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EXPERIMENTAL RESEARCH ON COMBUSTION OF BIOGAS OBTAINED THROUGH ANAEROBIC FERMENTATION OF TANNERIES WASTES

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This paper deals with the energy use of biogas obtained, through anaerobic fermentation, from protein wastes of the leather industry. As the experimental installation is not realizing a sufficient flow of biogas to analyze its energy use, a synthetic biogas has been used. The composition of this synthetic biogas was done based on the elemental analysis of the combustion compounds of biogas, produced by fermentation in our conducted experiments, as well as of the limits of other existing biogas plants. Thus, it is possible to analyze the energy behavior of biogas produced by fermentation of wastes from the leather industry, and beyond.

This paper highlights the opportunity to use anaerobic fermentation as a solution to leather industry and the benefits brought to renewable energy sector by biogas combustion. Tanneries usually processes around 70 t/month of crude leathers, resulting in almost 15 t/month of waste. Fats represent 10% of this animal waste, while the rest are proteins. Through anaerobic digestion, animal proteins from tanneries wastes can yield biogas. This biogas can be used through combustion to generate energy.

Keywords: anaerobic digestion, biogas, combustion, tannery, waste.

1. Introduction

Anaerobic digestion represents a biochemical complex process in which protein-like organic material is decomposed by different types of micro-organisms in the absence of oxygen.

Biogas represents the main product of anaerobic digestion, strongly related to the composition of the organic matter. Animal fats are an important secondary product of the leather industry [1]. In the tanneries, the animal fats represent the most important waste. The animal fats have high heating value and are mainly constituted by triglycerides of saturated monocarboxylic fat acids with even number of carbon atoms [2].

Leather industry, in its preparation processes such as fleshing, trimmings, cuttings and chips from hides, produces large amounts of wastes. These wastes

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have high content of animal proteins, raising the opportunity to use an anaerobic digester for their treatment. The biogas is an important source of energy that can be very well used in the internal manufacturing processes. In addition, this solution is more ecologically friendly than the direct combustion [3].

The energy conversion of animal proteins can be realized through anaerobic digestion [4]. The usual chain of biogas energy recovery contains all necessary phases: anaerobic digestion, filtration, storage, dehumidification and effective end use. The research developed until now covered:

- finding energy characteristics of the animal proteins;
- design and construction of a pilot digester;
- demonstrative operation and biogas generation.

High concentration of animal protein found in the wastes coming from tanneries have led to the opinion of using this process as an alternative source of energy that can be used in-house [5].

Two dominant components characterize the quality of the biogas: CH_4 and CO_2. Statistically speaking, it has been shown that the typical values for methane per unit mass of biogas production vary between 50% and 73%, usually attained after a 14 weeks anaerobic digestion process, while after a 10-week process corresponds to a 40% [6], [7].

Under these considerations, biogas a multi-gas mixture, seems to be an important source of renewable energy as it can be produced by the degradation of biodegradable materials, such as organic wastes under the eco-friendly way of anaerobic digestion [8].

All the researchers highlight the negative impact of CO_2 on the combustion performances. The proportion of CH_4 varies in the limit of CO_2=30-70%, nitrogen in the limits of N_2=1-7%, the rest until 100% being represented by the concentration of CO_2. Lower calorific values have spread through 16.500-21.500 kJ/m^3_N. Also, a high content of CO_2 leads to a decrease of the initial temperature in the flame, low values of the velocity combustion and gives more constraints for the air concentrations needed for lighting and extinction limits [9].

This paper deals with managing the wastes resulting from a tannery. The large amounts of wastes can be converted into a form of energy by analyzing the possibility for combustion, with a high efficiency rate, the biogas obtained through anaerobic fermentation.

2. Installation set-up

The biogas produced through anaerobic fermentation of protein wastes in a pilot plant has ecological and economical importance. The anaerobic fermentation is an ecological processing of protein mass instead of incineration (ecological point of view). The biogas can be easily used in energy purposes (economic aspect).

The anaerobic fermentation plant comprises 3 reactors coupled in two cascading technological stages. The biogas obtained mainly contains of CH_4 and CO_2, in a proportion from 40/60 to 60/40. The secondary components are H_2, N, H_2S, butin very small concentrations.

