Influence of the Initial Carbon/Nitrogen Ratio of the Substrate on the Production of Biomethane in a Continuous Reactor

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Abstract— The prediction of biogas production is based on different mathematical models of anaerobic digestion. Several models exist and make it possible to describe the anaerobic processes with a reduced number of parameters but especially with various methods of resolution, thus posing the problem of the precision of the results obtained. The present model is based on the AM2HN (Anaerobic Model N°2 Hydrolyse Nitrogen) model and predicts biomethane production from the initial C/N (Carbon/Nitrogen) ratio of the substrate. This model has been implemented in Scilab computational software through a classical Runge Kutta numerical resolution method of order 4. The model is then validated by performing a comparative study between the results from the model and those from the literature under the same conditions. Simulations and comparisons with the results from the scientific literature show that the numerical results are satisfactory with respect to the experimental data. In addition, the cumulative volume of simulated biomethane decreases slightly as the C/N ratio increases in a range of 10/1 to 14/1. On the other hand, for a C/N ratio ranging from 16/1 to 22/1, this volume increases progressively and peaks at 22/1. However, the cumulative volume decreases slightly as the C/N ratio increases beyond this optimal value. In agreement with the results of the literature, it appears from the present study that the optimal C/N ratio depends on the type of substrate to be treated and in the case of solid substrates, it is between 20/1 and 25/1.

Keywords: Methanation, Biogas, Modelling, Carbon/ Nitrogen, Methane

I. INTRODUCTION

The current global energy system is characterized by a dependence on fossil fuels. The consumption of fossil resources, whether for the production of goods or energy, causes an increase in greenhouse gases, which are the main cause of global warming [1].

Nowadays, the development of new energy sources has become a priority in the fight against climate change. There is growing interest in renewable energy from biomass, particularly biogas from the methanisation of organic matter. Anaerobic digestion is a natural process of decomposition of organic matter by anaerobic bacteria. This decomposition leads to the formation of biogas rich in methane (CH_4), thus forming a renewable energy source.

Anaerobic digestion still faces many challenges, although the process is already a relatively advanced and widely used technology for treating sewage sludge and wastewater [2-3]. However, given the complexity of the biochemical mechanisms and the specific experimental conditions of each bioreactor, there are some technical issues related to process instability, production optimization and optimal process operating conditions. In Benin, most of the digesters installed in rural areas for the production of biogas as a substitute for charcoal/firewood are shut down for the same reasons.

Modelling of the methanisation process is therefore an appropriate solution to overcome the problems of optimising biogas production.

Several mathematical models of anaerobic bioreactors have been proposed. The main models cited in the literature in terms of anaerobic digestion can be summarized as phenomenological and empirical models, models dedicated to the control and observation of anaerobic digestion systems [4-5-6].

This work fills a scientific and technical void in terms of predictive models of the performance of anaerobic digestion systems. Its goal is to prove how it is possible to increase the quantity and quality of biogas based on the C/N ratio of the substrate at the inlet of continuous digesters, without going through experimentation.

The main objective of this work is to optimize biogas production based on a predictive model by acting on the C/N ratio of the initial substrate.

The specific objectives are to model biogas production kinetics from biochemical reaction patterns and to study the influence of the C/N ratio on biogas production.

The interest of this work is to better understand the knowledge in the field of biogas production in order to contribute in an innovative way to the development of this very promising field.

II. MATERIALS AND METHODS

Dans In this work, we have numerically solved the differential equation system of the proposed model. For this purpose, the Scilab numerical solver software is used.

A. Anaerobic Digestion Steps Considered

Four steps are generally considered in the description of anaerobic degradation of organic matter (Fig. 1) [7]. These are hydrolysis, acidogenesis, acetogenesis and methanogenesis. In the present work we have chosen a macroscopic approach based on three main reactions [8, 9, 10]. This model follows a sequence of three successive steps in which the products formed serve as a substrate for the next step.

