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Research Article

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Biogas production from corn silage and sludge

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Abstract Climate change has adverse effects on the quality and quantity of plants in general and those of energy crops in particular used for biogas production. The purpose of the study is to improve the amount of biogas obtained through energy crops. In order to limit the damage caused by climate change on the production of biogas from energy crops, it was proposed to determine the quantity of biogas produced by corn silage and the sludge chosen instead of water.

0.8 L of sludge were introduced with 150 g of corn silage or 151.15 g of dry organic matter (DOM) which allowed us to obtain 49.5 L of biogas including 29.7 L of methane (CH_4) *i.e.* a content of 60%. These values brought back to the standards give 46.9 NL of biogas and 28.2 NL of CH_4. The corrected volumes give 46.4 NL of biogas and 33.9 NL of CH_4, *i.e.* a percentage of 73%.

Keywords biogas, energy crops, co-digestion, climate change

Introduction

Energy crops, representing 41% of substrates, are increasingly used for the production of biogas [1]. Among these crops, maize occupies 78% in its ensiled form [2]. Silage allows better production because it is more easily degraded by bacteria during fermentation.

The use of energy crops is threatened by the effects of climate change on the quantity of production as well as the quality of plants. The increased increase in temperature limits the growth of the plant and decreases the key elements for the good production of biogas.

In the next 30 to 50 years, the expected temperature change is expected to be in the range of 2 to 3°C and could reach 6.4°C by the end of the century [3]. Maize yield increases until the temperature reaches 29°C and continuously decreases above this temperature. A warming of 1°C decreases the yield by 2 to 9%. An increase of 1°C, 2°C and 3°C respectively reduces the yield by 10%, 14% and 21% [4].

To increase the yield of biogas produced from plants, several methods have been proposed, including silage, which is a wet method of preservation through anaerobic fermentation.

Co-digestion is also often used for a better yield, especially in methane. Co-digestion has many advantages: dilution of the toxic substance from one of the substrates involved, better balance of nutrients, synergistic effects on microorganism, high rate of digestion and possible detoxification based on the co-metabolism process. Animal waste, particularly cow dung has an average C/N ratio of around 24, plants such as cereal straws contain a high percentage of carbon so the C/N ratio is also high. Materials with a high C/N ratio can be mixed with those with a low C/N ratio to bring the mix ratio down to a desirable C/N ratio [5].

Sludge, which is an excellent substrate rich in methane, the content of which varies from 75 to 80%, is often put into co-digestion [6]. Thus several studies have been made on the co-digestion of corn silage and sludge in the presence of water considered essential.

However, the production of biogas without water is rare, if not almost not realized. In our study, corn silage is only mixed with mud without using water in order to obtain a better yield. In the first part we will present the material as well as the experimental protocol.

In the second part we present the results obtained followed by the discussion before drawing a conclusion.

Materials and Methods

This experimental part was carried out at the biomass laboratory of the University of Technical Application THM of Giessen in Germany.

The main substrate used is corn silage, which is the most widely used substrate in this country, so we can easily obtain it on site in its natural or ensiled state. The fodder is first chopped into particles whose length is around one cm, then compacted using a tractor in order to expel as much interstitial air as possible and finally placed in definitive anaerobiosis by covering it with a tarpaulin. of polyethylene. We used sludge instead of water in order to hope for a better yield because sludge is known to be a good substrate due to its high production of biogas and methane.

The ovens

To determine the dry matter, a Memmert UNB 500 type oven whose temperature varies from 5 to 220 °C and whose volume is 108 L is used, the substrate is placed in a test tube whose mass of l together was determined beforehand before being introduced into the oven and brought to a temperature of 105°C. 24 hours after the tube is removed and weighed again, the difference in mass corresponds to the mass of water evaporated.

Figure 1: Oven Memmert UF 260 (505 °C)

Similarly, another oven of the Memmert UF 260 type (Figure 1) with ventilated convection, with a volume of 256 L and the temperature of which is raised to 505° C., is used to determine the content of organic matter and mineral matter. Figure 2 is an internal view of the oven.

The substrate obtained after drying at 105°C is ground before being weighed and put in the oven where it will remain for 2 to 3 days, a part is recovered in the form of ash also called mineral matter and the evaporated part constitutes the organic matter whose mass is determined by weighing.

