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EVALUATION OF BIOGAS CALORIFIC POTENTIAL FOR USE IN MEDICINAL PLANT DRYERS

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ABSTRACT. The objective of this study was to evaluate the use of thermal energy from the burning of biogas for heating air and its potential use in a drying chamber. A prototype was built to evaluate the air heating in the heating system and in a drying chamber. The biogas composition used was 60.00% methane (CH_4). Treatments were composed by pressure difference applied to biogas, in which: T0 (no heating), T1 (pressure 130.00 to 200.00 kPa), T2 (pressure 200.00 to 270.00 kPar) and T3 (pressure 270.00 to 340.00 kPar) in six replications. A gas water heater (LPG) was adapted for use with biogas. The drying chamber was built with MDF (Medium Density Fiberboard) boards and thermally insulated with a total usable volume of 0.544 m³ and air velocity of 1.58 m.s^{-1}. The burning of biogas generated 36,10MJ h^{-1}, 68.95MJ h^{-1} and 76.03MJ h^{-1} for treatments T1, T2 and T3 respectively, meeting the need for heating in the drying chamber operating at temperatures of 43.05 ºC (T1), 52.56 ºC (T2) and 53.56 ºC (T3). The heating system proposed has proved to be effective for drying different species of medicinal plants, since it meets the temperature range specified in the literature.

KEYWORDS: Alternative energy sources; drying; energy; heat energy

RESUMO. O objetivo deste estudo foi avaliar o uso de energia térmica, a partir da queima do biogás, para aquecer o ar e avaliar o seu potencial uso em uma câmara de secagem. Um protótipo foi construído para avaliar o aquecimento do ar no sistema de aquecimento e numa câmara de secagem. A composição do biogás utilizado foi 60,00% de metano (CH_4). Os tratamentos foram compostos por diferença de pressão aplicada ao biogás, em que: T0 (sem aquecimento), T1 (pressão 130,00-200,00 kPa), T2 (pressão 200,00-270,00 kPar) e T3 (pressão 270,00-340,00 kPar) em seis repetições. Um aquecedor de água a gás (GLP) foi adaptado para utilização com biogás. A câmara de secagem foi construída com MDF (Medium Density Fiberboard) placas de isolamento térmico e com um volume útil total de 0,544 m³ e velocidade do ar de 1,58 ms^{-1}. A queima do biogás gerado 36,10MJ h^{-1}, 68.95MJ h^{-1}e 76.03MJ h^{-1} para os tratamentos T1, T2 e T3, respectivamente, satisfazendo a necessidade de aquecimento da câmara de secagem operando a uma temperatura de 43,05 ° C (T1) , 52,56 ºC (T2) e 53,56 ° C (T3). O sistema de aquecimento proposto provou ser eficaz para a secagem de diferentes espécies de plantas medicinais, uma vez que se encontra com a gama de temperaturas especificada na literatura.

PALAVRAS-CHAVE: Fontes de energia alternativas; secagem; energia; energia de aquecimento

1 INTRODUCTION

The use of herbal medicine and drugs extracted from medicinal plants in Brazil is reported historically and has been increasingly discussed in various studies, thus attracting the attention of new researchers (MING, FERREIRA & GONÇALVES, 2012) .

As herbal medicine has great importance in daily life, we have been using herbs, flowers and fruit extracts, such as clove, with analgesic effect in dentistry. Other example of use of herbal derivative is the application of garlicextract and lemon grass as anti-fungal on agricultural products (CAVALCANTI, 2005; SOUZA, ARAÚJO & NASCIMENTO, 2007).

According to De Carvalho, Da Costa & Carnelossi (2010), highlight that high levels of biological contamination occur due to low quality in the post-harvest processing of medicinal plants, compromising the reliability of use by consumers.

As Soares (2006) points out, the feasibility of production of medicinal and aromatic plants is committed to reducing costs during the drying process. Melo, Radünz & Berbert, (2002) reported that the amount of energy required for heating air bands between 30 °C and 50 °C is 10,000 kJ per kg of water removed from plants in the drying process.

The temperature range generally used, regardless of the

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method, for most medicinal plants is between 50 and 60 °C (MELO, RADÜNZ & MELO, 2004).

