w/m ^{2} °C), Ep: thickness (m), ep: thickness of the metal plate (m), L: characteristic length (m), Is: solar irradiation (w/m ^{2})]

2.4 Indices:

(p: plate, v: glazing, sub: substrate, is: thermal isolation, vin: interior glazing; vex: external glazing)

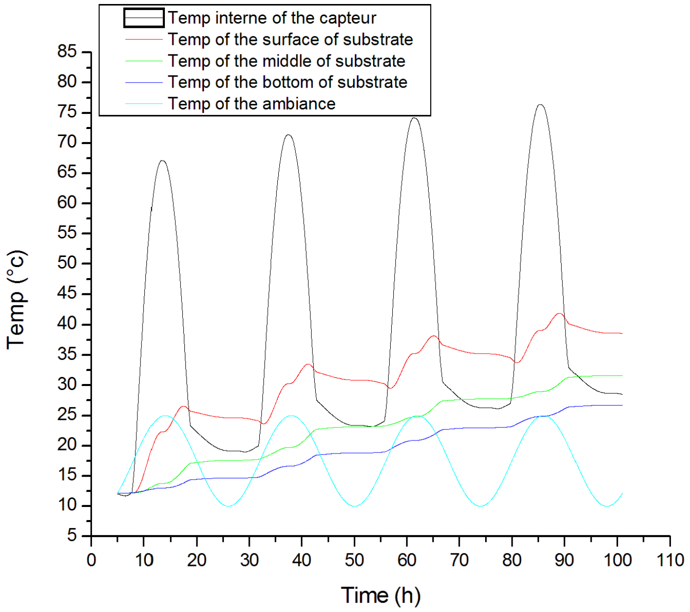

Fig. 2. Evolution of theoretical temperatures of the system

The curve of fig.2 presents the evolution of the ambient temperature, the collector internal temperature and the temperatures inside the digester which mean that there is storage of heat inside the digester.

3. EXPERIMENTAL PART

3.1. Materials and methods

3.1.1. The solar digester description:

The digester is composed of a cylindrical tank with double separated walls by a glass wool insulator of 5 cm thickness.

The tank capacity is 200 liters. The digester is equipped with an integrated solar collector of 120 cm of length, 30 cm width and two valves, the first one in the top, to recover the biogas, the second in the bottom is for supplying and emptying the digester with substrate as well as sampling the different analysis and thermocouples output those allow the control of the temperatures in different levels inside the digester fig.3.