Figure 2: Inside view of oven UF 260

The ultra-centrifugal grinder

For the determination of the ash and organic matter content, the substrate after having been dried at 105°C is transformed into powder. Processing is done using a Retsch ZM 200 ultra-centrifugal grinder as shown in Figure 3. This device has the ability to transform dry corn silage into powder. Thanks to this transformation, the product obtained is more easily usable from the point of view of transformation into ash but also easier to analyze when taking samples. The powdered dry maize obtained is introduced into the oven and brought to a temperature of 505°C in order to determine its MM content.

Figure 3: Centrifugal grinder

Elementary analyzer CHNS/O

To determine the percentage composition by mass of the various elements contained in corn, a CHNS/O thermo research elementary analyzer was used. The proportions of carbon, hydrogen, sulfur and nitrogen were determined, while that of oxygen was obtained by difference.

Approximately 5 mg of crushed corn was placed in a tin capsule which contained an oxidant before combustion in a reaction at 1000°C. This led to a violent reaction creating a condition where all resistant substances became completely oxidized.

The resulting products were passed through high purity copper at 500°C to rid the process of any oxygen that was not completely consumed during the combustion process. It is necessary to use high-purity substances during CHNS/O analysis for oxidation purposes and to remove unwanted materials that may interfere with analytical results.

Complete oxidation was ensured using tungsten trioxide and copper downstream of the combustion chamber. Combustion products such as carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) obtained after analysis were all separated by gas chromatography and the elements measured with a detector of thermal conductivity.

The digesters

The digesters are small prototypes of about 1000 cm^3 equipped with a thermometer to control the temperature and also a stirrer to homogenize the mixture. Digestion is of the mesophilic type because the temperature varies between 25 and 27°C. Figure 4 shows the digester fitted with a thermometer. The biogas obtained is collected in insulated bags which will be transported to the volumeter and the gas detector to deduce its composition and the volume of gas produced.

Figure 4: Digesters

The volumeter and the gas analyzer

The biogas obtained is routed to the volumeter every 3 days in order to know its volume and also its composition. The ADOS multi-channel gas and biogas analyzer is the device used for the determination of the percentage composition of all the gases present in the biogas. Figure 5 illustrates the device giving the percentages of CH_4, CO_2, H_2, O_2 and H_2S. Similarly, the device supplies the volume of biogas contained in the tank.

Figure 5: Biogas analyzer and volumeter

Results and Discussion

Results

Determination of dry matter and organic matter

The dry matter content and the percentage of organic matter of the different substrates were determined while the percentage composition by mass was obtained only for corn silage. As a precaution, a double measurement was carried out for each substrate using two test tubes. Table 1 presents the results obtained before and after drying of all the substrates.

Let m_a be the mass of the vacuum tube, m_b that of the tube containing the substrate, m_c that of the assembly after drying at 105°C and m_d that of the assembly after calcination at 505°C.

Table 1: Mass in gram of the different substrates

Substrate	m_a	m_b	m_c	m_d
Corn	63.71	94.99	74.99	64.23
Corn	61.07	94.54	72.97	61.63
Sludge	68.17	83.34	73.27	68.74
Sludge	63.81	80.43	69.11	64.41

The percentage of dry matter (% DM) is given by the following formula:

$$\% \text{ DM}=\frac{mc-ma}{mb-ma}\text{x}100$$

The percentage of ash or mineral matter (% MM) is calculated as follows:

$$\% \text{ MM}=\frac{mc-md}{mc-ma}\text{x}100$$

The percentage of dry organic matter (% DOM) is deduced from the other percentages by the formula below:

% DOM= % DM*% MM*0,01

Table 2 gives us the results in MS, MM and MOS obtained at the end of the drying and by application of their formulas of determination.

Table 2: Percentage of dry, mineral and organic matter of the substrates.

Substrat	% DM	Average	% MM	Average	% DOM	Moyenne
Corn	36.06	35.8	95.39	95.3	34.40	34.1
	35.55		95.29		33.86	
Sludge	33.62	32.8	88.82	88.7	29.86	29.1
	31.89		88.68		28.28	

Percentage composition of corn silage

For more details, three samples of ground corn of 5 mg each were analyzed and the results obtained are given in Table 3. We note the strong presence of the carbon element, probably due to the effect of silage, followed by the element oxygen and hydrogen.

Nitrogen and sulfur are present in trace form and the presence of the latter projects the appearance of hydrogen sulphide and ammonia in the biogas as shown by the Buswell equation.

