MOSTCH4 – Mini Onsite System to Valorize Manure into Methane

WPS 2.2: Monitoring

Technical report

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30 April 2024

Zusammenfassung

Mit WPS 2.2 sollte die beste Vorbehandlung von Gülle und Mist vor der Einspeisung in einen anaeroben Vergärungsprozess überprüft werden.

Als beste Vorbehandlung wurde die Kavitation der Biomasse ermittelt, die den doppelten Vorteil einer Homogenisierung der Biomasse und einer höheren Effizienz bei der anaeroben Vergärung mit sich bringt.

Der erste Vorteil ist besonders hervorzuheben, da das Hauptziel des «NOSES»-Projekts darin besteht, die Größe von Biogasanlagen zu verringern, damit sie auch in kleinen landwirtschaftlichen Betrieben gebaut werden können, ohne dass die Biomasse zu Konsortialanlagen transportiert werden muss.

Denn die Inhomogenität der Biomasse könnte bei kleinen Anlagen zu erheblichen Verstopfungsproblemen führen.

Résumé

Le WPS 2.2 avait pour but de vérifier le meilleur prétraitement du lisier et du fumier avant de les introduire dans un processus de digestion anaérobie.

Le meilleur prétraitement identifié est la cavitation de la biomasse, qui présente le double avantage d'une homogénéisation de la biomasse et d'une plus grande efficacité lors de la digestion anaérobie.

Le premier avantage est particulièrement appréciable car l'objectif principal du projet «NOSES» est de réduire la taille des usines de biogaz afin qu'elles puissent également être construites sur de petites ferme d'élevage, sans qu'il soit nécessaire de transporter la biomasse vers des usines de consortium.

En effet, l'inhomogénéité de la biomasse pourrait causer des problèmes de blocage très importants dans le cas de petites installations.

Summary

WPS 2.2 was intended to verify the best pre-treatment of slurry and manure before feeding them into an anaerobic digestion process.

The best pre-treatment identified is the cavitation of the biomass, which achieves the double advantage of homogenisation of the biomass and greater efficiency during anaerobic digestion.

The first advantage is particularly appreciable because the main aim of the «NOSES» project is to reduce the size of biogas plants so that they can also be built on small farms, without the need to move biomass to consortium plants.

Indeed, the inhomogeneity of the biomass could cause very significant clogging problems in the case of small plants.

Contents

Abbreviations

IBC = Iso Box Container

lt = litre

MOSTCH4 = Research project MOSTCH4: Mini Onsite System To valorize manure in methane; subsidized by INNOSUISSE project n. 27685.1

NOSES = Reactor not stirred and with biomass attached

PLC = Programmable Logic Controller

RT = Retention time

SUPSI BET = Scuola Universitaria Professionale della Svizzera italiana – Istituto microbiologia – Biotecnologie ambientali

VS = Volatile Solids

WPS = Work Packages

NCM = Normal Cubic Metre

1 Introduction

1.1 Background information and current situation

The main objective of this project is the size reduction of a reactor (digester) for the production of biogas from waste zootechnical biomass (manure and slurry). Such biomasses are normally inhomogeneous due to the presence of straw and impurities. Furthermore, coming from previous animal digestion, they are not particularly rich in Volatile Solids, which are the nutrients of methanogenic bacteria.
Before proceeding to the design and implementation of a new digester concept, it is necessary to verify whether there is a method of pre-treatment of the livestock biomass, which makes it effectively manageable by adduction pipes to the digester and by the digester itself, since there are small pipelines, which could present considerable congestion problems.
In addition, pre-treatment using energy should allow for a better digestibility of the biomass so that the increased production obtainable from it is not nullified by its own energy consumption.
That is, pre-treated biomass is required to produce energy in the biogas at least equal to that consumed for its pre-treatment.
To realise the second objective, the previous research project we conducted called MOSTCH4 had identified two particularly promising pre-treatments in the laboratory phase: Micro-Aeration and Cavitation.
Before proceeding with the start of the design of this new «NOSES» digester concept, it was therefore deemed useful and necessary to conduct preliminary research on these two pre-treatments with a monitoring phase in a pilot plant replicating the situation in a normal context.
This pilot plant for testing the two pre-treatments was therefore constructed and positioned at the dairy cattle barn at the Cantonal Agricultural School in Mezzana, Canton Ticino.
In this report, the results of this preliminary activity, which has been named WPS 2.2 MOSCH4, are presented.