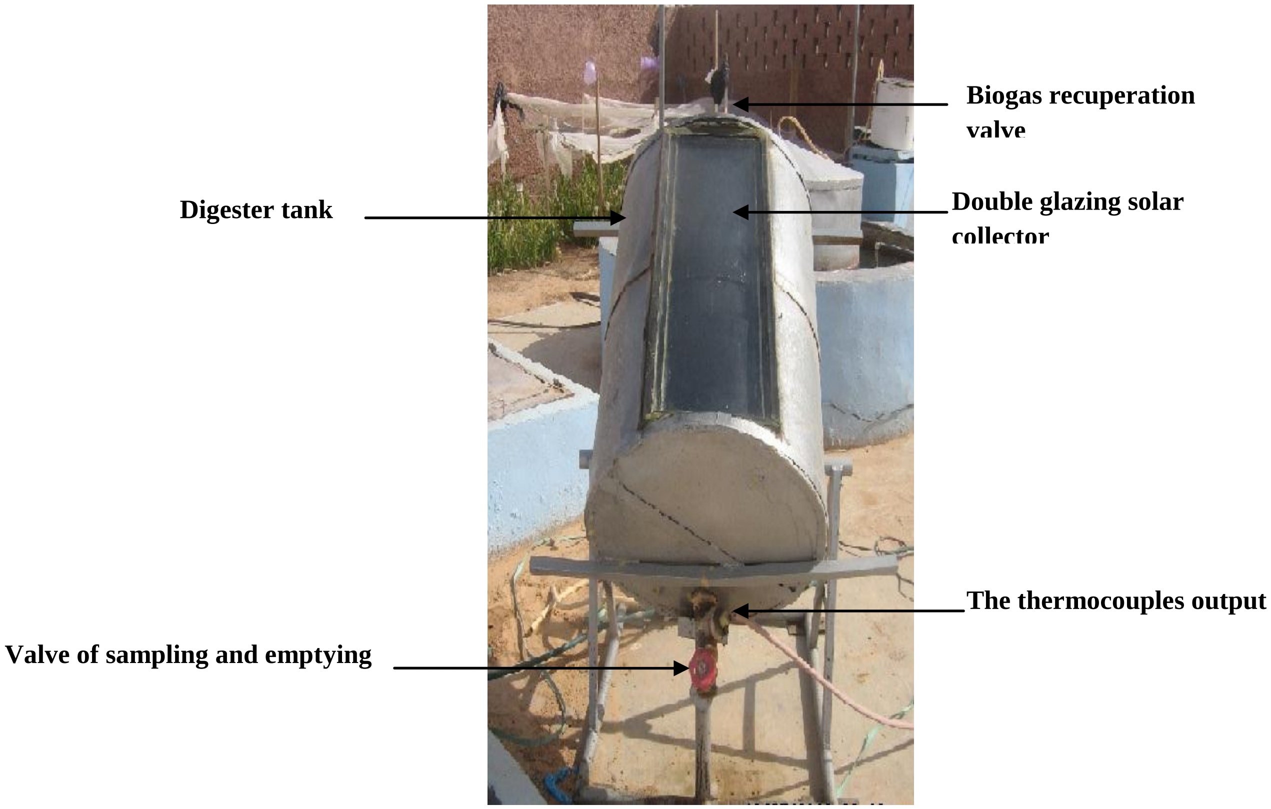

Fig. 3. Photo of operational solar digester (the batch type)

3.2. Experimental device:

The digester is filled with 3/4 of its volume, (i.e. 150 the sludge of the purification by natural lagoon diluted to 80% and letting digest.

The temperature evolution inside the digester is ensured by three thermocouples of K type, fixed at the medium and at three different levels (base, middle and surface), Fig.1. The thermocouples are connected to data acquisition HYDRA FLUK which ensures the recording and data storage of temperatures.
The follow-up of methanization is elaborated by the different physicochemical analyses necessary within the laboratory, as well as the fllowing-up of the flammable biogas production.
Dry sludge was used as substrate to supply the digester, this substrate resulting from Adrar city treatment plant. These sludge characteristics are gathered in Table I.

Table I
Rough sludge Characteristics of the city STEP by natural lagoon:

Ph	6.60
Organic matter (OM)	50%
COD	3466 mg O_2/l
BOD_5	2100 mg O_2/l

The pH, COD, BOD_5, OM and the produced biogas volume were measured to distinguish the energy influence brought by the double glazing solar collector on the methanisation progress.

3.3. Analytical methods:

The pH was measured using a pH-meter of METROTOLLEDO model. The supernatant obtained after centrifuging the samples (6 min at 10,000 rpm) was used to measure the Chemical Oxygen Demand (COD), COD was determined using the method reported by (Raposo, Borja et Martin) **[**16]. For this analysis, 10 mg of the sample was mixed with 2 ml of $K_2Cr_2O_7$ 1.2 N and 3 ml of H_2SO_4-Ag_2SO_4. At the end the mixture was titrated with a ferrous ammonium sulphate solution. BOD_5 was analyzed using the Oxitop device, which measures the barometric depression inside a bottle of 500 ml. The produced biogas volume was determined by the moved liquid method (Charnay) **[**17**]** and (Moletta) [18].

Organic Mater (OM) and Dry Mater were measured by the following standard methods (AFA. 1995) [19].

Methane content of the produced biogas in the headspace was determined as follows; a known volume of the biogas was withdrawn by a syringe and injected into bottle containing 20 gl^{-1} of KOH. This serum bottle was then shaken for about 3 min to be able to have all the CO_2 and H_2S absorbed in the KOH solution. The ratio of total biogas volume before and after absorption by KOH provided us the percentage of CH_4 [20].

4. RESULTS AND DISCUSSION

The fig.4 presents the temperature variations inside the digester in the medium; the first thermocouple is placed at the base, the second is in the medium and the third is on the surface.

We notice that the two curves of temperatures on the surface and at the medium are in general over than 25°C during the 7/8 of the day (approximately 20hours), but the base temperature is sometimes lower than 20°C (approximately 4hours), that can a bit influence methanization, hence an optimal methanization is riched, we consider that as a very good yeld. Especially that our digester functions with solar energy which is a renewable energy.