Table 3: Percentage of different elements

	% C	% O	% H	% N	% S
Sample 1	91.7	6.5	1.4	0.3	0.1
Sample 2	89.3	9.5	0.8	0.3	0.1
Sample 3	89.5	9	1.1	0.3	0.1
Average	90.2	8.3	1.1	0.3	0.1

Determination of the amount of biogas and methane

The anaerobic digestion tests took place from June 18 to July 10, 2014. In the digester 0.8 L of sludge were introduced with 150 g of corn silage or 51.15 g of MOS. Readings are constantly taken in order to have an idea of the quantity of biogas produced and the variation in composition over time. The volumes in liters of biogas, of methane and the temperature variation are recorded respectively in Table 4. Table 5 gives the variation of the different biogas compounds as a function of time.

Table 4: Volume of biogas and methane in liters in the digester

Date	Temperature °C	Volume of biogas	Volume of methane
18/06	25	0	0
23/06	26	37	20
26/06	26	40.5	24.7
30/06	26	42.8	25.7
10/07	27	49.5	29.7

Table 5: Variation in the composition of the biogas in the digester.

Date	% CH_4	% CO_2	% O_2	% H_2	% H_2S
18/06	0	0	0	0	0
23/06	54	35	1,3	0,01	0
26/06	61	25	1,8	0	0
30/06	60	23	0	0	0
10/07	60	23	0	0	0

Volume in normal liters

In international standards, the volume of biogas is expressed in normal liters or normal liters, which is the volume reduced to normal conditions of temperature and CNTP pressure. To obtain the normal volume in liters, the following formula is used:

$$NL = V(L)\ \frac{(Pb - PH2O + Pgaz)}{1013(Tgaz + 273)}$$

NI: Volume in normal litre.
Pb: Atmospheric pressure.
PH2O: Water pressure given by the pressure table (table 6)
Pgas: Gas pressure.
Tgas: Gas temperature.
V(I): Volume of gas in liters.

Table 6: Table of water pressure according to temperature

Temperature °C	Pression (hPa)	Temperature °C	Pression (hPa)	Temperature °C	Pression (hPa)
5	8.72	15	17.04	25	31.67
6	9.35	16	18.17	26	33.60
7	10.01	17	19.36	27	35.64
8	10.72	18	20.62	28	37.78
9	11.47	19	21.96	29	40.04
10	12.27	20	23.37	30	42.41
11	13.12	21	24.85	31	44.91
12	14.01	22	26.42	32	47.53
13	15.00	23	28.08	33	50.29
14	15.97	24	29.82	34	53.18

Table 7: volumes of biogas and methane in normal liters

Date	Temperature °C	Volume of biogas	Volume of methane
18/06	25	0	0
23/06	26	35.1	19
26/06	26	38.6	23.5
30/06	26	40.4	24.3
10/07	27	46.9	28.2

Corrected gas volume

Biogas is made up of several gases, the main ones being methane and carbon dioxide. Some gases are present there in trace form, such as dihydrogen and hydrogen sulphide which is responsible for its smell, others not being considered as sewer gases are present there by default, such as nitrogen and oxygen. These gases should not in principle appear in the final composition, they must therefore be removed from the final percentage. Table 8 gives us the corrected volumes of methane and biogas.

$$A = \%H_2 + \%CO_2 + \%CH_4 + \%H_2S$$

$$N_2 = 100 - (A + \%O_2)$$

$$\%CH_{4\ corrected} = \frac{\%CH4}{A} x100$$

$$\%CO_{2\ corrected} = \frac{\%CO2}{A} x100$$

$$\%H_{2\ corrected} = \frac{\%H2}{A} x100$$

$$\%H_2S_{corrected} = \frac{\%H2S}{A} x100$$

Table 8: Volume corrected in normal liter of maize silage

Date	Temperature °C	Volume of biogas	Volume of methane
18/06	25	0	0
23/06	26	34.64	21
26/06	26	37.9	26.3
30/06	26	40.4	29.5
10/07	27	46.4	33.9