1.2 Purpose of the project

The purpose of the activity WPS 2.2 - MOSTCH4 Monitoring was to verify whether at least one of the two pre-treatments of livestock biomass from a dairy cow barn shows an increase in biomethane production in an anaerobic digestion process following the said pre-treatments, compared to the biomethane production of the same biomass fed into an anaerobic digestion process without pre-treatment.
The two pre-treatments are: cavitation and micro-aeration.
<u>Cavitation</u>
The cavitation is defined as a sequential phenomenon of formation, growth, and collapse of cavities, within a liquid, resulting in very high local energy densities. In literature (Garuti et al. 2018; Langone et al. 2018) it has been successfully applied to disrupt the lignocellulosic fraction of manure rich substrates such as pig slurry and energy crops and cow manure.
<u>Micro-aeration</u>
Micro-aeration consists of insufflating a small amount of air into the biomass.
Air is blown in from the bottom of a tank where the biomass to be pretreated has been placed. The air in microbubbles bubbles into the biomass (Dry Matter 4-6%) producing a regulation of the microbial flora, in particular by promoting the development of oxygen-resistant microorganisms such as *Methanobacterium.* This regulation of flora leads to an increase in methane production or a reduction in methane production in the case of overdosing according to the literature (Rong et al. 2022). The causes

of the reduction in production have not yet been defined; they could be related to the development of microorganisms that develop non-methane fermentation processes.

1.3 Objectives

The object of the experiment consisted of analysing the production of biomethane in a pilot plant over a period of approximately 6 months in which three anaerobic digestion lines fed semi-continuously from the same biomass were operational. One of these lines was the reference line, simulating the operation of a normal CSTR digester, while the other two differed from the first because the biomass underwent the respective pre-treatments of cavitation and micro-aeration before being fed into the CSTR digester. In addition to the production of biomethane, the input biomass and output digestate from the three digestion lines were analysed to comparatively verify the level of reduction of Volatile Substances, as an indirect indicator of process efficiency.

2 Description of facility

The pilot plant consists of three digestion lines that are operated in parallel. Each line is fed from the same feed tank, which is located at the beginning of the process and ensures a homogenic and equal feed for all three process lines. The lines are built as following:

- The reference line consists on a single digester (500 lt) equipped with load cells for fill level monitoring, heater to maintain the optimal digester temperature, pressure sensor for gas volume conversion and a gas flow sensor to measure the produced biogas.
- The micro-aeration line consists of a micro-aeration reactor (100 lt) equipped with pH sensor, oxygen probe to monitor the O2 concentration, load cells to record the fill level and insufflation tubes connected to a compressor for oxygen supply. The out-flow of the micro-aeration reactor is connected to a digester (500 lt) with reference line specifications to allow comparison.
- The cavitation line consists of a cavitation loop made of the cavitator, an expansion valve and intermediate storage tank for recirculation. Downstream of the cavitator a digester (500 lt) with reference line specifications is located for the biogas production.

All digesters are connected to a gas quality analyzer (Awite, Germany). The produced biogas is analyzed in hourly intervals on its methane, carbon dioxide and oxygen concentration.
In addition the environmental gas composition is measured.
All reactors are connected to a central switchboard with a programmable logic controller (PLC) for the data acquisition, plant operation and a remote access module.
All the reactors and peripheric equipment is installed in a standard 20-foot container. As shown in Figure 2 the feed section is located near the principal door, whereas the digestors are located on the back end of the container. An outdoor fan and heater ensure stable temperature in the container and a gas sensor (methane/hydrogen) is installed to ensure the safety.