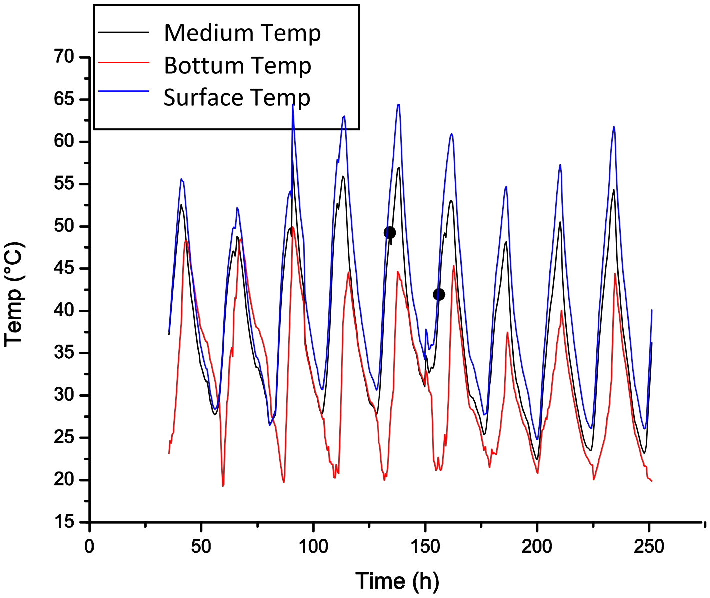

Fig. 04. Temperature variation inside the digester

pH measurement is very important during anaerobic digestion because the acid or basic media deteriorates the chemical balance of the enzymatic reactions. The optimum conditions for pH is different for the optional anaerobic flora and those are in anaerobic strict from the process of anaerobic digestion [21]. Thus, the value of pH can limit a microbial activity or induce different anaerobic metabolic ways within the microbial community (Kim *and Al* 2004 [14]; Ueno *and Al* 2006 [13]).

fig.5 presents the pH variation during the anaerobic digestion of the studied substrate, where we observe a strong drop of pH during the five first days, this variation is due to the solubilization of the organic matter contained in the waste by the hydrolytic bacteria which generates an increasing in the VFA (Volatile fatty acids), thus the accumulation of this last involves an acidification of the medium. From the 6th day to the 13th day; we get an increasing of pH, it is the acetogenesis phase in which the VFA are transformed into acetate [22], after the 13th day the methanogenesis phase begins to form methane and carbon dioxide, We notice an increasing of pH value during this last phase, due to the VFA degradation.

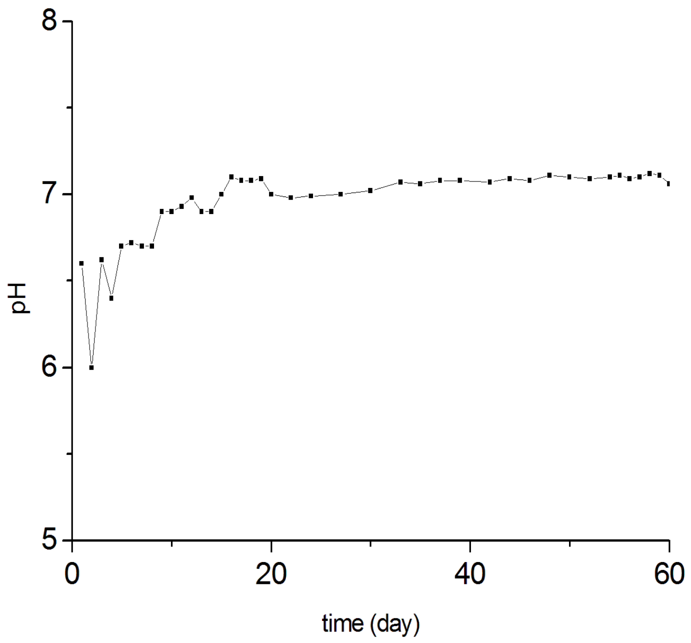

Fig. 05. pH evolution during anaerobic digestion

The chemical demand for oxygen COD and the biological demand for oxygen BOD are represented in figures 5 and 6 respectively. The concentration increasing of the COD during the first days is due in particular to the production of VFA during the acidogenesis phase which can constitute intil 95 % of the total organic carbon [23]. From the 27th day we record a decreasing in the COD value which is due to the production of biogas during the methanogenesis phase, the reduction of COD value continues until the end of methanization leading to the reduction in the produced biogas volume, during 60 days of methanisation, the value of the degraded COD is equal to 4900 mg O_2/l, which corresponds to a rate degradation of 81%.