The production of biogas from anaerobic digestion is considered a promising source of renewable energy and can contribute beneficially to the treatment of agricultural waste, favoring the reduction of costs in the implementation of more efficient systems, as well as in the reduction of organic load to the support of agro ecosystems and recycling minerals into a form that nourishes the plants and improves soil quality (BERGLUND, BORJESSON & BÖRJESSON, 2006). Basically, biogas can be used for generating electrical, mechanical and heat energy. Thus it can easily be adapted and used along with natural gas.

For heating purposes biogas does not need any reinforcement or mix with other gases and the level of contamination does not restrict its use, however, it needs to undergo condensation, removal of undesirable particles, compression, cooling (if necessary) and dehumidification Seadi et al. (2008). According to Jönsson et al. (2003) average concentrations for the biogas produced by anaerobic digesters of rural installations are 50-60% CH_4, 30-40% CO_2, <1% N_2 and 10 to 2000 ppm of H_2S. Deshmukh, (2005) describes that the calorific value of methane (CH_4) is 35.80 MJ m^{-3}.

This research deals with the construction of a prototype for burning biogas aiming air heating and its use in a drying chamber. The objective was to evaluate the feasibility of using heat energy from biogas in dryers for operation in the temperature range required for drying medicinal plants.

2 MATERIALS AND METHODS

A prototype for evaluating the use of thermal energy from biogas burning (heating system and drying chamber) was installed at the Experimental Station Prof. Dr. Antônio Carlos dos Santos Pessoa at UNIOESTE (Western Paraná State University), in the municipality of Marechal Cândido Rondon, Paraná, Brazil (24º 30'12" S, 54º 01'10" W).

The structure used has a bio-digester model Bioköhler B20 with capacity of 20.00 m^{-3} of manure, engine compressor, biogas condenser, filter, pump for waste maintenance, gas meter and a 5.00 m³ storage balloon. The digester is fed with cattle manure from the animals housed on site and the bio-fertilizer is intended for pasture fertilization.

Biogas composition was measured daily, by a portable equipment model Drager X-am 7000 with an infrared sensor. During the experimental period the proportions measured were 59.54% ± 0,46% CH_4, 39.63% ±0,12% CO_2 and 0.83% ±0,09% for other gases (H_2S, CO, O_2, NH_3, N_2 and H_2O) (mean ± SD). As the reading was performed before filtering, the methane proportion considered is 60.0% for methane (CH_4).

The biogas produced is stored in a balloon made from LLDPE (Linear Low Density Polyethylene) geo-membrane and drives an air compressor 0.074 m³ min^{-1}; it is then directed to the pipeline network. Before reaching the compressor unit, biogas has its impurities removed by passing through a particulate filter and is dehumidified by means of a cylinder condenser. In the trial period the production remained at an average of 3.00 m³ day^{-1}.

Tests were conducted with different settings in the compressor, which sucks the biogas stored and compresses it into the pipeline connected to the burner. The air compressor was connected to a pressure switch adjusted to operate in pressure ranges between 130.00-200.00 kPa, 200.00-270.00 kPa and 270.00-340.00 kPa, which comprise normal working pressure of the system. With other settings, such as below 100.00 kPa, there was no lighting of the burner and above 360.00 kPa the equipment was overly stressed operating continuously, what contradicts its operation manual.

The quantification of the biogas used for burning was determined with a gas meter G 0.6 LAO, installed in the biogas passage to the burner and connected by 8.0 mm thick pneumatic hoses type PU (polyurethane) for quick coupling connections.

A water heater type passage was used without description of make and model for being an old appliance. The equipment has been completely adapted, especially with the removal of all water pipes (input, exit and movement) and the withdrawal of original valves of water and gas. Two main components were used: the burner type grid with 14 outputs of flame and operating pressure of 2.80 kPa and the outer frame (metal box).

The burner had its gas nozzles modified on the output thickness (originally 0.60 mm) which went through manual drilling with a new 1.00 mm drill. The distance between the nozzle and the burner input (originally 3.00 cm) was canceled by decreasing the oxygen input in order to allow the burning of biogas. For combustion it was also necessary to install a valve for gas (LPG) with a flow rate of 7 kg h^{-1} in order to regulate the pressure of the biogas in the burner at 2.80 kPa.

To carry out the ignition and control of biogas input, a temperature controller was installed - brand INOVA, model 32101 (specific for gas, wood or electricity furnaces) - accompanied by a stove and a spark arrestor. This apparatus was used to simplify the use of the burner and provide more safety during operation.

Air heating was possible due to the use of a FLEXTIC 100.00 mm aluminum pipe, with total length of 1.50 m and 1.00 mm thick. Such pipe was arranged on the burner at an angle distance of 6.00 cm in the input (air temperature), and 13.00 cm at the output (heated air) in relation to the maximum height of the burner.

