CHEMICAL ENGINEERING TRANSACTIONS

VOL. 87, 2021

A publication of AIDIC

The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Laura Piazza, Mauro Moresi, Francesco Donsì

ISBN 978-88-95608-85-3; **ISSN** 2283-9216

DOI: 10.3303/CET2187050

Experimental Trials and Dynamical Simulation of the Potential Biogas Production in a Frozen Food Industry

Filippo Catalano[a], Biagio Bianchi[b], Antonio Berardi[c], Alessandro Leone[b], Antonia Tamborrino[b,*]

[a] Department of Biosciences and Territory, University of Molise, C.da Fonte Lappone – Pesche (IS), Italy
[b] Department of Agricultural and Environmental Science, University of Bari Aldo Moro, Via Amendola, 156/, Bari, Italy
[c] Dipartimento di Science Agrarie, Alimenti, Risorse Naturali e Ingegneria (DAFNE), Università degli Studi di Foggia, via Napoli, 25 – 71122 Foggia – Italy
antonia.tamborrino@uniba.it

Food industry determines the production of huge quantities of by-products, solid and waste. Identifying an ecological and economically viable solution for the management and disposal of horticultural wastes helps reducing the environmental impact of this kind of industries. In this paper a biogas production potential was obtained during one year of hourly data observation in a frozen food industry through dynamical simulation. This provides useful data for the correct management of an anaerobic digestion plant using the horticultural wastes coming from the production lines.The experimental analysis was carried out in an Italian cooperative firm, that process and market canned foods and frozen foods. Material flows were analysed especially considering the production of wastes. From the quantitative point of view, the hourly, daily, monthly, and annual flows of the single by-products of the studied processing cycle were determined. A dynamical simulation tool was developed to determine an optimized waste management procedure for biogas production. Design criteria was obtained for a biomass treatment to recover the organic substance for biogas production.

1. Introduction

Anaerobic Digestion (AD) is a biological process that transforms organic matter into biogas in the absence of oxygen, i.e. a mixture consisting mainly of methane and carbon dioxide (Fan et al., 2018). The methane content varies between about 50 and 75%, depending on the type of starting organic substance and the conditions in which the digestion process takes place (Gunaseelan, 2004).

In most biogas plants, various mixtures of raw materials are used simultaneously to stabilize the process and optimize the production of biogas. This technique is called co-digestion.

The typical raw material for biogas plants can come from vegetables and/or animals (Mane et al., 2015):

- animal waste (manure, slurry, dung)
- agricultural residues and by-products
- organic waste from food and agri-food industries
- food residues from catering services
- sewage sludge from waste water treatment plants
- dedicated energy crops (e.g. corn, sugar beet, grass)

In particular, there are various food industries that produce high quantities of by-products suitable for AD, especially horticultural wastes: in some cases, AD helps reducing the environmental impact of this kind of industries (Scarlat et al., 2018).

In this paper the possible reuse of wastes from horticultural products, processed in a frozen food industry located in Molise (Italy), was evaluated. Main aim is to show how, through dynamical simulation, it is possible to overcome some problems, raised by the high variability of the waste feeding rate and materials potential, when studying the feasibility of AD plant in this context. To this aim biogas production potential was obtained during one year of hourly data observation in the studied industry through dynamical simulation (Perone et al., .2017; Catalano et al., 2020).

Paper Received: 26 August 2020; Revised: 16 March 2021; Accepted: 6 April 2021
Please cite this article as: Catalano F., Bianchi B., Berardi A., Leone A., Tamborrino A., 2021, Experimental Trials and Dynamical Simulation of the Potential Biogas Production in a Frozen Food Industry, Chemical Engineering Transactions, 87, 295-300 DOI:10.3303/CET2187050

2. Materials and Methods

In the studied food industry there are 3 production lines:
1) Leafy vegetables: spinach, chard, chicory and turnip greens (cubes, small plates or 2.5 kg bags)
2) Grilled and frozen zucchini, peppers, etc.
3) Minestrone: different types of vegetables are produced in rounds and cubes of various sizes (zucchini, carrots, celery, cabbage, leeks, potatoes, broccoli, cauliflower, asparagus).