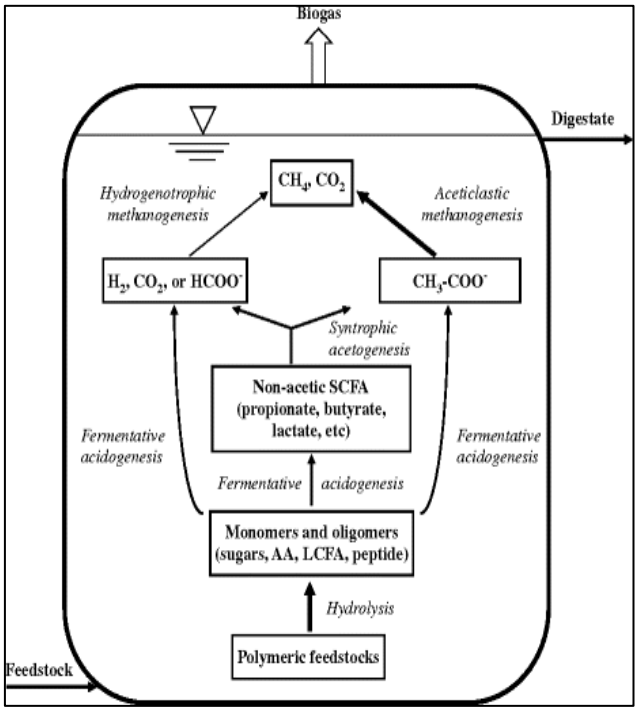

Fig. 1: Metabolic fluxes of anaerobic digestion [7].

1) Hydrolysis stage

The first step is that of hydrolysis, where the solid organic matter S_0 is transformed into soluble substrate S_1 according to the following biochemical reaction:

$$S_0 \rightarrow k_h S_1 \quad [8] \qquad (1)$$

2) Acidogenesis stage

The second step is acidogenesis modeled by a population of acidogenic bacteria that decomposes the carbonaceous S1 substrate into Volatile Fatty Acids and carbon dioxide. Volatile Fatty Acids are considered to be present only in un-ionized form and behave like acetic acid. The modelled biochemical reaction is therefore as follows:

$$k_1 S_1 \rightarrow X_1 + k_2 S_2 + k_4 CO_2 \quad [8] \qquad (2)$$

The growth rate used is that of Monod :

$$\mu_1 = \mu_{1max} \frac{S_1}{S_1 + K_{S_1}} \qquad (3)$$

3) Methanogenesis stage

The third reaction is that of the methanogenesis step, where the microorganisms X_2 grow at a specific rate by consuming the substrate S_2 at a rate proportional to the growth rate and producing methane and carbon dioxide as a product. This biochemical transformation is carried out by methanogenic bacteria according to the following equation :

$$k_3 S_2 \rightarrow X_2 + k_5 CO_2 + k_6 CH_4 \quad [8] \qquad (4)$$

The growth rate used is that of Haldane :

$$\mu_2 = \mu_{2max} \frac{S_2}{S_2 + K_{S_2} + \frac{S_2^2}{K_{12}}} \qquad (5)$$

B. Model assumptions

The mathematical description of the dynamics of the processes involved in biogas production is based on assumptions that defined the framework of the model and simplified the reaction equations by considering only the predominant phenomena. The assumptions made are as follows:

H_1: The predicted gas is composed mainly of CH_4 and CO_2, which are comparable to perfect gas.

H_2: Hydrogen production and consumption were neglected during the digestion procedures.

H_3: No carbon consumption for maintenance; all the carbon in the substrate is consumed by the microorganisms exclusively for their growth.

H_4: Methane is very poorly soluble and is instantly found in the gas phase.