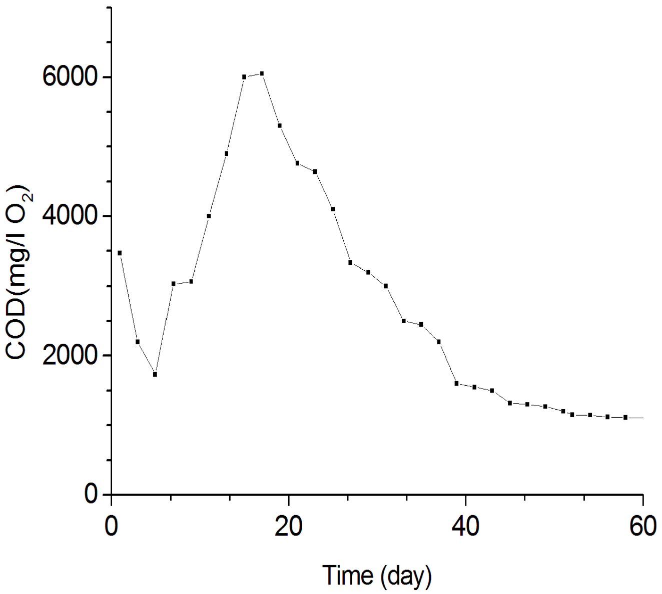

Fig.6: COD evolution during anaerobic digestion

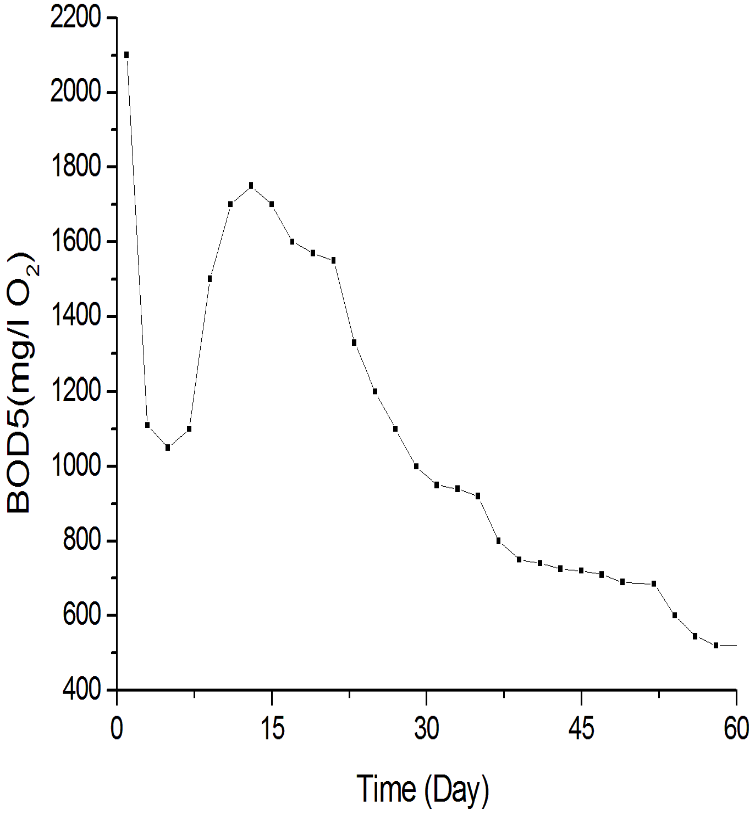

Fig. 7. BOD evolution during anaerobic digestion

The ratio of COD/BOD_5 varies between 1.6 and 3.5, this result shows that the used substrate is fairly biodegradable, knowing that an easily biodegradable waste has a COD/BOD_5 ratio lower than three [24].

VFA are intermediate products, their concentrations reflect the stability of the anaerobic digestion process.

The high concentrations of VFA can involve a fall of the methane production, (*Gourdon and Vermande, 1987)* [25]; (*Ahring and Westermann, 1988)*[26]. Aguilar *and al.* (1995) [27] observe a significant inhibition of anaerobic digestion from 10 g.l^{-1} of each VFA species. The origin substrate and the methanization process used influence the stability and the resistance of the process in high VFA concentration. Moreover, the VFA have a great influence on the whole microbial chain [28].

