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Efficient Biogas Management to Generate Thermal Energy

Molina Morejon V.[1*], Molina Romeo V.P.[2], Garcia Bermudez F.[2] and Gutierrez Castillo O.W.[1]
[1]Faculty C. Administration, Campus Torreon, Autonomous University of Coahuila. Mexico.
[2]Faculty C. Administration, Campus Saltillo, Autonomous University of Coahuila. Mexico.
[*]Corresponding author email id: vmolinaa2005@yahoo.com.mx

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Abstract – **The objective of this work was to present a procedure to design and develop an efficient energy management process and to demonstrate the technical feasibility of the use of biogas as a source of energy from milk manure and to eliminate the warming of water through electrical resistance.**

A test bench was built in a real environment where 12 experimental tests were performed with a repeatability of 3 samples in each test. The result showed that there were no significant differences between the temperature increases depending on the warm-up time and the work hypothesis was verified. The result is in the process of being introduced into the agricultural sector.

Keywords – **Renewable Energy, Biomass Energy, Biogas Digester, Energy Consumption, Technologic Management.**

I. Introduction

One of the most attractive alternatives to renewable energy is bioenergy or energy from biomass. This type of energy is mainly obtained through animal waste, such as manure. The waste is collected in covered lagoons, called bio digesters, where a biological degradation process is carried out, and biogas and other by-products are produced.

Dairy farms demand hot water mainly for sanitization in the area of mechanical milking and to activate heat plate exchangers where milk is warmed to feed the calves. Currently the heating of water is produced by means of electrical resistances generating an expense that can be minimized if the biogas were used at least for water heating.

This work is divided into three parts. It starts with the theoretical framework that supports the main concepts and the problem investigated. Then the methodology of the research, which is characterized by a mixed qualitative and quantitative approach, with evaluation of the methane generated in the selected bio digesters and experimental runs on a test brench, finally, fundamental research results are presented where the solutions used are geared towards efficient biogas management to generate thermal energy.

II. Material and Methods

This section presents the Literature Review and the research methodology.

2. Literature Review

2.1. Renewable Energies and Biogas

Currently, the use of renewable energies is considered the best strategy to achieve international objectives related to alternative energy production that helps to mitigate global warming, generate competitiveness and technological development [1]. Renewable energies are obtained from natural resources and are considered inexhaustible, in addition to having multiple social and economic benefits, such as the generation of jobs and a minimum or null environmental impact [2].

Biogas technology has been used in regions with intensive livestock activity, thanks to its many benefits including: low-cost electricity generation for self-sufficiency, disposal of wastes and compliance with standards and recovery of liquid and solid manure used as organic fertilizer. It also contributes to the promotion of the commercialization of carbon credits in the country and the mitigation of greenhouse gases by reducing the use of conventional fuels in the energy sector [3]-[4].

Biogas is composed mainly of methane gas (CH_4), a potent greenhouse gas, used as fuel to generate heat or produce electricity. The use of biogas represents an area of opportunity with economic factors that can enhance sustainable development [3]-[4], especially in developing countries such as Mexico [5], where one of the main economic activities within the agricultural sector is cattle raising [6].

Methane gas is produced as the final product of anaerobic putrefaction of plants and comes from carboniferous layers; constitutes more than 90% of natural gas and is a non-conventional source of gas. This natural process can be used to produce biogas as an energy source. The possibility of converting a greenhouse gas into an energy source makes it an attractive fuel from an environmental perspective [7].

Biogas Generation Systems (B.G.S.) are considered a source of clean energy. Taking advantage of the gases generated from decaying organic waste and not allowing them to reach the atmosphere reduces greenhouse gases. Biogas can be used in the same way as any other fuel, both for cooking food, replacing fuelwood, kerosene, and liquefied gas, etc., and for lighting, using lamps adapted to biogas. Mixtures of biogas with air, in a 1:20 ratio, form a highly explosive detonating gas, which allows it to also be used as fuel in adapted internal combustion engines.

The biogas generated with much less than 50% methane content ceases to be flammable. Its High Calorific Value (H.C.V.) is on average 18003.24 kJ/kg, which allows generate between 1.3-1.6 kWh, which is equivalent to approximately half a liter of oil. The energy content of 1m^3 of biogas (60% CH_4 and 40% CO_2) is 6 kWh/m^3 approximately. This energy can be stored and distributed in different forms (low, medium or high pressure gas), hot water or electric energy.