C. Modelling of biological reactions

Organic substrates are carbonaceous substances and therefore their degradation is assimilated to the consumption of their organic carbon by microorganisms. The structure of the model is as follows:

$$C_{S_0} \rightarrow k_h C_{S_1} \qquad (6)$$

$$k_1 C_{S_1} \rightarrow X_1 + k_2 C_{S_2} + k_4 CO_2 \qquad (7)$$

$$k_3 C_{S_2} \rightarrow X_2 + k_5 CO_2 + k_6 CH_4 \qquad (8)$$

The mass balance equations of the model are written as follows:

$$\frac{dX_1}{dt} = (\mu_1 - \alpha D) X_1 \qquad (9)$$

$$\frac{dX_2}{dt} = (\mu_2 - \alpha D) X_2 \qquad (10)$$

$$\frac{dC_{S_0}}{dt} = D(C_{S_{0in}} - C_{S_0}) - k_h C_{S_0} \qquad (11)$$

$$\frac{dC_{S_1}}{dt} = D(C_{S_{1in}} - C_{S_1}) + k_h C_{S_0} - k_1 \mu_1 X_1 \qquad (12)$$

$$\frac{dC_{S_2}}{dt} = D(C_{S_{2in}} - C_{S_2}) + k_2 \mu_1 X_1 - k_3 \mu_2 X_2 \qquad (13)$$

Where C_{S_i} is the carbon content of substrate S_i , k_i is the stoichiometric coefficients, D is the dilution ratio and The parameter $\alpha \in [0, 1]$ represents the fraction of biomass leaving the reactor.

Methane flow is directly related to the growth of the methanogenic bacterial population.

Thus, we can write the following relationship :

$$q_{CH_4} = k_6 \mu_2 X_2 \qquad (14)$$

D. Modelling of phase transfer processes

In reality the degradation products are obtained in their soluble form. The gaseous products are then obtained by transfer from the liquid to the gaseous phase. Since methane is not very soluble and is instantaneously found in the gas phase, we have chosen to represent only the transfer of CO_2 from the liquid phase to the gas phase. For this purpose, two new variables are introduced. These are inorganic carbon C, consisting of CO_2 and bicarbonate B, and total alkalinity Z, which is defined as the sum of dissociated acids (bicarbonate and Volatile Fatty Acids) in the liquid phase. Thus we can write the following relationships:

$$C = B + CO_2 \qquad (15)$$

$$Z = B + C_{S_2} \qquad (16)$$

A mass balance done on inorganic carbon and alkalinity allows to write :

$$\frac{dC}{dt} = D(C_{in} - C) - q_{CO_2} + k_4 \mu_1 X_1 + k_5 \mu_2 X_2 \qquad (17)$$

$$\frac{dZ}{dt} = D(Z_{in} - Z) \qquad (18)$$

Where q_{CO_2} is the throughput of CO_2whose liquid-gas transfer dynamics is governed by the two-film theory:

$$q_{CO_2} = k_{La}(CO_2 - K_H P_{CO_2}) \qquad (19)$$

Using relations (15), (16) and (19) we obtain :

$$q_{CO_2} = k_{La}(C + C_{S_2} - Z - K_H P_{CO_2}) \qquad (20)$$

The partial pressure of CO_2 is calculated from the gas flow rates using Dalton's law:

$$P_{CO_2} = \frac{q_{CO_2}}{q_{CO_2}+q_{CH_4}} P_T \qquad (21)$$

By combining relations (20) and (21) we obtain successively:

$$P_{CO_2} = \frac{k_{La}(C+C_{S_2}-Z-K_H P_{CO_2})}{k_{La}(C+C_{S_2}-Z-K_H P_{CO_2})+K\mu_2 X_2} P_T \qquad (22)$$

$$P_{CO_2} = \frac{C+C_{S_2}-Z+\frac{k_6}{k_{La}}\mu_2 X_2+K_H P_T-\sqrt{\Delta}}{2K_H} \qquad (23)$$

$$\Delta = \left(C + C_{S_2} - Z - K_H P_T\right)^2 + 2\frac{k_6}{k_{La}}\mu_2 X_2\left(C + C_{S_2} - Z + K_H P_T\right) + \left(\frac{k_6}{k_{La}}\mu_2 X_2\right)^2 \qquad (24)$$

E. Integration of the Carbon/Nitrogen ratio parameter

By posing $C/N]_S = w$ we can write the following relationships:

$C_S = [N] \times [C/N]_S$ [11] (25)

$C_S = [N] \times w$ (26)

C_S: Substrate carbon concentration ;
[N]: Nitrogen content of the substrate;
w: Carbon/Nitrogen ratio of the substrate.