Discussions

Table 4 shows the volumes of biogas and methane in liters obtained from the 3 weeks of testing. Corn silage produced 49.5 I of biogas including 29.7 I of methane with a content of 59% CH_4. As for the values brought back to international standards, that is to say in normal liters, the results are given by table 7 where the production is 46.9 NI in biogas and 28.2 NI in methane. The corrected volumes of biogas provided a greater quantity of methane because we do not take into account certain gases which are not considered as having to appear in the final composition of the biogas thus we obtain 46.4 NI of biogas and 33.9 NI of methane. For a retention time of 22 days, the percentage of methane varies from 54% to 61% the first 3 days before stabilizing at 60% for the rest of the tests. The characteristics of the two substrates, which are the percentage of dry matter, dry organic matter and percentage composition by mass, are presented in Tables 2 and 3. Maize has a DM content of 36%, 34% DOM and contains 90, 2% carbon. Carbon is the main constituent of methane and represents 75% of its mass, its strong presence in the starting substrate makes it possible to obtain a good yield in biogas and methane in particular. The DOM or volatile solid represents the quantity of degradable material of the substrate composed essentially of cellulose, hemicellulose and lignin. The high DOM content of a lignin-free plant substrate results in high methane production. The results on the characteristics explain the good yield in biogas and methane on the one hand. Maize is the substrate most used in the wide range of energy crops and therefore the one with the most publications. There are significant differences between the results obtained, which range from simple to double. These different results can be explained by the fact that the latter has several varieties, the harvest stage, the treatment method and the experimental conditions. 80% of methanizable products in Germany are made up of corn due to its high yield of biogas per tonne of fresh material and per hectare. For its use, corn is often ensiled before being introduced into the digester because it increases the yield.

According to Chandra [5], the maize plant has a potential of 338 I/kg DOM, i.e. a volume of 17.2 I of gas. This quantity can be improved by means of silage before methanization. Silage has a positive effect on maize production as it can improve yield by up to 11% [8].

According to Herrmann, the methane production by maize is between 342 and 378 NI/kg DOM. Asam [9] has shown that maize silage produces a quantity of methane of 680 I/kg of substrate or 236 I/kg DOM. He proved that silage provides 289 NI/kg DOM in CH_4 corresponding to a volume of 14.7 NI for 51.15 g of DOM against 225 NI/kg MOS for untreated green maize, i.e. a reduction of 25%.

According to Vervaeren [7] the methane potential varies from 280 to 420 I/kg DOM for maize and sorghum, i.e. a maximum of 21.4 I for a quantity of 51.15 g of DOM and from 230 to 380 I /kg DOM for other ensiled cereals. According to Amon, the amount of methane produced by maize at the milk stage varies from 312 to 365 NI/kg MOS against 268-286 NI for maize at full maturity. He argues that silage increases the amount of methane by 25%. Our values obtained during our experiment are above those found in the literature. The maximum value found in the literature for a quantity of DOM equivalent to that introduced into our digester is 21.4 I in methane, we were able to obtain a volume of 29.7 I. The only possible explanation for this observed difference is turns out to be the use of mud instead of water. Mud is known to be a good substrate and to have a good methanogenic potential sometimes reaching 70 to 80%.

Table 2 shows us the results of the analysis of this substrate where we see that it has values close to corn silage in DM (31.8) and DOM (28.28) and its use at the instead of water can achieve a high value of biogas and methane. It is a substrate rich in proteins and lipids representing 30 to 40% of the dry matter. Eva found a methane quantity of 310 Ncm^3/g SV from sludge under mesophilic conditions, a value close to that of maize silage [10]. While some argue that water is fundamental in anaerobic digestion, our experiments have proven the opposite by doing without it in favor of sludge, which has given us a better yield of biogas and methane.

Conclusion

Biogas production has aroused renewed interest in recent years due to the possibility of using renewable energy sources. Thus the work presented in this thesis is the subject of the impact of climate change on the production of biogas using energy crops as a substrate. We have seen the use of energy crops for the production of biogas which, nowadays, is one of the most widespread areas of use, especially in developed countries where a large part of arable land is allocated to this sector.

The rise in temperature, on the other hand, is detrimental to the growth of the plant and also causes a drop in the content of certain nutrients such as minerals. Their combined effects do not lead to compensation for losses caused individually. Thus the use of energy crops to produce biogas is in the future threatened by the fact that the key elements that microorganisms need to produce the latter are negatively affected by the effect of climate change in particular. This is the case of minerals and proteins, which some claim are responsible for the production of methane. Faced with this threat to the future of energy crops, solutions to deal with what can be a brake on their use are the subject of research.

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