Considering how the mix of air and fuel is done, the process of combustion of gaseous fuels can be:

- kinetic, if the mix of air and fuel is done previously. The mix has a common jet;

- diffusive, if the mix of air and fuel is done in the burner. The two fluids have different jets;

- incomplete, if in the mix an insufficient quantity of air is introduced, required in forming the carbon particles for increasing the heat exchange through radiation (carbonization of the flame).

The mixing process of air and fuel is done in the burners, while the combustion process is done in the furnace. Depending on the characteristic of the flow in the furnace, the combustion may be normal (at relatively low speeds generally at laminar flow) or turbulent at high speeds [10].

Laminar motion is the flow in which the fluid layers move without mixing (flowing into small diameter tubes and reduced fluid velocities). As the current speed increases, there is an intense mixing of these layers, changing the current characteristics such as speed distribution and pressure loss [11].

All the investigations highlighted the negative role of very high content of CO_2. This negative effect is manifested by the reduction of the temperature in the initiation phase of combustion, the decrease of the combustion rate, and the narrowing of the concentration and air curve for the limits of ignition and extinguishing [12].

To thermodynamically characterize the biogas flame, it is necessary to introduce the specific criterion *R* defined by the ratio between the CH_4 content volume and CO_2 content volume of the fuel:

$$R = \frac{CH_4}{CO_2} \quad (1)$$

The criterion is clearly different from the C/O one used for synthetic fuels dominated by CH_4, H_2 and CO components. The C/O criterion considers the combustion of CO component. For the case of CO_2 component, the biogas not participating in the combustion will not modify the C/O ratio. Thus, it was necessary to introduce another criterion to characterize the biogas from anaerobic fermentation of protein mass.

The combustion stability is achieved by comparing the combustion rate S_L with the flow rate u:

$$u \leq S_L \tag{2}$$

For diffusive combustion, the burning rate in turbulent flow S_T will depend on R_e number:

$$S_T = f\left(S_L^*, d_0, R_e\right) \tag{3}$$

where d_0 is the diameter of the flow channel.

The gaseous fuels are modifying their quality depending on the calorific value and pressure. All variations are determined by the quantity of heat needed in the furnace:

$$BQ_d = const \tag{4}$$

which leads to the balance expression:

$$B_1 Q_{i,1}^i = B_2 Q_{i,2}^i \tag{5}$$

The capacity of the gas passing through the burner's nozzle depends on the pressure and density, according to::

$$B = \mu f \sqrt{\frac{2\Delta p}{\rho}} \left[m^3 / s \right] \tag{6}$$

where: μ is the capacity index of the nozzle [-],

f – the total area of the nozzle [m^2],

Δp – gas pressure [$kg\ m^{-1}\ s^{-2}$],

ρ - gas density [kg/m^3].

Using (5) and (6), it can be obtained that:

$$f_1 \sqrt{\Delta p_1} \frac{Q_{i,1}^i}{\sqrt{\rho_1}} = f_1 \sqrt{\Delta p_2} \frac{Q_{i,2}^i}{\sqrt{\rho_2}} \tag{7}$$

The proportion $Q_i^i / \sqrt{\rho_2}$ is called Wobbe criterion (Wo). It translates the fact that the gas pressures must vary inversely with their Wobbe numbers if the burner characteristics remain the same [13]. The furnaces for burning gaseous fuels can be open chamber furnaces, semi-open-type, closed-type, cyclonic, or rotational outbreaks. In the energy applications area, the open chamber type is the most frequently used.

3. Experiment description

Firstly, the biogas burning test was carried out by coupling a Bunsen burner to the exhaust pipe of the pilot plant of anaerobic fermentation, as shown in Fig. 1.

The biogas has been obtained from a pilot installation using a three cascade stages fermentation process.

This test revealed the possibility of using biogas for energy purposes, as the flame was stable and with a blue color similar to the combustion of methane with excess air (λ>1). The biogas quantity delivered by the pilot plant is reduced and its quality varies over time. Thus, for energy purposes, it was analyzed the possibility to use gas obtained by mixing desired compositions in pressurized cylinders delivered by specialized companies (like Linde).