All these processes produce a great amount of by-products, requiring their disposal. One of the most appropriate methods for the type of available by-products is that of anaerobic digestion aimed at the combined production of heat and electricity for self-consumption in the firm.

The sizing of an anaerobic digestion plant aimed at producing biogas must be carried out by evaluating the availability of biomass, whose chemical-physical characteristics change considerably according to the type of available product. The determination of the biogas potential is made on the content of dry matter (total solids) and on the content of organic matter (volatile solids). Moreover, the organic substance has a degradability value that depends on its composition. For example, the protein, lipid and carbohydrate fractions are more or less degradable and, for each family of organic compounds, a yield in biogas and methane can be estimated. It follows that the biomasses must have a fairly uniform flow throughout the year and the digester must be regularly fed with quantity and quality such as to respect the required hydraulic retention times, i.e. the number of days that the family of organic compounds remains and are optimally degraded in the digester itself.

In the studied plant different types of horticultural products are frozen and the total amount processed for one year is shown in Table 1. Methane (average) potential was recovered from different sources (BMU, 2012; Yan et al., 2017; Li et al., 2013; Mane et al., 2015; Garcia et al., 2019).

Table 1: One-year production and waste, and biogas potential in terms of methane production

Product	Raw materials (kg)	Waste (kg)	CH_4 potential (Nm^3/kg)	CH_4 production (Nm^3)
spinach	4,481,053	1,478,747	0.040	59,149
chard	1,506,317	406,705	0.040	16,268
turnip	236,826	71,048	0.040	2,841
broccoli	486,493	9,729	0.025	243
cauliflower	208,536	18,768	0.025	469
leek	119,473	2,389	0.025	59
curly endive	405,182	81,036	0.025	2,025
cabbage	128,876	10,567	0.025	264
zucchini	3,281,780	787,627	0.025	19,690
celery	98,510	1,970	0.010	19
potatoes	4,300,391	1,419,129	0.065	92,243
carrots	3,650,696	949,181	0.040	37,967
eggplant	580,405	139,297	0.025	3,482
TOTAL	19,484,538	5,376,193	-	234,719

A simple (static) analysis of these data leads to the wrong conclusion that the high amount waste useful for AD is always and regularly available. This seems confirmed by a good methane production that can be obtained from the waste, 234,719 Nm^3 against an annual consumption of 1,188,000 Nm^3, that is about the 20 % of the required gas. On the other hand, first of all we have to consider that there are about half of the cultivars giving very few waste or small methane potential, such as turnip, broccoli, cauliflower, leek, curly endive, cabbage, celery, and eggplant while the remaining cultivars allow to produce about the 96 % of the total methane. Moreover, these last cultivars are unevenly distributed throughout the year: all these considerations lead to the need of a more accurate analysis. This analysis was carried out calculating the methane produced by a hypothetical AD plant with a weekly sampling, considering again the methane potential shown in Table 1, through a dynamical analysis as outlined in Catalano et al., 2020. It was proposed for the first time, and applied, in that case to overcome the problems find when selecting and dimensioning a Combined Heat and Power (CHP) plant for the same industry.