According to the approach used in this work, only substrate carbon is involved in the various reactions of anaerobic digestion. So the nitrogen content of the substrate remains constant during these different reactions. In this case, the variable C_S is replaced by [N]×w and w becomes the variable parameter of the model.

F. Differential equations of the model and matrix representation

By combining the equations from the modeling of biological reactions, the modeling of the phase exchange process and the C/N ratio parameter relations, we obtain a model composed of 9 first-order coupled ordinary differential equations. This model has 15 parameters μ_{1max}, μ_{2max} k_h, k_1, k_2, k_3, k_4, k_5, k_6, k_{La}, K_{S_1}, K_{S_2}, K_{I2} K_H, P_T as shown in the following system, in addition to the bacterial growth equations and CO_2 partial pressure.

$$(27):\begin{cases}
\frac{dX_1}{dt} = (\mu_1 - \alpha D)X_1 \\
\frac{dX_2}{dt} = (\mu_2 - \alpha D)X_2 \\
\frac{dw_0}{dt} = D(w_{0in} - w_0) - K_h w_0 \\
\frac{dw_1}{dt} = D(w_{1in} - w_1) + K_h w_0 - \frac{1}{N} k_1 \mu_1 X_1 \\
\frac{dw_2}{dt} = D(w_{2in} - [N]w_2) + \frac{1}{[N]} k_2 \mu_1 X_1 - \frac{1}{[N]} k_3 \mu_2 X_2 \\
\frac{dC}{dt} = D(C_{in} - C) - q_{CO_2} + k_4 \mu_1 X_1 + k_5 \mu_2 X_2 \\
\frac{dZ}{dt} = D(Z_{in} - Z) \\
q_{CO_2} = k_{La}\left(C + [N]w_2 - Z - K_H P_{CO_2}\right) \\
q_{CH_4} = k_6 \mu_2 X_2 \\
P_{CO_2} = \frac{C+[N]w_2-Z+\frac{k_6}{k_{La}}\mu_2 X_2+K_H P_T-\sqrt{\Delta}}{2K_H} \\
\Delta = \left(C + [N]w_2 - Z - K_H P_T\right)^2 + 2\frac{k_6}{k_{La}}\mu_2 X_2\left(C + [N]w_2 - Z + K_H P_T\right) + \left(\frac{k_6}{k_{La}}\mu_2 X_2\right)^2 \\
\mu_1 = \mu_{1max}\frac{[N]w_1}{[N]w_1 + K_{S_1}} \\
\mu_2 = \mu_{2max}\frac{[N]w_2}{[N]w_2 + K_{S_2} + \frac{([N]w_2)^2}{K_{I2}}}
\end{cases}$$

The matrix representation of the system of equations of the model is : Y'=f(Y,t) (28)