Thus, the heating area was determined, space in which the pipe was on the burner. The aluminum pipe was flattened in this space, for a better utilization of the flame, leaving 3.00 cm high by 15.00 cm wide. The ambient air input was arranged at a distance of 60.00 cm below the height of the burner and the output at 20.00 cm above it. At the end of the aluminum pipe (heated air output) there was a 100.00 mm flexible PVC tube, for conducting the heated air into the drying chamber with a length of 1.80 m. This conductive pipe was then insulated with glass mat (0.30 kg m^{-2}) and covered with insulation reflective plastic tape.

For protection against wind and rain, a shelter was constructed with dimensions 0.80 x 0.75 x 0.80 m (front, depth and height), while the base is open for air input and the distance is 0.10 m from the floor. The heating system is composed of: burning structure, ignition and heating tube.

The drying chamber was made of 2.50 cm thick MDF (medium density fiberboard) boards. The chamber was insulated with 2.00 cm thick Styrofoam plates and sealed in joints with polyurethane foam. The dimensions of the drying chamber in useful volume were 0.80 X 0.80 X 0.85 m (front, depth and height) totaling 0.544 m^3.

A set with 7 J type thermocouples was used in a system data logger model NOVUS FIELDLOGGER with capacity of 512 kB in 8 analog input channels. Originally the thermocouples had 1.50 m in length, which were added with PP type cables of to a total length of 7.50 m, then going through calibration under temperatures between 0.00 and 98.00° C.

The sensors were arranged at the (1) ambient air input of the pipe, (2) at 5.00 cm above the flame of the burner, (3) at the exit of heated air from the burner, (4) at the input of the drying chamber, (5) at the center of the drying chamber (6) at the exit of the drying chamber, and (7) in the upper cover (above the burner device). Figure 1 shows the position of the thermocouples and schematic model of the heating system and drying chamber.

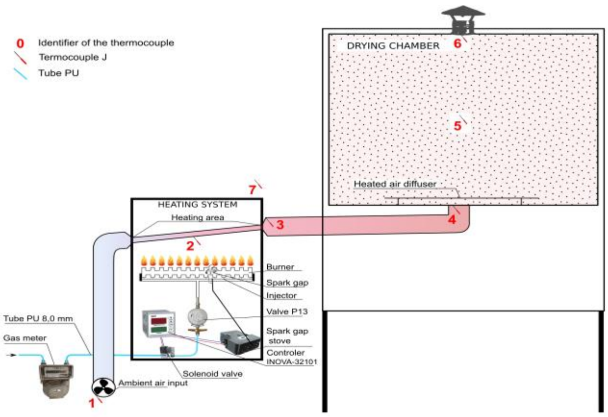

Figure 1 - *Diagram system of the heating and drying chamber with the provision of the temperature sensors (Thermocouples Type J)*

The experimental period was from 15 December 2012 to 13 January 2013, covering the period of testing and adjustments to the operation of the components and data collection.

The treatments were: T0 - no heating, T1 - heating and pressure regulation between 130.00-200.00 kPa, T2 - heating and pressure regulation between 200.00-270.00 kPa, and T3 - heating and pressure regulation between 270.00-340.00 kPa.

Six replications were performed, with each section comprising 40.00 min, 10.00 min with the system turned on for preheating and system stabilization and 30.00 min for data collection. The collection times were 11:00 a.m., 1:00 p.m., 3:00 p.m. and 5:00 p.m. conducted from 08/01/13 to 13/01/13.

The air velocity in the pipe was measured by using a portable digital anemometer KESTREL brand, at the entry of the drying chamber. The recorded velocity was 1.58 $m.s^{-1}$, providing air transport at 0.0124 m^3 s^{-1}. With the drying chamber corresponding to the volume of 0.544 m^3 complete renewal of the air occurred every 43.90 seconds.

Data collection from the loggers was performed daily, by using the standard software that comes with the equipment. Reading and analysis of results were prepared by using an electronic spreadsheet and statistical software R (version 1.8.1) in R-Commander graphical interface, applied by means of analysis of variance, means test and linear regression, as well as the numerical summary of the data (R Core Team, 2013).