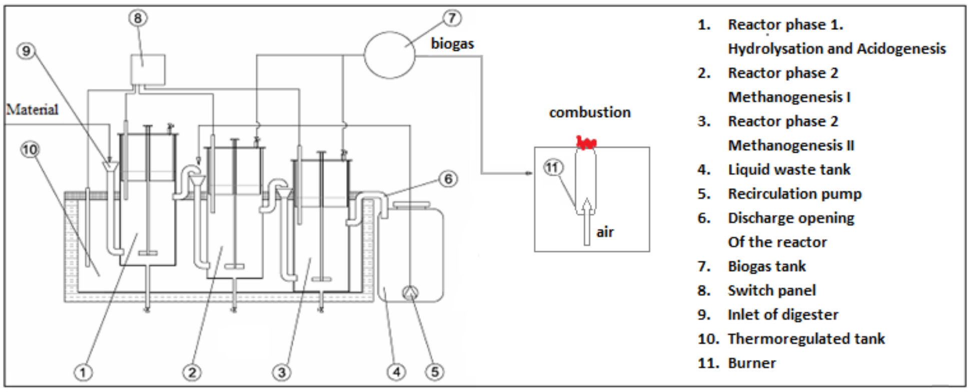


Fig. 1. Pilot anaerobic fermentation connected to the Bunsen burner

The average composition of the biogas obtained in the pilot anaerobic digester is reported in Table 1 [6]. Three versions of the synthetic gas were prepared with the compositions of Table 1.

Table 1

The gas compositions of the three prepared cylinders

	CH_4 [%]	CO_2 [%]	H_2 [%]	N_2 [%]	R [%]	H^i_i [kJ/m^3_N]
Cylinder I	52	45	1	2	1.15	18 700
Cylinder II	60	32	1	7	1.87	21 550
Cylinder III	40	56	1	3	0.71	14 400

During the experiments, a two-stage reduction head was used to reduce gas pressure in the cylinders, as shown in Fig. 2.

Fig. 2. The gas cylinder I with the reducer head fitted

The combustion of biogas was carried out with the burners that equip the stand for the testing of the combustion of gaseous fuels at University POLITEHNICA of Bucharest, Department of Thermotechnics.

In Fig. 3 the experimental set-up is illustrated. It was equipped with a gas analyzer for controlling the excess air and for determining the combustion compounds (polluting emissions). For determining the flame temperature, a SMART VIEW 4.1 Fluke Infrared camera was used, as illustrated in Fig. 4.


Fig. 3. Experimental set-up


Fig. 4. SMART VIEW camera 4.1.Fluke IR

The tests were performed in both regimes of combustions: kinetic (as shown in Figs. 5 and 6) and diffusive (as illustrated in Figs. 7 and 8).

The first experiment was carried on with a conventional burner: with single jet mixing air and gas (as shown in Fig. 6). This burner is generally used for a kinetic combustion, which implies a pre-mixture of air and fuel. It can be considered to be used for low flows of gas, which can be the also the case of tanneries. As the name states, the air is automatically introduced in the process and the fuel admission is done in the lower part of the burner.

Fig. 5. Kinetic combustion

Fig. 6. Burner with single jet: mix of air and synthetic gas

The second experiment was performed using a diffusive burner (as shown in Fig. 8). This one is more appropriate to medium -large flows of gas. For the case of diffusional combustion, characterized by separate fuel jet and lateral air inlet, an analysis of process behavior is done such that, passing to the new burning configuration, to yield good results through good synchronization of all parameters.

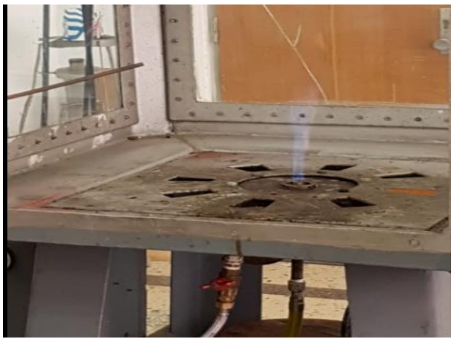


Fig. 7. Diffusive combustion

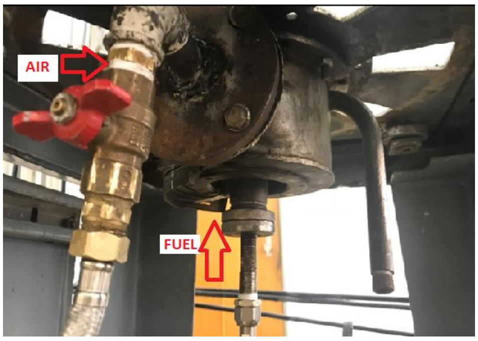


Fig. 8. Diffusive burner

By complying with the flame stability conditions, appropriate ignition and combustion of this gas with high concentration of CO_2 for both versions of technology (pre-mixture of gas-air (kinetic) and diffusion) was achieved.