$f = [f_1 \ f_2 \ f_3 \ f_4 \ f_5 \ f_6 \ f_7 \ f_8 \ f_9 \ f_{10}]^T$

$Y = [w_0 \ X_1 \ w_1 \ X_2 \ w_2 \ Z \ C \ P_{CO_2} \ q_{CO_2} \ q_{CH_4}]^T$

$$(29)\begin{cases}
\frac{dw_0}{dt} = f_1(t,Y) = D(w_{0in} - w_0) - k_h w_0 \\
\frac{dX_1}{dt} = f_2(t,Y) = (\mu_1 - D)X_1 \\
\frac{dw_1}{dt} = f_3(t,Y) = D(w_{1in} - w_1) + K_h w_0 - \frac{1}{[N]} k_1 \mu_1 X_1 \\
\frac{dX_2}{dt} = f_4(t,Y) = (\mu_2 - D)X_2 \\
\frac{dw_2}{dt} = f_5(t,Y) = D(w_{2in} - w_2) + \frac{1}{[N]} k_2 \mu_1 X_1 - \frac{1}{[N]} k_3 \mu_2 X_2 \\
\frac{dZ}{dt} = f_6(t,Y) = D(Z_{in} - Z) \\
\frac{dC}{dt} = f_7(t,Y) = D(C_{in} - C) - q_{CO_2} + k_4 \mu_1 X_1 + k_5 \mu_2 X_2 \\
P_{CO_2} = f_8(t,Y) = \frac{C+[N]w_2-Z+\frac{k_6}{k_{La}}\mu_2 X_2+K_H P_T-\sqrt{\Delta}}{2K_H} \\
q_{CO_2} = f_9(t,Y) = k_{La}\left(C + [N]w_2 - Z - K_H P_{CO_2}\right) \\
q_{CH_4} = f_{10}(t,Y) = k_6 \mu_2 X_2
\end{cases}$$

G. Digital model resolution

The Runge Kutta method of order 4 is an explicit and efficient method for solving problems of ordinary differential equations with initial values. It guarantees a stable computing time. This method has been adopted for the numerical solution of ordinary differential equations because of its accuracy. This method induces a total error in $O(h^4)$ [12], where h is the discretization of the time interval.

The numerical scheme of the system represented by equation (28): $Y' = f(t,Y)$ and $Y(t_0) = Y_0$ has been solved for discrete instants $t_0 < t_1 \ldots < t_n$ by the Runge Kutta method, at intermediate points $\{(t_{n,i}, Y_{n,i})\}_{1 \le i \le q}$, which recursively calculates the values (t_n, Y_n), where $t_{n,i} = t_n + c_i h_n$, h_n being the time step and c_i being in the interval [0 ; 1].

For each intermediate point, the corresponding slope is $p_{n,i} = f(t_{n,i}, Y_{n,i})$ and for each time step h, the calculations followed the representations given by the set of equations of the system (30). The following value (Y_{n+1}) was approximated by the sum of the current value (Y_n) and the product of the interval size (h) and the estimated slope. The slope was obtained by the weighted average of the slopes, where k_1 is the slope at the beginning of the interval; k_2 is a slope at the middle of the interval (using the slope k_1 to calculate the value of Y at point $t_n + h/2$); k_3 is the slope at the middle of the interval (using the slope k_2 to calculate Y); and k_4 is the slope at the end of the interval (with the value of Y calculated using k_3).

$$30)\begin{cases}
Y(t+h) = Y(t) + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \\
k_1 = hf(t, Y(t)) \\
k_2 = hf\left(t + \frac{1}{2}h, Y(t) + \frac{1}{2}k_1\right) \\
k_3 = hf\left(t + \frac{1}{2}h, Y(t) + \frac{1}{2}k_2\right) \\
k_4 = hf(t + h, Y(t) + k_3)
\end{cases}$$

The algorithm used for the numerical resolution of the model is as follows:

– Construction of a "Runge Kutta 4" function.

Function parameters: (Y_0: initial condition; N: number of discretization points; h: time step).

– Initialization of the time step h and the initial conditions: t = 0 and Y = Y(0).
– Using the "for" loop
• Calculation of $k_1 = hf(t, Y(t))$
• Calculation of $k_2 = hf\left(t + \frac{1}{2}h, Y(t) + \frac{1}{2}k_1\right)$
• Calculation of $k_3 = hf\left(t + \frac{1}{2}h, Y(t) + \frac{1}{2}k_2\right)$
• Calculation of $k_4 = hf(t + h, Y(t) + k_3)$
• $Y(t) = Y(t) + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)$
• t = t + h ;
– Construction of a prediction function.
– Model inputs: initial conditions and model parameter values.
– Calling the "Runge Kutta 4" function.
– Model outputs: graph of the cumulative biomethane production and the respective proportions of CH_4 and CO_2.

Programs under the Scilab environment have been developed and implemented to simulate the operation of the digester and to validate numerical data. The results representing the numerical solution of the ordinary differential equations of the anaerobic digestion system have been plotted using the graphical user interface in Scilab.

H. Initial conditions and model parameters

The parameters and input conditions for the model were taken from the literature. These values are presented in the following tables.