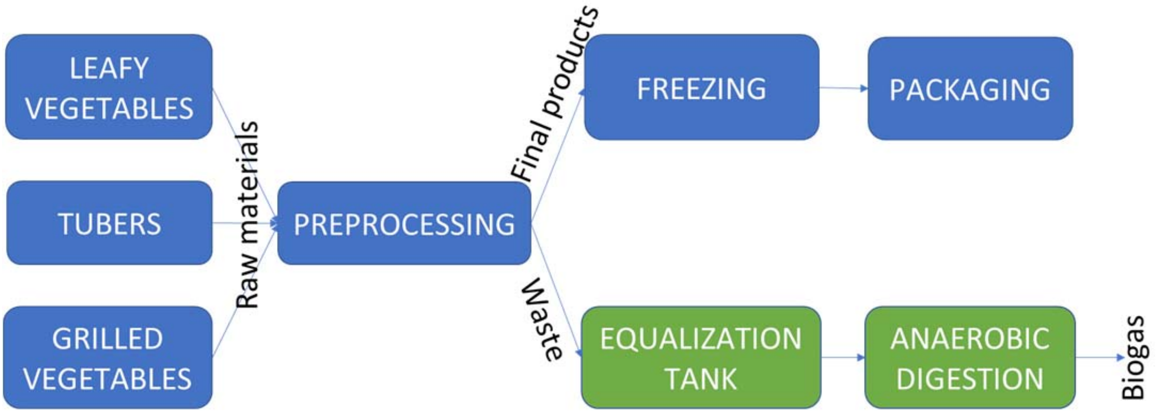

Figure 1: Scheme of the simulated waste treatment process. (blue blocks are existing processes, green blocks are simulated processes)

To this aim the production scheduling was hourly acquired throughout next year, and the weekly methane production was calculated simulating the presence of a tank to cumulate and equalize the waste flow rate. The scheme of the simulated plant is shown in Figure 1. Each process uses mass balance equations as shown in Catalano et al., 2020 (energy balance equations are not considered in this paper), and not repeated here for the sake of brevity.

3. Results

Figures 2 and 3 show respectively the trend of the cumulative production (i.e. summing the wastes of all cultivars for each observation interval) and the trend of the cumulative waste production. The result shown in Figure 3 is from a simulation carried out with only the existing processes (blue blocks in Figure 1) so it considers no equalization tank present in the plant.