3 Procedures and methodology

How and when biomass was sampled, loaded and analysed

The Mezzana farm produces liquid manure that is normally separated at source to have slurry for spreading and separated solid that is used for bedding.
In order to recreate the conditions of the biomass as it is, periodically (approximately every 15 days) the slurry and the separated solid were taken from the barn and mixed in order to have the same total dry matter input for all lines. A decision was made to use 4%-6%.
The mixing of the two components was done by loading a 1 cubic metre container (Iso Box Container - IBC).
The biomass was then periodically taken from the IBC and fed into the loading tank that fed the three digestion lines.
At each loading of the IBC (approximately every 15 days) the biomass was sampled for laboratory analysis of the biomass.
The three digestion lines started to provide biogas production data from April 2023.
In the first period up to 10 July 23 a quantity of biomass of 20 kg per week was fed into each digester.
From 11 July until 31 January 2024, a quantity of biomass of 30 kg per week was loaded and discharged into the three digesters; this reduced the retention time of the plant to 35 days.
Three times a week, the amount of biomass required to load the three digesters (30 litres per line) was then taken from the IBC.
The biomass was pre-treated as follows:

- For Micro-aeration the pre-treatment lasted one week (100 litres tank loaded/unloaded for 90 litres per week).

- For Cavitation the pre-treatment lasted 2 minutes.

Digestate sampling method and timing

At approximately weekly intervals, the digestate coming from the 3 digesters was taken for analysis in the SUPSI laboratory.

Data collection methodology and final analysis

The monitoring data were collected and validated by SUPSI BET.
The granularity of the data collected by SUPSI BET was as follows:

- Biomethane production: hourly.
- Input biomass analysis: approximately every 15 days (IBC load)
- Digestate output analysis: approximately every week

Under Laborex's request, SUPSI BET then provided statistics of the daily biomethane production data and the Dry Matter and Volatile Solids data found in each laboratory analysis performed on the biomass input and digestate output from the process.
Laborex then summarised the above data to obtain correlations, which represented the result of the monitoring of WPS 2.2 from the point of view of the efficiency to be sought, in order to direct future steps towards the industrialisation of a small-scale agricultural and livestock biomass digestion plant.

4 Activities and results

Feasibility of installations in stables with livestock moving to alpine pastures

The first positive result that emerged from the monitoring of the Pilot concerns the answer to the question we asked ourselves as to whether the anaerobic digestion process can remain in operation even during the period of livestock moving to alpine pasture.
Well, the monitoring period went right through this period, and all three digestion lines proved that they could be kept in operation even in the absence of all the cattle that make up the herd at the Mezzana cantonal school's cowshed due to moving to alpine pasture.
This result was obtained using liquid manure accumulated before the departure of the herd and, even in the presence of non-fresh biomass, the three processes remained active in order to resume immediately with greater force when the herd returned in October.
This condition is of particular importance for the Swiss farming system in which herd summering is a very common practice, encouraged and incentivised by the Federal and Cantonal Agriculture Departments.

Plant reliability even at small dimensions

The second positive result concerns the smooth operation and reliability of the three digestion lines achieved despite their small size, which made us fear continuous blockages of the biomass transfer lines in the processes due to their non-homogeneity.
We already mentioned in the previous (internal) reports that the Pilot had already been activated for a period of three months prior to the present monitoring.
At that time, all the engineering limitations typical of a prototype became apparent and we were only able to start up the three digesters, which produced up to 4 litres per hour each. It was not possible at that time to also monitor the operation of the two pre-treatments, but it certainly highlighted all the possible improvements that could be implemented to increase plant reliability.
The current monitoring period showed that the Pilot's engineering implementations proved effective to the extent that the production results of the three lines provided comparable data for a continuous period of 293 days (30 March 23 to 1 February 24) with a percentage of validated data close to 95% of the total (279 / 293 days).
The Pilot operated semi-automatically, with operators only present on biomass loading and digestate unloading days.
There is a management routine for the loading and unloading of the three lines described in a special procedure and a record of the maintenance carried out.
The latter were limited to repair and replacement of small, easily and quickly solved wear parts.
It was therefore demonstrated that, even with such small dimensions, it is possible to have digestion processes in conditions and contexts similar to the real ones, which produce reliably and with relatively simple processes that can be further improved and automated.
Apart from the loads and discharges of biomass, the process is remotely controlled, with appropriate and effective alarm systems and limited tele-management.
Thus, the following statement has been verified:

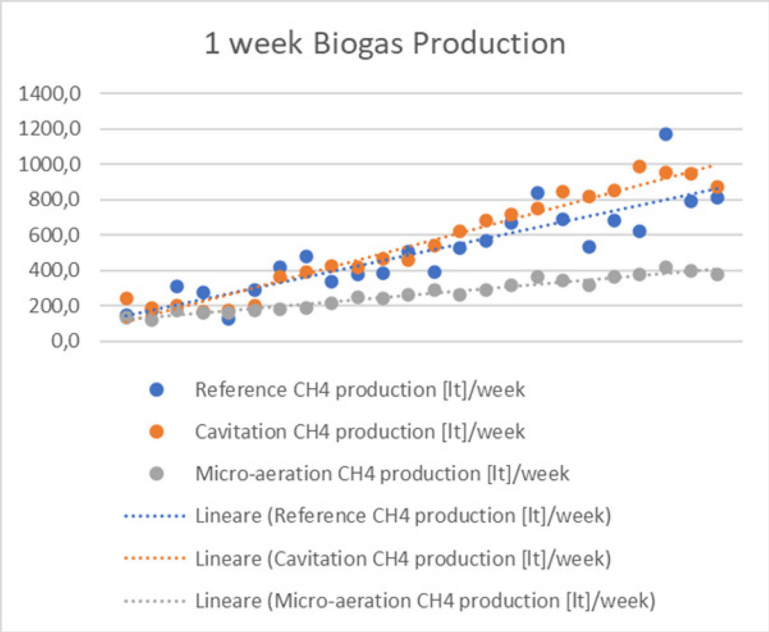
"The NOSES project intends to verify with a small-scale pilot that all this is technically feasible, that it is able to produce biogas with a degree of efficiency at least equal to that of medium-sized plants, and that it is reliable to the point of avoiding, even in such a small plant (the pilot plant), the clogging of loading and drainage pipelines and valves, which are one of the reasons for the greatest loss of production and the need for intervention even in large plants."

Biomethane production

Starting from SUPSI BET statistics on daily data on biomethane production in litres in the three digestion lines, the data were grouped into weekly productions, resulting in the following table

	period 1 week	Reference CH4 production [lt]/week	Cavitation CH4 production [lt]/week	Micro-aeration CH4 production [lt]/week
Jun	0612-0618	295,8	209,7	135,0
	0619-0625	159,0	204,9	116,1
	0626-0702	79,1	162,2	132,0
Jul	0703-0709	256,2	175,1	135,0
	0710-0716	209,5	217,5	269,3
	0717-0723	77,9	186,9	138,8
	0724-0730	288,3	202,5	155,1
Aug	0731-0811	274,6	179,0	173,2
	0812-0818	146,8	240,4	133,0
	0819-0825	173,0	186,5	119,2
	0826-0901	309,1	202,1	174,0
Sep	0902-0908	279,9	171,4	164,5
	0909-0915	128,7	172,4	163,3
	0916-0922	292,3	205,3	176,6
	0923-1001	416,0	362,2	183,2
Oct	1002-1009	480,0	392,0	187,3
	1010-1016	334,8	428,1	214,7
	1017-1023	377,3	421,2	247,7
	1024-1030	382,1	464,0	244,0
Nov	1031-1106	505,1	456,6	262,8
	1107-1113	394,0	542,6	291,9
	1114-1120	528,8	623,5	263,1
	1121-1127	568,1	685,3	292,9
Dec	1128-1204	670,1	715,1	318,5
	1205-1211	836,9	752,8	362,4
	1212-1218	689,8	846,2	342,3
	1219-1225	535,5	817,4	319,6
Jan	1226-0101	683,5	855,9	365,3
	0102-0108	619,6	987,0	376,5
	0109-0115	1169,9	951,7	417,2
	0116-0125	794,9	944,8	400,7
	0126-0201	813,8	873,7	380,9

The table shows increasing weekly production data for all three lines until December, then stabilising in January (when the process almost reached steady state).
The weekly data also show a higher production of cavitation than both the reference line and micro-aeration, the latter at values far removed from the first two.
The figure below graphically shows the statistical series and their respective linear regressions.