Variables	w_{0i}	w_0	X_1	w_1	X_2	w_2	Z	C	P_{CO_2}	q_{CO}	q_{CH}
Initial values	25	0	1.42	0	1.12	0	10	50	0	0	0

Table 1: Input Conditions [6, 13]

Parameters	Significances	Values	Units
μ_{1max}	Maximum growth rate of the acid-producing population	0.33	j^{-1}
μ_{2max}	Maximum methanogenic population growth rate	0.13	j^{-1}
k_1	Yield of substrate degradation S_1.	20	gCOD gV S^{-1}
k_2	Production Yield of Volatile Fatty Acids	464	mmol gV S^{-1}
k_3	Degradation Yield of Volatile Fatty Acids	514	mmol gV S^{-1}
k_4	CO_2 production efficiency	310	mmol gV S^{-1}
k_5	CO_2 production efficiency	600	mmol gV S^{-1}
k_6	CH_4 production yield	253	mmol gV S^{-1}
K_{S_1}	Half-saturation constant associated with substrate S_1.	0.4	gCOD/L
K_{S_2}	Half-saturation constant associated with substrate S_2.	2.93	mmol/L
k_h	Hydrolysis constant	5	j^{-1}
K_{I2}	Inhibition constant associated with substrate S_2.	207	mmol/L
k_{La}	Gas/liquid volume transfer coefficient	24	j^{-1}
K_H	Henry constant	27	$mmol.L^{-1}.atm^{-1}$
D	Dilution rate	0,3	-

Table 2: Kinetic and phase transfer parameters [6, 13].

III. RESULTS AND DISCUSSIONS

A. Assessment of cumulative biogas production

The volume of biomethane is an important parameter for the control and monitoring of the anaerobic digestion process. The simulation result allowing to graphically visualize the temporal evolution of the cumulative volume of biomethane is presented in Fig. 2.

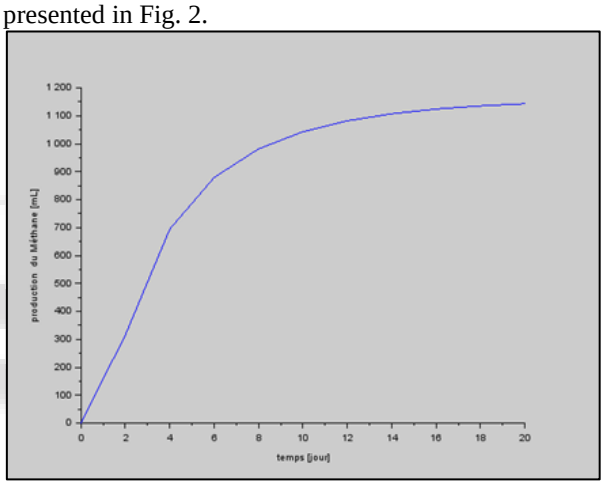

Fig. 2: Cumulative volume of biomethane.

For a residence time of 20 days, the volume of biomethane recovered is 1135.55 mL. We note that the kinetics of biomethane production can be subdivided into three main phases:

– Latency phase which corresponds to the adaptation of the microorganisms to their new culture medium. The duration of this phase is very short (0 to 2 days);
– Exponential growth phase: during this phase, the multiplication of microorganisms is optimal, which leads to a significant production of biogas (2nd to 14th days);
– Stabilization phase or terminal stage characterized by a stationary cumulative production of biomethane.

Moreover, the molar composition of the biogas produced by simulation of the present model is as follows: methane (84.72%) and carbon dioxide (15.28%).

These results clearly show the predominance of biomethane in the gas mixture, which gives the simulated biogas the combustible character with percentages of the same order of magnitude as those given in the scientific literature.

B. Influence of initial substrate C/N ratio

Quantitative and qualitative output was recorded after simulation of this model. We built up a database by varying this parameter between 10/1 and 28/1 with a step of 2 and noting the cumulative quantities of methane and the molar composition of the biogas in each case. The results are presented in the following table.