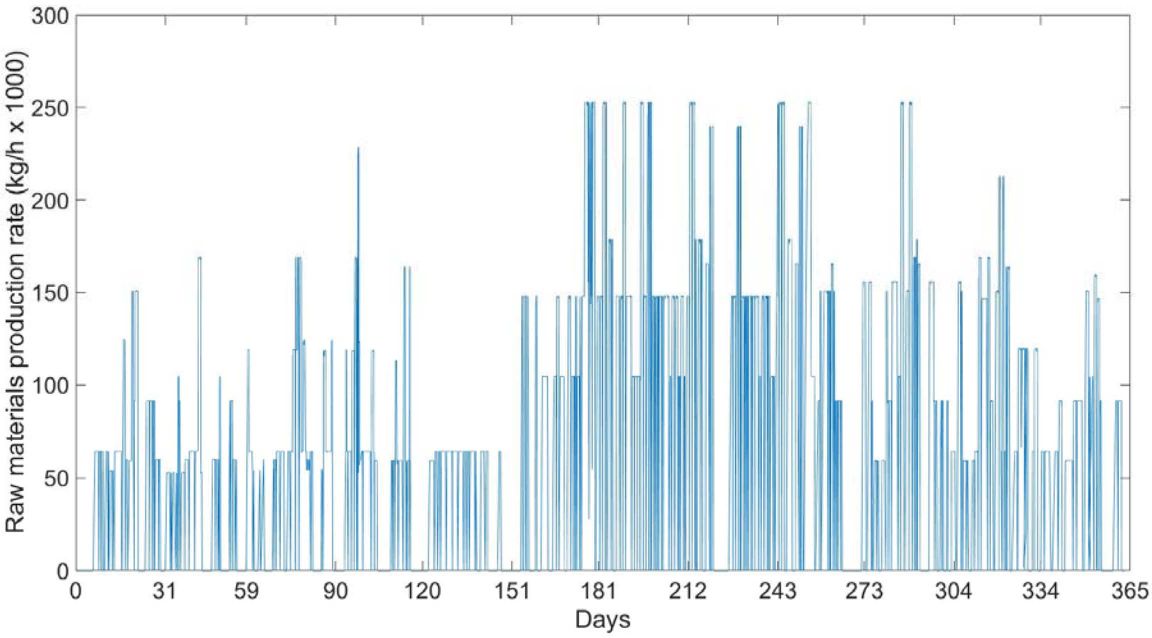

Figure 2: Trend of the raw materials production rate for one year

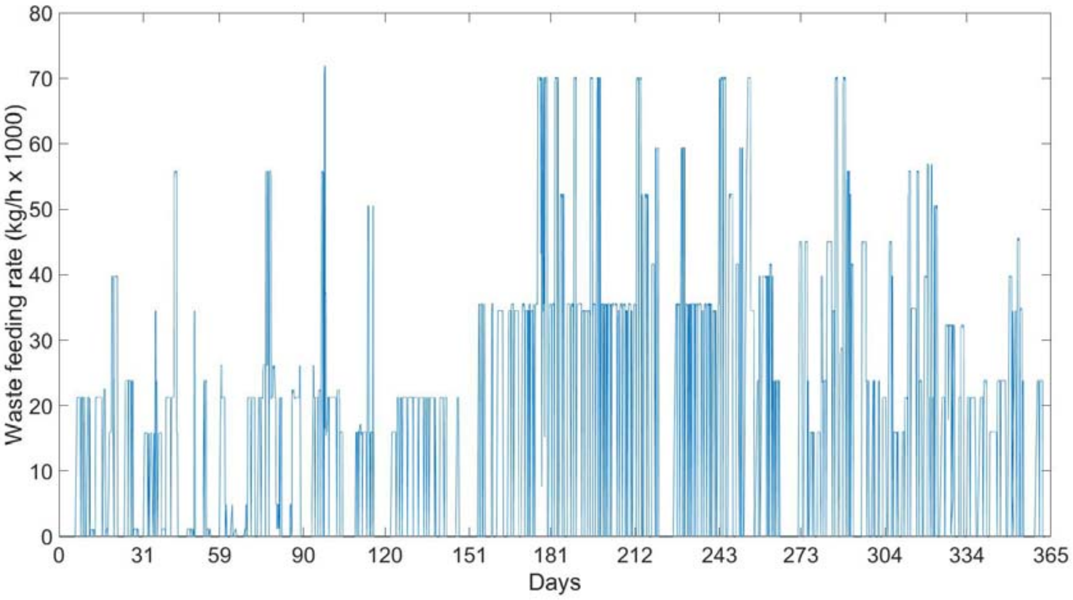

Figure 3: Trend of the waste production rate for one year

As regards raw materials even though we can highlight some variability in the production rate there are mainly two periods characterized by different mean production rate: 60-70 (10^3 kg/h) during winter and spring, 150-160 (10^3 kg/h) during summer and autumn. This variability could be easily addressed, but the great difference in the yield of individual products leads to a much greater variability in the waste production rate (Figure 3).

In fact, it is clear the higher variability of the available waste especially during the period winter-spring. This behaviour – high variability of raw materials and waste production rates - was already noticed in Catalano et al. 2020 leading to develop a new modelling technique, that uses the dynamical simulation approach.

In the present case we have a similar problem, and the simulation was repeated considering the presence of an equalization tank with a residence time of about one week as shown in the scheme in Figure 1. The result is shown in Figure 4.