3 RESULTS

The biogas used, was a gas mixture with a composition of 59.54% ± 0,46% CH_4, 39.63% ±0,12% CO_2 and 0.83% ±0,09% for other gases (H_2S, CO, O_2, NH_3, N_2 and H_2O) (mean ± SD), being considered the methane proportion of 60.0%. Thus it was possible to establish the calorific value of CH_4: 35.80 MJ m^{-3} and biogas: 21.48 MJm^{-3}. The values of biogas consumed in m^3 h^{-1} are described in Table 1 for each treatment and with the net values of MJ m^{-3}.

Table 1 – *Average values of biogas consumption for each treatment and correspondents in MJ m^{-3}*

Treatment	Operating pressure (kPa)	Biogas consumption (m^3 h^{-1})	Net Calorific Value (MJ m^{-3})
T0	-	-	-
T1	130.00-200.00	0.168	3.59
T2	200.00-270.00	0.321	6.88
T3	270.00-340.00	0.354	7.60

The experiment had shown that the consumption of biogas varied with the change of pressure used in the pipeline compressor system, influencing the heating potential. So the highest pressure applied resulted in higher biogas passage through valve P13 to the burner at 2.80 kPa.

The average data obtained for the treatments on the heating system and drying chamber are shown in table 2.

Table 2 – *Average heating data recorded by the temperature sensors with the data logger system.*

Treatment	Temperature (º C)					
	Heating System			Drying Chamber		
	Input	Flame	Ouput	Input	Center	Output
T0	31.49	31.20	31.55	29.84	32.32	30.66
T1	31.97	309.79	79.03	55.56	43.05	40.66
T2	31.36	491.97	119.19	80.97	52.56	49.84
T3	30.58	545.06	121.53	84.52	54.56	51.42

Treatment T0 had control effect, with no heating. Thus, the small temperature variation between sensors is explained by the difference in the ambient air input and structural conditions of the components.

Lower temperature values in the drying chamber are due to its insulating capacity, preserving the temperature prior conditions to data collection. The average values of flame heating identified by the temperature sensor on the burner (thermocouple 2) indicate that the highest passage of biogas through valve P13 enhances combustion in the burner.

To check the data variability of the treatments was carried out an average test of the data related to the temperatures observed at air input, at the flame and at output heated air for each treatment. The averages are shown in Table 3.

Table 3 – *Means test for data recorded in the heating system*

Treatment	Temperature (ºC)								
	Ambient Air Input			Flame			Air Exit		
	Means	SD	CV (%)	Means	SD	CV (%)	Means	SD	CV (%)
T0	31.49 a*	1.32	4.20	31.20 c	2.19	7.05	31.55 c	2.28	7.22
T1	31.97 a	1.74	5.44	309.79 b	63.67	20.55	79.03 b	5.98	7.57
T2	31.36 a	1.33	4.25	491.97 a	36.55	7.43	119.18 a	6.38	5.35
T3	30.58 a	1.32	4.32	545.06 a	46.85	8.59	121.53 a	6.53	5.37
P>0.001	0.435	-	-	2.12^{-14}	-	-	2.0^{-16}	-	-

* Different letters in the column correspond to Tukey's test at 5%; SD – Standard Deviation; CV – Coefficient of Variation.

At Table 4 presents the same results previously shown concerning to the variance by the means test for the sensors placed in the drying chamber, namely: heated air input temperature, and heating at the center and at the exit of the drying chamber.

Table 4 – *Means test for data recorded in the drying chamber*

Treatment	Temperature (º C)								
	Chamber input			Chamber center			Chamber exit		
	Means	SD	CV (%)	Means	SD	CV (%)	Means	SD	CV (%)
T0	29.84 c	2.53	8.46	32.32 c	2.66	8.23	30.65 c	2.69	8.79
T1	55.56 b	4.09	7.36	43.05 b	3.31	7.70	40.66 b	3.60	8.86
T2	80.97 a	4.10	5.06	52.93 a	2.56	4.83	49.84 a	3.07	6.16
T3	84.52 a	5.04	5.97	54.56 a	2.47	4.53	51.42 a	2.35	4.58
P>0.001	8.34^{-16}	-	-	1.94^{-11}	-	-	2.42^{-10}	-	-

* Different letters in the column correspond to Tukey's test at 5%; SD – Standard Deviation; CV – Coefficient of Variation.

As observed in the heating system, the results show that the heating inside the drying chamber followed the potential of energy use from the burning of biogas. Treatments T2 and T3 did not differ significantly, however, higher burning led to higher temperature inside the drying chamber. Treatment T1 presented the lowest biogas consumption what caused temperatures lower than those of T2 and T3, however it showed heating when compared to the control treatment (T0) allowing the operation at temperatures around 43.05 ºC.