C/N)	10	12	14	16	18	20	22	24	26	28
V_{CH4}	720.29	695.88	544.55	706.86	723.69	724.35	725.07	718.01	701.06	694.46
% CH_4	86.11	84.73	84.25	87.30	87.51	87.43	87.30	87.16	87.02	86.89
% CO_2	13.89	15.27	15.75	12.70	12.49	12.57	12.70	12.84	12.98	13.11

Table 3: Recapitulation of biogas production as a function of C/N ratio

It is clear from Table 3 that the proportion of methane in the gas mixture predominates. The cumulative volume of simulated biomethane decreases slightly as the C/N ratio increases in a range of 10/1 to 14/1. On the other hand, for a C/N ratio ranging from 16/1 to 22/1, this volume gradually increases and peaks at 22/1. However, the cumulative volume decreases slightly as the C/N ratio increases beyond this optimal value.

These results are consistent with those in the literature. According to Yen and David [14], the optimal C/N ratio for co-digestion of algal sludge and paper waste is in the range of 20/1 – 25/1.

Also Li et al. [15], in a study on the assessment and modelling of biogas production from municipal fats, oils and greases and synthetic kitchen waste, showed that a high methane potential is obtained when the C/N ratio is in the range of 20/1 – 25/1.

Similarly, according to Lu et al. [16], C:N ratios between 17/1 and 24/1 gave better methane potential for co-digestion with pre-treated maize straw and cattle manure.

Thus, the initial C/N ratio of the substrate is a limiting parameter in the anaerobic digestion process and an imbalance in the C/N ratio may present risks of process malfunction. This study shows that the optimal C/N ratio depends on the type of substrate to be treated. In the case of liquid fermentations, the optimal value can go down to 15/1 and in the case of solid substrates, it is between 20/1 and 25/1.

C. Model Validation

For the same type of substrate, the numerical results of the present model were compared with the results of the work of Mottelet et al. [17] on the one hand and those of Guérin et al. [18] on the other hand. The experimental conditions are presented in the following table.

Figure 3 shows the evolution of the cumulative volume of biomethane as a function of time obtained with the proposed model and that obtained by Mottelet et al. while Figure 4 shows the evolution of the cumulative volume of biomethane as a function of time obtained with the proposed model and that obtained by Guérin et al. The simulated values and data from Mottelet et al. and Guérin et al. are presented in Table 4, along with the residual errors.

	Suggested model	Mottelet et al.[17]	Guérin et al.[18]
C/N ratio	8	8	8
Digester volume	500 mL	500 mL	500 mL
Temperature	35 °C	35 ± 0.2 °C	35 ± 0.2 °C

Table 4: Experimental conditions taken from the literature [19, 20]

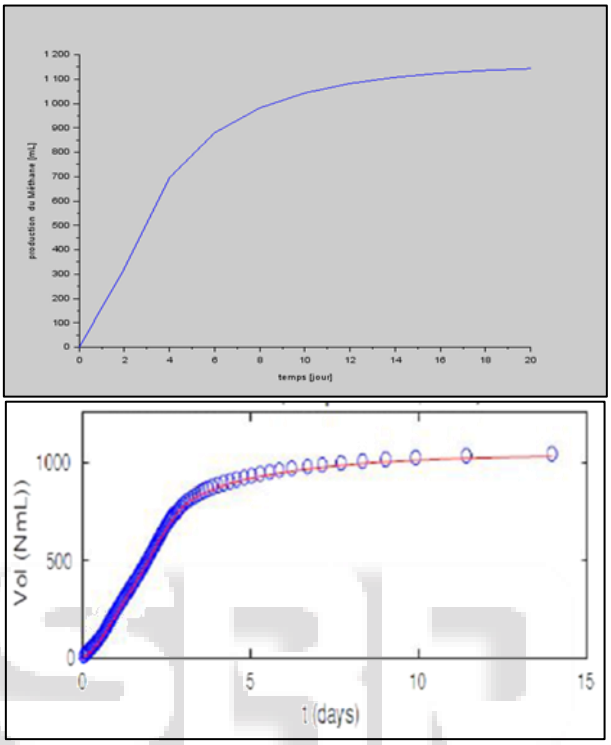

Fig. 3: Cumulative volume of biomethane obtained with the proposed model and that obtained by Mottelet et al. [17]