Biogas is also used to supply power to fans, steam disinfection equipment, and refrigeration machines for the agricultural and food sector. Methane gas-fed air conditioners are machines made mainly with a burner to produce heat and with a heat exchanger where the hot gases obtained from the combustion give thermal energy to the air that is to be heated. This equipment is known as hot air generators. Its technology is known as Adsorption Cooling. [8].

2.2. Use of Biogas in some Regions of Latin America

In Guatemala [9], one of the largest oil palm producers in the region, became the first oil palm company in the world to become Rainforest Alliance certified for being environmentally friendly. In 2011, Agrocaribe is the first palm oil company in the world to receive the Business Alliance for Secure Commerce Certification (BASC). Agrocaribe uses biogas for their production but the biogas surplus is burned at a controlled temperature higher than 600°C to reduce greenhouse gas; as shown, they have not found other uses, unlike the proposal of this investigation.

In Bolivia [10], has started burning biogas from its Wastewater Treatment Plants (PTARs), north and east of the capital of Santa Cruz. This action, for the benefit of the environment, was framed within the contract signed between the Cooperative and the World Bank in the city of Cologne, Germany, in March 2007. The implementation of the biogas capture and burning project formulated by SAGUAPAC will bring diverse benefits to the community, the cooperative will receive "Green Bonus"; That is, economic resources provided by the World Bank for each ton of methane gas eliminated.

In the Robago farm located in the Central Pacific of Costa Rica, they have bag digesters for 560 kg of manure per day to generate electricity [11]. The generated methane is driven to a 30 kW diesel engine or to a 25 kW LPG plant.

2.3. The Importance of this Subject in Mexico

The importance of this subject is reflected in the Strategic Technological Program of “Petroleos Mexicanos” [12] in its EO10, which states "Improving environmental performance, business sustainability and the relationship with communities" is an objective that belongs to the Strategic Technological Area of "Development of new products and services" where the problem is identified as "lack of exploitation of non-conventional hydrocarbons". In this program the technological challenge is identified as "Biogas utilization" and the technological need is expressed as: "Evaluate the state of the art, identify, evaluate and implement technologies for biogas use".

The main tough closer findings to the proposal of this project are related to an unproductive alternative such as that related to the burning of biogas to the atmosphere in order to eliminate methane. This procedure, whose only advantage is not to pollute with greenhouse effect gases, represents the simplest solution for the use of this biofuel.

In several rural areas of Mexico City, according to the National Commission for the Efficient use of Energy, [13], the use of biogas as a fuel is a very good practice; fuelwood consumption can be satisfactorily replaced by methane and thereby reduces CO_2 emissions into the atmosphere due to the combustion of coal and bagasse.

The most important region in cattle activity is the Comarca Lagunera, located in the north-central region of Mexico and is conformed of different municipalities of the states of Durango and Coahuila. According to [14], the region of La Laguna has a stocking population of 600,000 heads of cattle (meat and milk), which generate 12,427 tons per day (ton/d) of manure [6].

2.4. Using Biogas to Generate Electricity in Mexico

The solution of using biogas to generate electricity with a motor-generation system has caused great disappointment in the region. The presence of hydrogen sulphide (H_2S) in biogas causes toxicity, corrosion, diminishes caloric value, produces unpleasant odors due to the decomposition of sulfur compounds, and generates mercaptans, carbonyl sulfides and carbon disulfide, [14]. Different companies sell special filters to reduce this harmful acid to values below 1000 ppm, but this requires an expensive investment, a sustained maintenance, and repair work. At the moment the stables that generate electricity, using the recommended filters, do it with motors that do not exceed the 6 000 hours of work, at the end of which a major repair is needed.

The biodigestion systems, in general and in this particular case, those of the Comarca Lagunera, present several factors that influence the quality of the biogas, which is considered good for the production of electric energy when 55-60% of the gases mixture is CH_4, since 1 m^3 of biogas equals 20 MJ of energy with an electric potential of 1.7 kW/m^3 of biogas.

2.5. Use of Electricity for Water Heating

Dairy farms demand hot water mainly for sanitization in the area of mechanical milking and to activate heat plate exchangers where milk is warmed to feed the calves. Currently the heating of water is produced by means of electrical resistances generating an expense that can be minimized if the biogas were used at least for water heating.

In the technical project 196007 of the Innovation Stimulus program (PEI) of the National Council of Technological Science and Innovation C.O.N.A.C.Y.T. of Mexico, the authors developed the project "Energy efficiency in deep well pumps and milking mechanic in Stables of the Comarca Lagunera" [15], it was identified the use of electrical resistances to heat water in a dairy, in general, are used for the pasteurization system nine electric resistances each of 5000 W, or 45 kWh in total. For the general washing system by pressure machines, the water was heated with three 5000 W resistors and six 3000 W resistors, for a consumption of 35 kWh. In total 80 kWh. These resistances work on average 8 hours a day consuming around 640 kWh during the 365 days of the year; this represented a consumption of more than 235,000 kWh a year that at a value of 1.10 $/kW generated a cost of 260,000 pesos.