4. Results and discussion

The tests were conducted for both combustion technologies. When the burners were adjusted, the Wobbe criterion was considered. The calorific power has different values function of natural gas (CH_4) Density:

$$W_0 = \sqrt{\Delta p}\,\frac{H_i^i}{\sqrt{\rho}} \tag{8}$$

Where: Δp is over pressure [kg m^{-1} s^{-2}],

H_i^i – calorific power,

ρ - gas density [kg/m^3].

Fig. 9 shows the variation of the biogas density function of gas composition, characterized by the criterion R. It can be observed an increase of the biogas density function of CO_2 content growth, which exceeds the net methane value of density (ρ=0.705 kg/$m^3{}_N$).

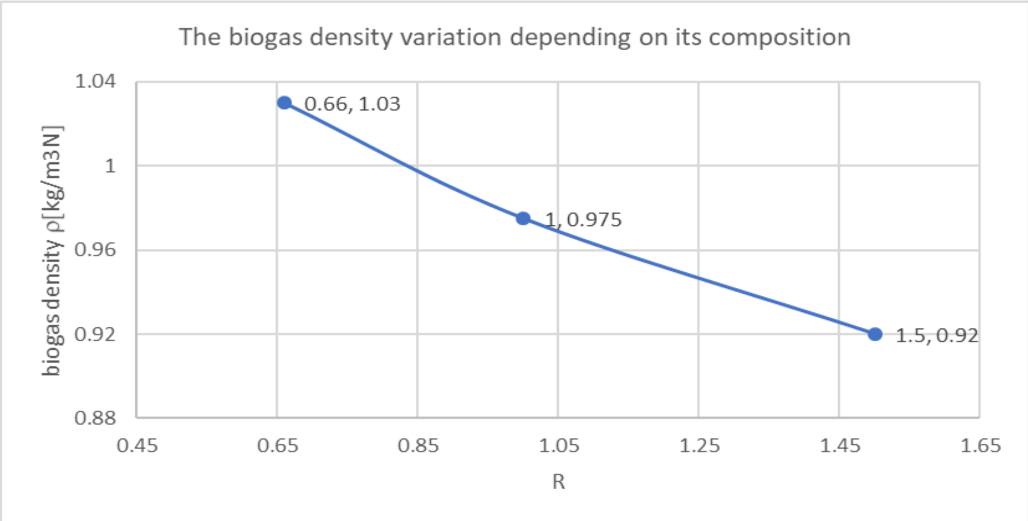


Fig. 9. Synthetic gas density variation depending on its composition

By analyzing the Wobbe criterion, the highest influence of working parameters setting is for kinetic combustion with air pre-mixture. For diffusive combustion, if the working pressure does not change, it can directly work on the size of the gas nozzle. This criterion also highlights the problems that a combustion process encounters when there is a drop-off of the burning rate of methane under the influence of CO_2 and the technological limits that are determined by process challenges.

For the gas concentrations reported in Table 1, the variation of the ratio between Δp_2 and Δp_1 function of R is illustrated in Fig. 10.

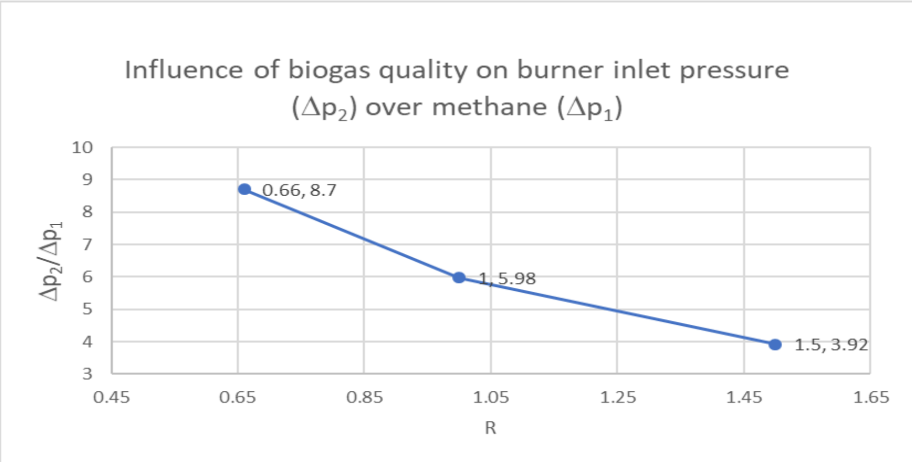


Fig. 10. Influence of synthetic gas quality on burner inlet pressure (Δp2) over methane (Δp1)