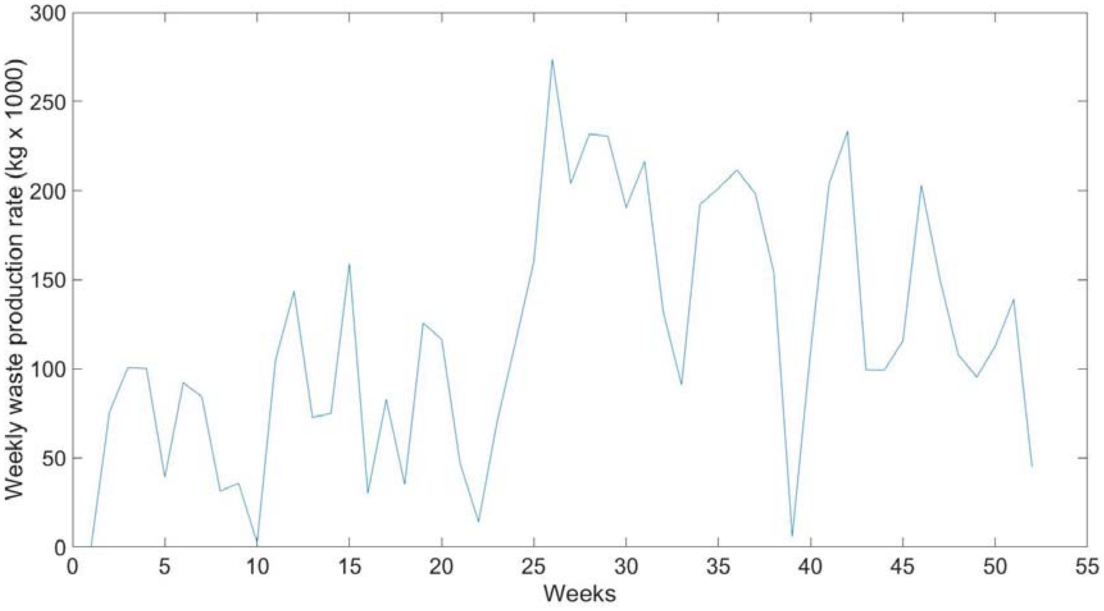

Figure 4: Simulated trend of the waste production for one year considering the use of an equalization tank

The trend of biomass feeding the AD is much smoother than that of waste entering the equalization tank. While it still changes more than required by a correctly operated AD process, the trend is slow enough (with a cycle between 3 and 5 days) to allow including further biomass feeding the digestor, e.g. using the sludge from the purification plant, or acquiring suitable biomass, e.g. manure from livestock farming, etc. This is even more necessary as the specific methane potential varies with the processed cultivars leading to the trend of weekly methane production shown in Figure 5.

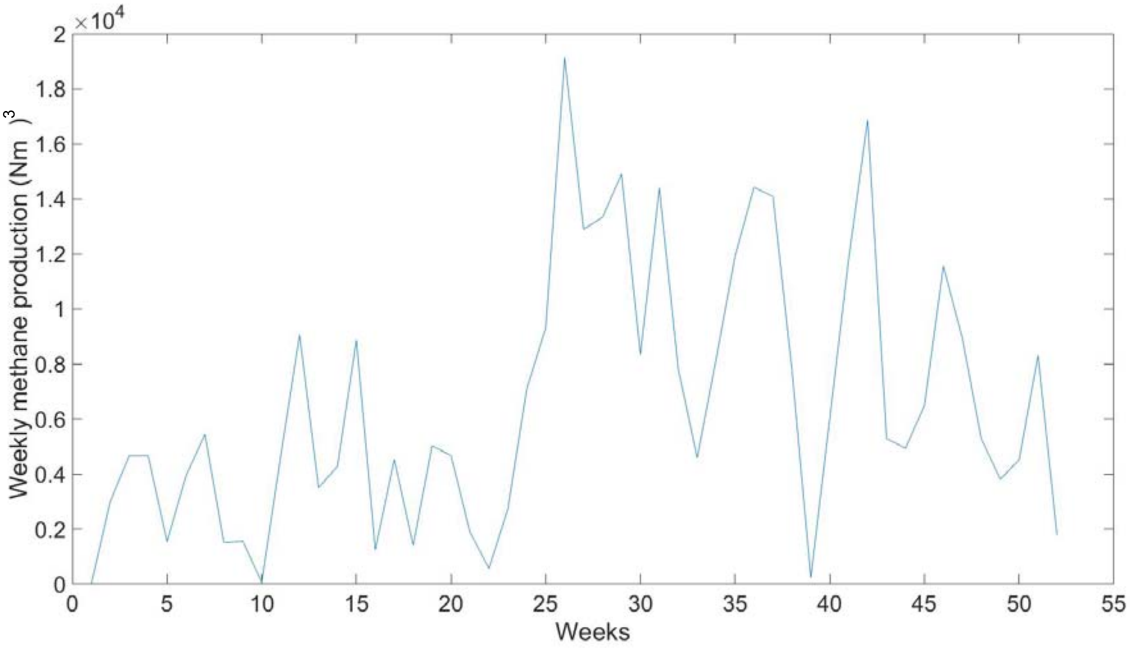

Figure 5: Simulated weekly trend of the methane production considering the use of an equalization tank

We have to notice that the most efficiently processed wastes are mainly produced during summer and autumn giving, on average, a higher methane production rate just during this period than in winter-spring.