The most significant processes in which this water can be used in the stable that was investigated, and which is quite representative of the rest of the stables of more than 4,000 dairy cows are: Sanitizing water, water for the process of pasteurizing the milk with which they feed the calves, and the use of this water for heating in the winter.

III. Research Methodology

To choose the stables where this research could be carried out the following requirements were determined: a stable performance of the biodigester, that do not use biogas to generate electricity, that use liquefied petroleum gas LPG, or electrical resistances to heat water, that in the stable there are technical staff trained in the operation of the Biodigester, that the stable has a population above 1600 heads of cattle.

Of the 30 stables that burn the biogas to the atmosphere without any economic use, only ten met the five requirements mentioned above, that is, our population "N" was reduced to 10 stables.

Finally the stables selected were El Coronel and Victoria in the municipality of Gomez Palacio, in the state of Durango and Adelita and Monegro in the municipality of Matamoros, in the State of Coahuila. The general characteristics of these stables are shown in Table I.

Table I. Selected Stables in the studio.

Stables	Population	No. Biodigesters	Production estimated manure (kg/day)	Production estimated CH_4 (m^3/year)
Victoria	2950	1	64900	16237,39
Adelita	2400	1	52800	13210,08
El Coronel	4600	3	101200	25319,32
Monegro	1600	2	35200	8806,72

3.1. Evaluation of the Methane Generated in the Selected Biodigesters

Fig. 1 shows the results of the study conducted by Dr. Nagamani Balagurusamy Director of the Bioremediation Laboratory of the Faculty of Biological Sciences of the Autonomous University of Coahuila, during 12 weeks of July 2016. CH_4 was evaluated live using Multigases Analyzer Drager X-am® 7000, coupled with this, the results obtained were verified with a gas chromatograph.

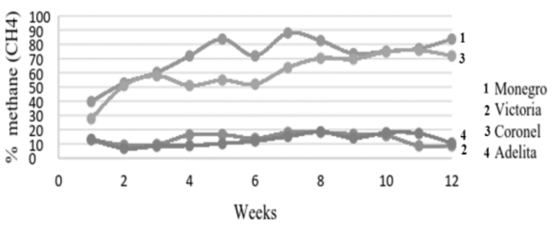

Fig. 1. Percent methane in selected stables

3.2. Selection, Location and Generalities of the Pilot Plant

The pilot plant was installed in the stable El Coronel, of the municipality of Gomez Palacio, the Popular region of the State of Durango, located in the coordinates: 25° 40' 33" N and 103° 27' 6" W, its three biodigesters, verified a stable operation, they had qualified technical personnel authorized to carry out all the experiments planned in order to fulfil the objective to demonstrate the technical feasibility of using biogas as a source of energy to heat water that was employed in Sanitation and pasteurization. Fig. 2.

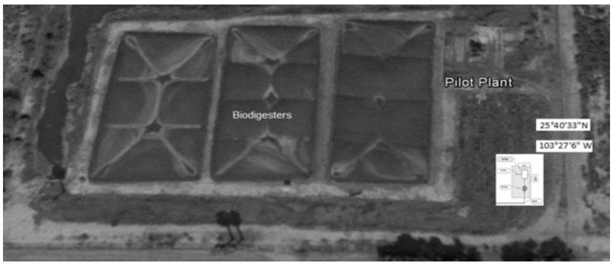

Fig. 2. Location of the stable El Coronel in the region of La Popular, Durango

3.3. Process Flow

In Fig. 3 it is appreciated that the biogas was transported to the pilot plant PP, which resulted in a construction that involved earth movement, foundation, piping, accessories, acquisition and assembly of the equipment and instruments of measurement and the set-up to carry out the expected measurements.

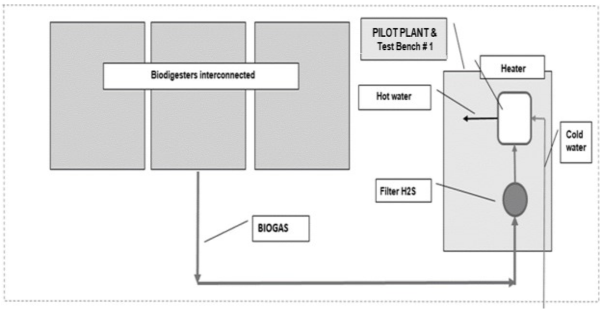

Fig. 3. Processes Flowchart

3.4. Test Brench # 1 (BE-1)

The BE-1 Fig. 4 has equipment, appliances, instruments, piping, accessories and instruments that allowed and/or facilitated obtaining key parameters such as biogas composition (it is equipped with a sampling device); Biogas flow and pressures, and inlet and outlet temperatures, pressure and water flow.