Regression analysis was performed by considering the ratio between the air temperature and the consumption of biogas, making it possible to observe the linearity of the amount of biogas consumed with the temperatures inside the drying chamber and at the flame under the burner, within the scope of the conditions set in this work. It can be said, therefore, that the temperature is influenced by the consumption of biogas which forces passage according to the operating pressure of the compressor. The graphs in Figure 2 show the result of linear regression analysis between the consumption of biogas and temperature data at the center of the chamber and at the flame.

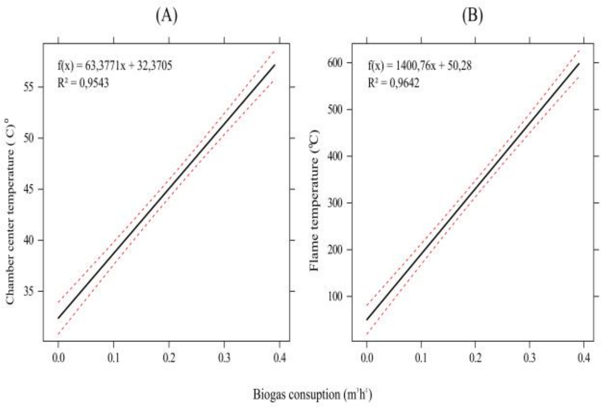

Figure 2 - *Linear regression relating the biogas consumption with temperature in the center of the chamber (A) and in the flame temperature (B)*

4 DISCUSSION

One could observe that the consumption of biogas according to the variation of pressure applied explains the temperature at the flame of the burner, directly influencing the temperature of operation in the center of the drying chamber. Average temperatures recorded in the drying chamber for treatments T1 (43.05 ºC), T2 (52.56 ºC) and T3 (54.56 ºC) grant them the capacity of drying.

The temperature ranges in the operation of the three treatments were within the established for drying medicinal plants. Soares (2006) found that the drying temperature of 40.00 °C is ideal for the extraction of essential oils in Basil (*Ocimum basilicum* L.) and 54.40 °C to obtain linalool. The ideal temperature for the extraction of essential oils of guaco (*Mikania glomerata* Sprengel) is 50.00 ºC Radünz et al. (2010) . The authors also report temperature ranges of 60.00-70.00 °C as more suitable for plants such as: citronella (*Cymbopogon winterianus*), rosemary pepper (*Lippia sidoides*) and chamomile (*Matricaria recurtita*). Fudholi et al. (2010) reported that the drying of green tea (*Camellia sinensis*) at temperatures of 50.00 °C is satisfactory.

By analyzing the verified data it is possible to identify the main bottlenecks that need revision regarding their constructive aspects in order to point out the areas that need improvement. The first point relates to the heating system, in particular in the heating area which did not take all the heat generated what made the internal space of the shelter structure significantly increase its temperature. The average temperature at 5.00 cm from the ceiling of the shelter, recorded for treatment T1 was 78.47 ºC distinct from T2 (105.16 °C) and T3 (105.51 °C) that were similar. This indicates that changes in the heating area (such as the approach of the aluminum pipe to the flame) may result in increased air heating. Another efficiency factor concerns the difference in the air temperature within the aluminum pipe after passing over the burner and its arrival at the input of the drying chamber. It was found that there is great loss of temperature, being: 23.47 ºC in T1, 38.22 ºC in T2 and 37.01 ºC in T3. In this case, the inefficiency is associated to the thermal insulation applied to the heated air passage pipe, losing part of the thermal energy to the environment.

The correction of problems in the insulation and improvement in the efficiency of the heating system generate new important hypotheses, such as an increase in operating temperature, increase in the volume of the drying chamber, increase the air velocity and decrease in the amount of biogas required for system operation. All these factors could thus increase the potential use of biogas.

5 CONCLUSION

The use of thermal energy from biogas has proved to be effective for the designed system, meeting the temperature ranges applied in the drying of a wide variety of medicinal plants. The biogas with 60.00% CH_4 generated 3.61 MJ h^{-1}, 6.90 MJ h^{-1} and 7.60 MJ h^{-1} for T1, T2 and T3 respectively in the heating system supplying the power for operation of the drying chamber at temperatures of 43.05 °C (T1), 52.56 °C (T2) and 53.56 °C (T3).

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