4. Conclusions

In this paper a new modelling technique, based on the dynamical simulation approach, was used for the first time to study the feasibility of a biogas production plant. This plant uses wastes produced processing raw vegetables materials in a food freezing industry. The new approach, developed when selecting and dimensioning a CHP plant, comes from the need of overcoming the problems raised by the high time variability of the available waste amount and methane potential characteristics. In fact, it was shown that a static analysis leads to wrong conclusions about the true available methane potential for the AD plant, while, acquiring the waste production hourly, the variability can be dominated by introducing an equalization tank. The trend of methane potential in the final configuration was calculated using the proposed approach and suitable mass balance equations. This trend is smooth enough to give the chance of adding other biomass materials, coming from other by-products of the firm and/or acquired from livestock farming, etc.

This analysis represents an aspect of strong innovation for the company as it allows to evaluate the possibility of 'closing' the production cycle within the company itself through the direct recovery of by-products with energy production. As final consideration just some economic aspects that will be deepened in another paper. In any case, the economic evaluation must consider the production performance: process duration, biomass conversion yields, electricity self-consumption, etc. must be estimated considering average values for 15 years and not only in the first years of plant operation, typically higher. In the business plan, manpower, insurance, plant maintenance and extraordinary investments must be considered over the years to keep the plant efficient.

Acknowledgments

The authors have contributed to the same extent to the present study.

References

Aybek A., Serdar Ü, 2017, Biogas and methane productions of vegetable and fruit wastes with Hohenheim Batch Test method Vol. 10 No.4 209

BMU, 2012, Biomass Ordinance (BiomasseV) (as amended as of 1 January 2012); Federal Ministry for the Environment, Nature Conservation and Nuclear Safety; Germany;

Catalano F., Perone C., Iannacci V., Leone A., Tamborrino A., Bianchi B. 2020. Energetic analysis and optimal design of a CHP plant in a frozen food processing factory through a dynamical simulation model. Energy Conversion and Management, 225 (2020), 113444. doi.org/10.1016/j.enconman.2020.113444.

Fan Y.V., Lee C.T., Klemeš J.J., 2017, Challenges for energy efficiency improvement anaerobic digestion (AD), Chemical Engineering Transactions, 61, 205-210

Fan Y.V., Klemeš J.J., Lee C.T., 2018, Pre- and post-treatment assessment for the anaerobic digestion of lignocellulosic waste: p-graph, Chemical Engineering Transactions, 63, 1-6

Garcia N.H., Mattioli A., Gil A., Frison N., Battista F., Bolzonella D., 2019, Evaluation of the methane potential of different agricultural and food processing substrates for improved biogas production in rural areas, Renewable and Sustainable Energy Reviews, Volume 112, 1-10

Gunaseelan V.N., 2004, Biochemical methane potential of fruits and vegetable solid waste feedstocks, Biomass and Bioenergy 26, 389 – 399

Li Y., Zhang R., Liu G., Chen C., He Y., Liu X., 2013, Comparison of methane production potential, biodegradability, and kinetics of different organic substrates, Bioresource Technology 149, 565–569

Mane A. B., Rao B., Rao A.B., 2015, Characterisation of fruit and vegetable waste for maximizing the biogas yield, International Journal of Advanced Technologyin Engineering and Scince, Vol. 3, Special Issue 1, 489-500

Perone C., Catalano F., Tamborrino A., Giametta F., Bianchi B., Ayr U. 2017. Study and Analysis of a Cogeneration System with Microturbines in a Food Farming of Dry Pasta. Chemical Engineering Transactions, vol. 58, 2017, 499-504.

Scarlat N., Dallemand J.F., Fahl F., 2018, Biogas: Developments and perspectives in Europe, Renewable Energy 129, 457-472

Ya Y., Zhao C., Zhang J., Zhang R., Xue C., Liu G., Chen C., 2017, Study on biomethane production and biodegradability of different leafy vegetables in anaerobic digestion, AMB Epress 7-27