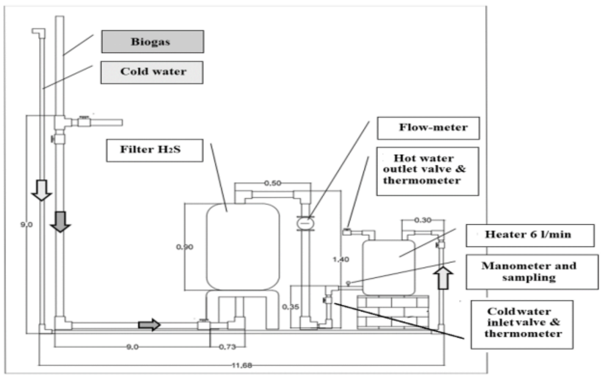

Fig. 4. Tech bench BE-1

Main equipment CINSA-CALOREX tank heater (only the chassis and crock are used) made in Mexico with the features: original liquefied petroleum gas LPG performance; Capacity 6 L/min, Weight: 25 kg., Measurements (length x height x width): 33 cm. x 72 cm. x 40 cm.

It is also equipped with a filter that reduces H_2S and biogas burner, both with their own designs, but their performance is far from the scope of this article. In Fig. 5 the actual image of the Test Brench # 1 (BE-1) is shown.

Fig. 5. Image of the Test Brench # 1 (BE-1)

3.5. The Hypothesis was Formulated

$H0_1$. There are no significant differences between the different experimental runs considering the temperature increases as a function of heating time.

It will be verified that there are no significant differences between the different experimental runs for "n" tests if in the equality of means the value of "t" is less than 1.94 and in the Levene test of equality of variances the value of the sig is > 0.05.

IV. Results and Discussion

3.1. Water Heating in Pilot Plant

For the determination of the results, the following variables were measured: biogas flow in the heater: m^3/min; Hydraulic water pressure to heat: kg/cm^2; Water temperature at the inlet of the heater (Ti): °C; Water temperature a heater output (To): ºC; Temperature Δ (To-Ti); Volume of water measured in graduated container: litres (l); Time the Δ temperature is reached: minutes (min); % methane present in biogas; Biogas caloric value: kJ/kg.

In total, 12 experimental runs were performed, with a repeatability of three samples in each run, in total 36 samples over the indicated period. The ANOVA table to determine the number of degrees of freedom, (an indicator of the number of repeated measurements) recommends between 30 to 45 samples for this type of simulation study [16].

The result of one of the 12 experimental runs is shown in Fig. 6: A biogas flow of 0.075 (+/-) 0.005 m^3/min comes to the heater. That makes the water temperature increase by a Δt of 60 (+/-) 2°C and reach 90 (+/-) 2°C. This increment Δt is reached at a time "X" that turned out to be 6 (+/-) 0.03 minutes. % of methane, oscillated at a value of 64%.

When this temperature of 90 (+/-) 2ºC is reached, the hot water outlet valve Fig. 4 is opened until a 5 l/min hot water flow is reached. As this flow begins to come out, a similar flow of cold water begins to enter until the water temperature is homogenized around 60 °C inside of the heater.

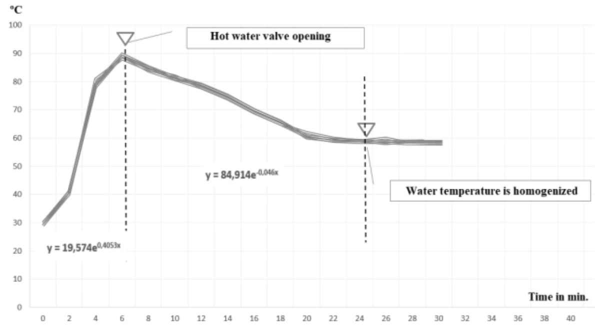

Fig. 6. Water heating behavior in test Bench # 1. August 2016

The average duration of these experimental runs is 30 minutes that are distributed in the following way: The first 6-7 minutes are used to reach the temperature of 90 degrees inside the heater, then for 23 minutes the hot water is mixed with the cold water. After 30 minutes the water reaches 60 °C and at this temperature it keeps flowing steadily.