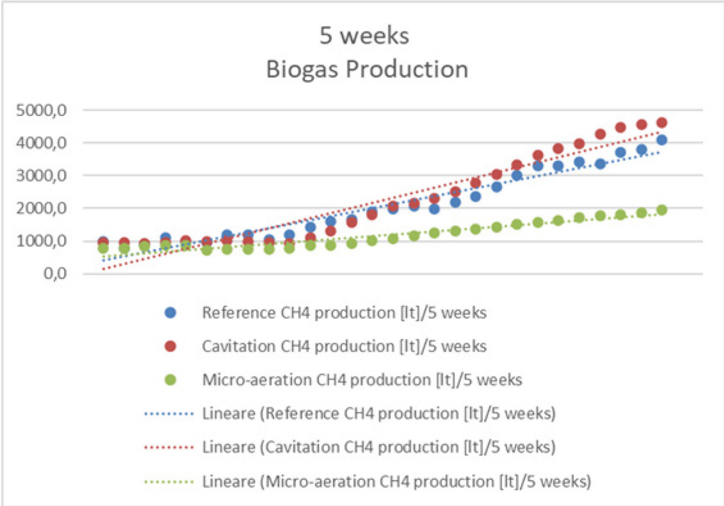
In the table below, the biomethane production data have been grouped by periods of time such that all the biomass in the digester is theoretically completely replaced by new biomass, i.e:

450 litres / 90 litres replaced per week = 5 weeks (RT retention time).

The production and efficiency data of the Pilot lines calculated over this period is the one that seems to us most logically comparable with that recorded in the laboratory phase.
Hence the following table emerges, which for each survey - data per line - sums up the production of 5 weeks.

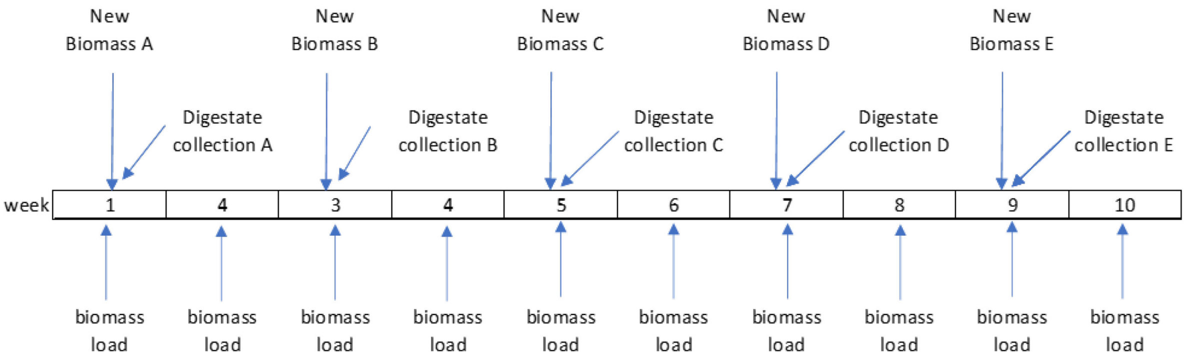
	Period 5 weeks	Reference CH4 production [lt]/5 weeks	Cavitation CH4 production [lt]/5 weeks	Micro-aeration CH4 production [lt]/5 weeks	Prod Cav / Prod Ref	Prod M-Aer / Prod Ref
Jul	0612-0716	999,7	969,3	787,3	-3,0%	-21,2%
	0619-0723	781,7	946,6	791,1	21,1%	1,2%
	0626-0730	911,0	944,1	830,1	3,6%	-8,9%
Aug	0703-0811	1106,5	960,9	871,3	-13,2%	-21,3%
	0710-0818	997,1	1026,2	869,3	2,9%	-12,8%
	0717-0825	960,6	995,3	719,2	3,6%	-25,1%
	0724-0901	1191,9	1010,5	754,4	-15,2%	-36,7%
Sep	0731-0908	1183,4	979,4	763,8	-17,2%	-35,5%
	0812-0915	1037,6	972,8	753,9	-6,2%	-27,3%
	0819-0922	1183,0	937,7	797,5	-20,7%	-32,6%
	0826-1001	1426,1	1113,4	861,6	-21,9%	-39,6%
Oct	0902-1009	1597,0	1303,3	874,8	-18,4%	-45,2%
	0909-1016	1651,9	1560,0	925,0	-5,6%	-44,0%
	0916-1023	1900,5	1808,9	1009,5	-4,8%	-46,9%
	0923-1030	1990,3	2067,5	1076,9	3,9%	-45,9%
Nov	1002-1106	2079,3	2161,9	1156,4	4,0%	-44,4%
	1010-1113	1993,3	2312,5	1261,0	16,0%	-36,7%
	1017-1120	2187,2	2507,9	1309,5	14,7%	-40,1%
	1024-1127	2378,0	2772,0	1354,7	16,6%	-43,0%
Dec	1031-1204	2666,1	3023,1	1429,3	13,4%	-46,4%
	1113-1211	2997,9	3319,2	1528,8	10,7%	-49,0%
	1114-1218	3293,7	3622,9	1579,2	10,0%	-52,1%
	1121-1225	3300,5	3816,8	1635,7	15,6%	-50,4%
Jan	1128-0101	3415,9	3987,3	1708,1	16,7%	-50,0%
	1205-0108	3365,4	4259,3	1766,1	26,6%	-47,5%
	1212-0115	3698,4	4458,2	1820,9	20,5%	-50,8%
	1219-0125	3803,5	4556,8	1879,4	19,8%	-50,6%
	1226-0201	4081,7	4613,1	1940,7	13,0%	-52,5%