The following figure shows the evolution of the VFA in fuction of time, we notice a fast increasing in the VFA concentration during the first 8 days to reach a maximum value of 1400 mg/l (acidogenesis phase), from the 8th day the concentration of VFA decreases, this reduction indicates the beginning of the methanogenesis phase, where the VFA are transformed into biogas. At the end of the experiment we record a minimal value near 110 mg/l

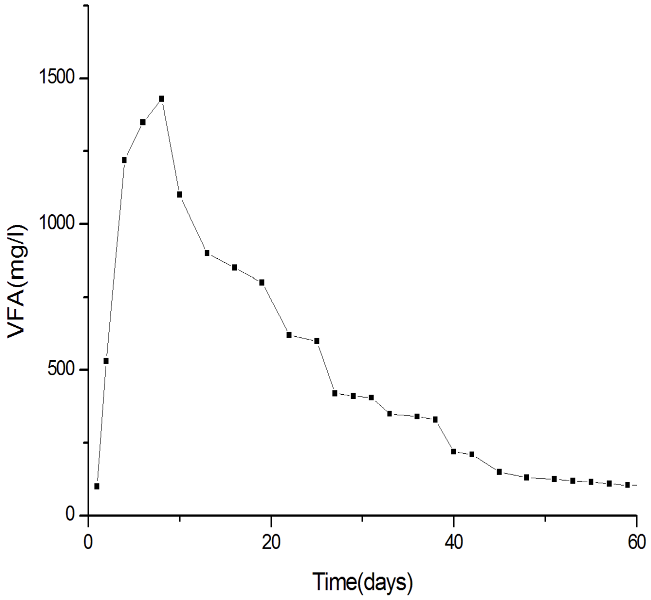

Fig. 8. VFA evolution during anaerobic digestion

The fig.8 presents the production of the cumulated biogas in function of time during the anaerobic digestion, on this curve we can distinguish three phases, the first is the adaptation phase of the methanogenic bacteria (from 0 to the 5th day) characterized by a weak production of biogas. The second phase is the growth phase (from 5th to 50th day) characterized by a volume increasing of biogas, in the last phase, we witness an exhaustion of substrate and reduction in the number of methanogenic bacteria [29], consequently a reduction in the volume of the produced biogas.

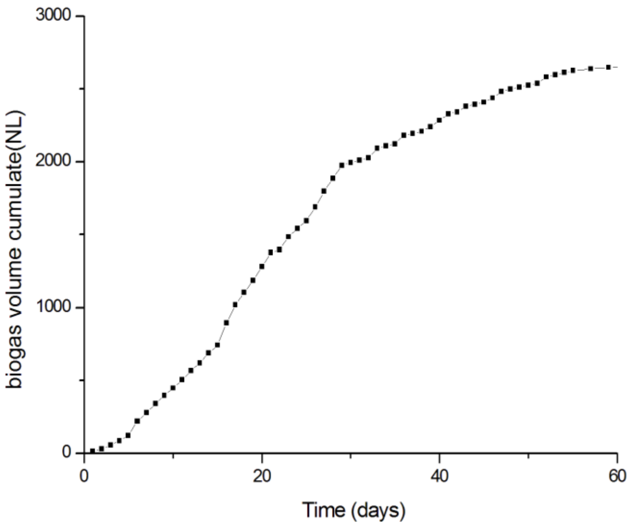

Fig. 9. Variation of the cumulative volume of biogas

The total volume of produced biogas is about 6661 NL, which corresponds to an output of 370 NL of biogas /Kg of O.M., knowing that the biogas yield of organic waste under the optimal conditions varies between 350L and 650 L/Kg of O.M. [30], this variation of yield can be due to the instability of the temperature inside the digester because of the failures of the realization (prototype constructed in an ordinary workshop not specialized) and on the other hand due to incomplete degradation of the organic matter. The percentage of methane measured by the Erguder method [20] corresponds to 55%.

5. MICROBIOLOGICAL ANLYSIS RESULT:

Monitoring the evolution of the loading rate of microorganisms was made only by comparing the number of species before and after treatment of the sludge treated by anaerobic digestion tableau2 [31].