As a complement, the proposed hypothesis is verified by applying Pearson's correlation. Table II.

Table II. Pearson's correlation.

t-test for independent samples								
		Levene Test of equal variances		Test t for equality of means				
		F	Sig.	t	gl	Sig. (bilateral)	Difference in means	Standard error difference.
Run 1 VS 2	Equal variances are assumed	0,002	0,969	-0,539	58	0,592	-2,833	5,259
Run 2 VS 3	Equal variances are assumed	0,195	0,660	0,025	58,000	0,980	0,133	5,276
Run 3 VS 4	Equal variances are assumed	0,020	0,887	-0,199	58,000	0,843	-1,067	5,364
Run 1 VS 3	Equal variances are assumed	0,000	0,990	-0,067	34,000	0,947	-0,333	4,976
Run 1 VS 4	Equal variances are assumed	0,093	0,761	-0,231	58,000	0,818	-1,200	5,198
Run 2 VS 4	Equal variances are assumed	0,072	0,790	0,316	58,000	0,753	1,633	5,169

The table II shows the two possible conditions in relation to equality of variance, and the equality of means. In all cases equality of variances > 0.05 and the value of "t" > 1.96.

By testing the equality of means the bilateral significance is > 0.05 and all Standard error difference are located within the 95% confidence interval of the mean difference.

From both results equal variances as equal means, it is concluded that there is not sufficient evidence to reject $H0_1$ and therefore, there are no significant differences between the temperature increases (delta) as a function of the warm-up time.

V. Conclusions

1. It has been possible to determine the behavior of the increase of temperature over time which is expressed by the equation $y = 19.57^{e0.4053x}$ (from 0 to 6 min) and the behavior of the lowering temperature up to its stabilization expressed as $Y = 84.914^{e-0.046x}$ (from 7 to 25 min). 2. The heater

reaches its homogenization temperature 30 minutes after starting heating. 3. The experimental runs were carried out with a biogas flow between 0.0068 and 0.0073 m^3/min (0408 and 0438 m^3/h) that is, the input energy values in real condition were found between 2366 and 2540 Wh. 4. There is stability of the values of methane generated by the bio-digester of Rancho el Coronel.

The result achieved in the Test Brench # 1 (BE-1) corresponds to the modeling of the heat transfer process that was performed considering that the heater behaves like a vertical cylindrical tube. But this procedure moves away from the purpose of this article.

This same methodological procedure will be followed by a larger heater, which is capable of reaching the necessary volume of hot water for the sanitation process of the stable during the three daily milkings.

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AUTHORS’ PROFILES

Dr. VICTOR MANUEL MOLINA MOREJON. Cuba, 1945. Prof. Molina obtained his Bachelor Degree in Mechanical Engineering from UCLV, Sta. Clara, CUBA in the year 1968, and Doctor Degree in Technical Sciences (1985) from the Odessa National Polytechnic University UKRAINE and Technological University of Havana J.A.E. CUBA. Prof. Molina has more than fifty years in teaching and research activities. His research interests are in technologic management, sustainability and efficient energy management. At present, is working as Research Professor of Autonomous University of Coahuila, Torreon. MEXICO.

MSc. VICTOR PEDRO MOLINA ROMEO.
Was born in CUBA in December 28, 1970. He graduated in 1994 as a Mechanical Engineering from the University of Cienfuegos, CUBA. He received his M.Sc. degree in Energy Efficiency from the same University in 2016. He worked as a Principal Production Specialist in the Thermoelectric of Cienfuegos, CUBA. He currently works as a professor at the Faculty of Administration Sciences of the Autonomous University of Coahuila, Saltillo, MEXICO.

Eng. FRIDA GARCIA BERMUDEZ
Was born in CUBA in July 10, 1982. She graduated as an Industrial Engineering in 2011 from the University of Cienfuegos, CUBA. She worked as a Quality Control Specialist at the Cienfuegos Thermoelectric Plant, CUBA. She currently works as a professor at the Faculty of Administration Sciences of the Autonomous University of Coahuila, Saltillo, MEXICO.

Dr. ORLANDO W. GUTIERREZ CASTILLO
Obtained his Bachelor Degree in Economics (University of Havana, Cuba, 1978); Master in Economic Statistics (Higher Institute of Economics, Sofia, Bulgaria, 1981); Doctor in Economic Sciences (Moscow Higher Institute of Economics, Russia, 1989). Professor at the University of Havana (1991-2014), and as Managerial Consultant in enterprises and government institutions. At the present he is Research Professor at the Autonomous University of Coahuila. MEXICO.