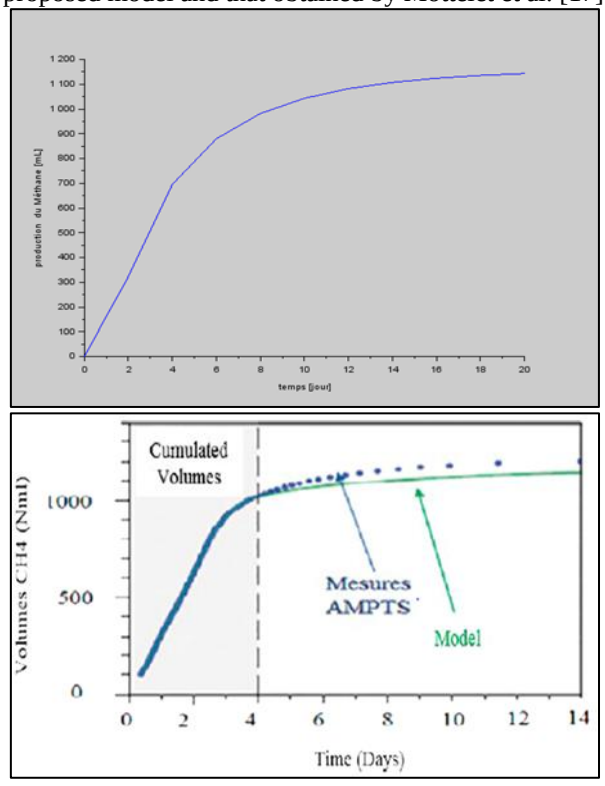

Fig. 4: Cumulative volume of biomethane obtained with the proposed model and that obtained by Guérin et al. [18].

	Cumulative volume of biomethane (mL)	Difference observed (mL)	Error (%)
Mottelet et al.	1050	50,58	4,82
Proposed model	1100.58	0,58	0,05
Guérin et al.	1100		

Table 5: Comparative study of numerical and experimental results from the literature.

We note that our results are close to experimental results from the literature. The comparison shows a good agreement of the curves obtained on the evolution of the cumulative volume of biomethane with errors of less than 5%. These discrepancies are justified by the fact that the values of the kinetic parameters of the proposed model were estimated from the ranges of values provided in the literature.

Considering the results given by the different simulations under Scilab environment and in comparison with the results drawn from the scientific literature, we can say that the proposed model has proven to be efficient for the prediction of biogas production.

D. Model Limitations

The limitations of this model are the values of the kinetic and phase transfer parameters that influence the results of the different simulations. These parameters are very difficult to determine due to the complexity of the biochemical mechanisms and the specific experimental conditions of each bioreactor. For this new model, these parameters have been estimated from the values published in the literature under experimental conditions that are not all similar.

IV. Conclusion and Prospects

Experimentation is the best solution to define methanization processes, unfortunately it remains very expensive. For this purpose, we have proposed a mathematical model governing the physico-chemical and biological phenomena of these processes. This model highlights the influence of the initial C/N ratio of the substrate at the digester inlet. From the analysis of the simulation results, it appears that the numerical results are satisfactory with respect to the experimental data. Moreover, the cumulative volume of simulated biomethane decreases slightly as the C/N ratio increases in a range of 10/1 to 14/1. On the other hand, for a C/N ratio ranging from 16/1 to 22/1, this volume increases progressively and peaks at 22/1. However, the cumulative volume decreases slightly as the C/N ratio increases beyond this optimal value. The present study shows that the optimal C/N ratio depends on the type of substrate to be treated and in the case of solid substrates, it is between 20/1 and 25/1.

We then plan to determine, through experimentation under very specific conditions, the kinetic and phase transfer parameters in order to study the combined influence of several operational parameters on biogas production.

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