Table II
OM number before and after treatment

	Number of OM Before treatment (colony per gram of dry matter.) Germs/ml	***Number of OM after treatment (colony per gram of dry matter.) Germs/ml***
fecal coliforms	*520*	*110*
fecal streptococci	*265*	*Abs*
staphylococci	*400*	*260*
Clostridium	*Abs*	*Abs*
salmonella	*Abs*	*Abs*
Escherichia. Coli	*Abs*	*Abs*
total germs	2×10^6	0.5×10^4

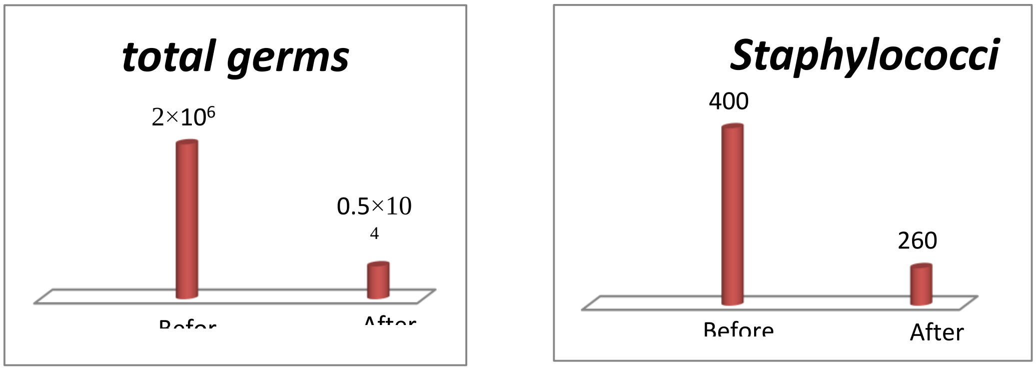

Fig. 10. Total Germs and staphylococci before and after treatment

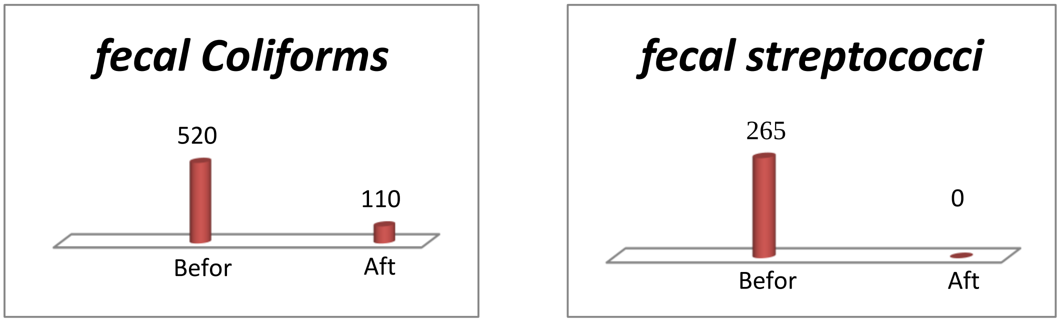

Fig. 11. Fecal coliforms and fecal streptococci before and after treatment

Thus we see from Fig.10 that the rate of germs of the total flora increased from 2 × 106 before treatment to 0.5 × 104 germs/ml after 35 days of stay in the digester. This clearly shows that hygienisation accompanies all changes occurring within the reactor.

Fecal contamination is well presented by the coliform population is always presented at the end of the digestion, but with a smaller number Fig.11

The hygienisation issue, moreover, the disappearance of certain species whose presence can be harmful, especially if we think about the digest value; in the case of Escherichia coli and fecal streptococci that have completely disappeared at the end of the treatment Table 02.

6. CONCLUSION

In this work we could use solar energy by the means of a double glazing solar collector incorporated in our digester, like means of energy contribution to heat this latter, consequently we obtained an interval of mesophilic temperature favourable to a good methanization during the most of the day.

The yield of the solar digester could be improved, if we could introduce a means of agitation for the homogenization of the substrate and consequently its internal temperature.

The modelisation, similation and experimentation allowed us to realize a patch solar digester with a veru low price could'nt be over than 500£. Forthermore, It contributes to the resolution of several energies problems, economic and environmental problems by the solar energy utilization which is an renewable energy instead of the electric power or any other kind of conventional energy for the warming of our digester, free biogas production which could be used in house or in other domestic fields and environmental protection by the presence of a treated sludge which can be thrown in nature without danger or to use it as fertilizer in agriculture.

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