To adjust the burner operation, without changing the biogas inlet pressure, the required size of nuzzles' diameter (d_2 for biogas, respectively d_1 for methane) should follow the data in Fig. 11.

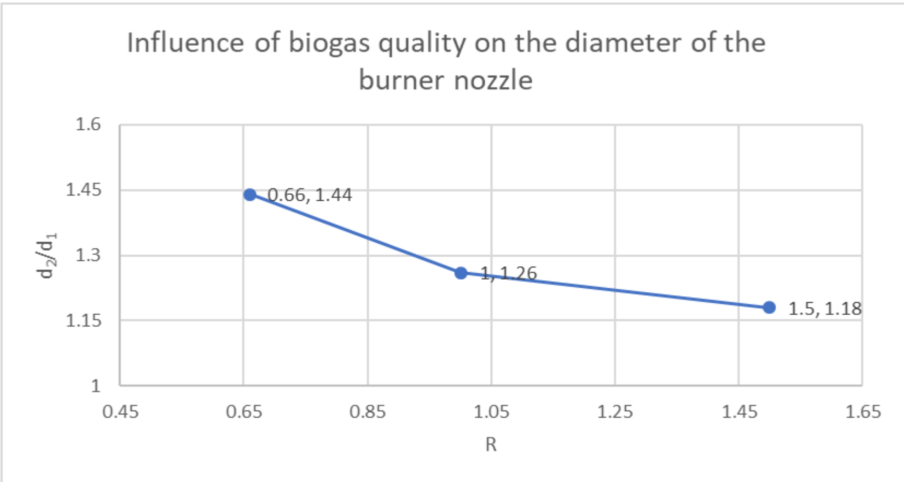


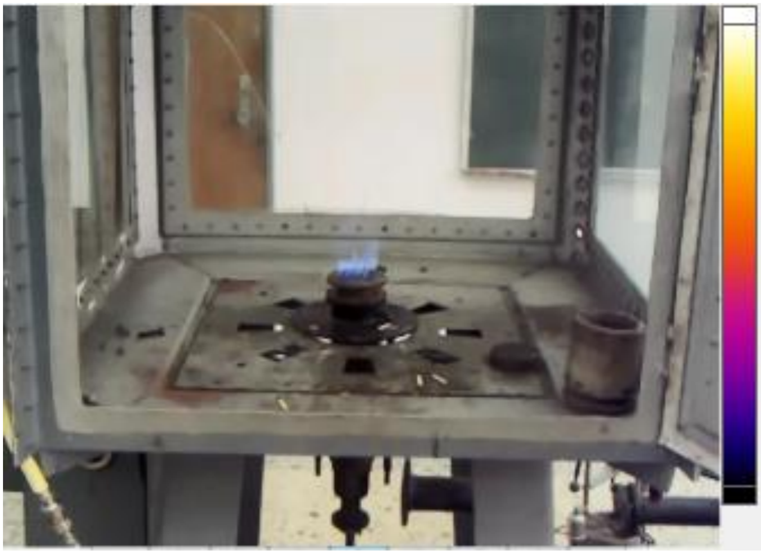
Fig. 11. Influence of biogas quality on the diameter of the burner nozzle

The flame for all the considered synthetic gas compositions and for both combustion technologies was stable, complete and with reduced pollutant emissions. The pollutant emissions have values within the limits of environmental regulations for both combustion technologies. Also, the are very similar for both technologies.

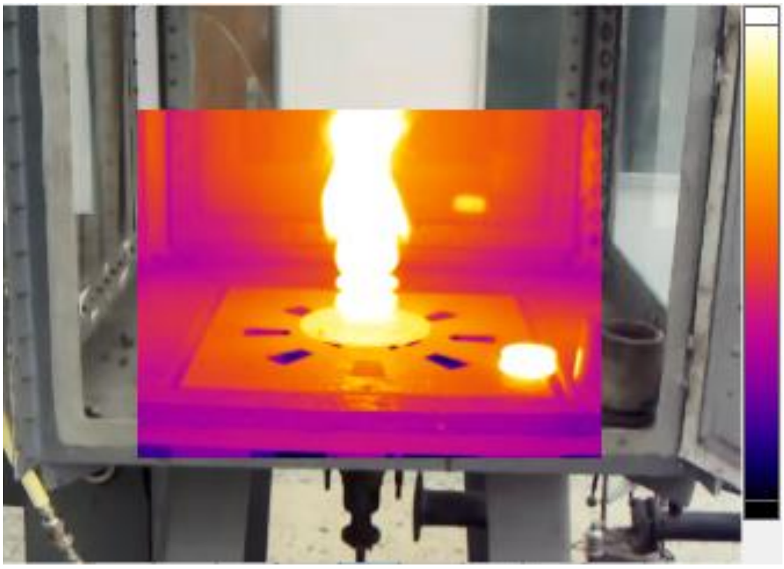
Considering in the experiments the gas from cylinder I as main reference, the biogas obtained from tannery wastes can be used, in its raw state, for combustion without any special preparation or usage of an additional support for burning. This is a great advantage as any other extra operation brings costs and extra labor.

The positive results obtained with both versions of combustion (kinetic and diffusive) represent also a positive thing in burning the biogas obtained from tanneries. Probably a diffusive burner will be more appropriate for higher flow values, but this depends also on the quantity of wastes and the size of the tannery**.**

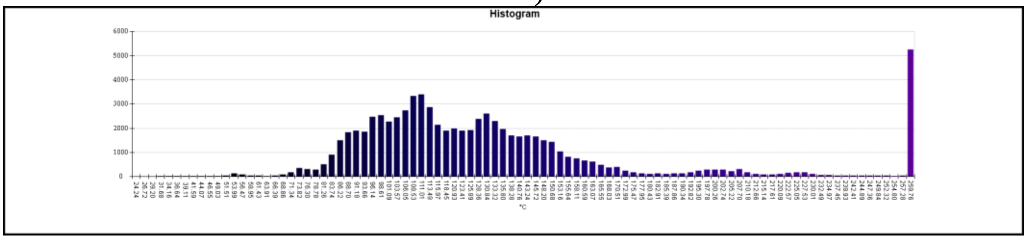
By decreasing the methane content below 50% it raises multiple fuel efficiency challenges. The conducted experiments revealed that this is not the case of tanneries which have high protein concentration, producing biogas of a good quality. The level of the flame during the combustion of synthetic gas from cylinder I and considering a pre-mixed burner is shown in Fig. 13. The temperature histogram in Fig. 13c) shows dominant temperatures in the range 700-1650 °C. The thermal histogram data indicate good flame deflagration when excess air is introduced in the unit. There is a flame concentration at the bottom of the burner, and a post-combustion supplementation, corresponding to the kinetic combustion assumptions.



a)



b)



c)

Fig. 12. Thermal distribution of gas combustion from cylinder I: a) General appearance of kinetic flame; b) Thermal distribution with respect to IR; c) Temperature Histogram

5. Conclusions

This paper deals with the combustion process of synthetic gas, resulting from the anaerobic fermentation of protein in the leather industry, and using CH4 burners. The tests were carried on with three cases of synthesis gas with concentrations slightly modified compared to the average composition of the biogas obtained in the pilot anaerobic digester.

The combustion experiments were carried on in presence of kinetic combustion and with diffusive combustion. The experiments cover the case of a pre-mixer burner with a flame-splitting stabilizer. Both the obtained temperature range and the resulting pollutant emissions indicated a good development of the combustion process. The experimental results reveal that the minimum quality threshold for efficient use of biogas for energy purposes is the R criterion of min 0.71. All calculated values were close to the ones obtained by trial, confirming the proper handling of the burners and a good configuration of the process.

Another important observation would be the fact that the biogas was used in its raw state, without a mixture with a flammable component in order to assure the combustion. This is also another advantage for tanneries, meaning that they are not forced to perform any other investments and can use directly the biogas resulted from anaerobic fermentation.

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