The fourth and fifth columns show the percentage comparison of the Cavitation and Micro-Aeration lines with the Reference respectively.
From November onwards, one can see a tendency for Cavitation to produce on average at least 15% more than the Reference, while Micro-Aeration to produce about half as much as the Reference.
In the figure below, the same results are shown graphically.



Reduction in Volatile Solids

The data produced by SUPSI BET's laboratory analysis of biomass input and digestate output from the process made it possible to measure and compare the decrease in volatile solids in the three prototype lines. This comparison leads to percentage values of degradation of volatile solids, which are a precursor to the production of biogas and thus biomethane, but which may not accurately indicate the energy efficiency of the digester, as it is not certain that all the degraded volatile solids have been transformed into biogas and thus biomethane.
The image below schematically depicts the flow of the sampling scheme with which the set of biomasses and digestate parameters were measured and analysed.



At the end of monitoring, the laboratory analysis data were then analysed regarding the Total Solids and Volatile Solids of the biomass input common to all three lines and the digestate output different for the three treatment lines.
Since the biomass remained in the digesters for the 5-week retention period then, taking the above diagram as a reference, a correlation was made between the VS contained in the biomass loaded into the IBCs at the beginning of each 5-week period with the average of those present in the digestate analysed over the following 35 days.

$$\%VS_{reduction} = \frac{Average\ VS_{(digestate\ during\ 35\ days\ period)}}{VS_{(biomass\ at\ starting\ 35\ days\ period)}}$$

This indicator is independent of the biomass loaded from the IBC to the digester lines because this quantity is constant for the three digesters.
This indicator was calculated for each of the three digester lines of the prototype producing the following table.

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INPUT BIOMASSES					OUTPUT DIGESTATE																	
Analisys date	Load date + 35 days	Mix Biomasses loaded			MICRO-AERATION						CAVITATION						REFERENCE					
		ST %	SV/ST	kgSV	Analisys date	ST %	SV/ST	kgSV	kg/SV reduced		Analisys date	ST %	SV/ST	kgSV	kg/SV reduced		Analisys date	ST %	SV/ST	kgSV	kg/SV reduced	
04/07/2023	08/08/2023	5,1	84,16	0,64																		
18/07/2023	22/08/2023	5,01	80,28	0,60																		
02/08/2023	06/09/2023	5,43	83,97	0,68	02/08/2023	3,73	76,71	0,43	0,21		02/08/2023	3,84	77,92	0,45	0,20		02/08/2023	4,26	78,16	0,50	0,14	
					08/08/2023	3,35	76,45	0,38	0,26	0,24	08/08/2023	3,6	78,51	0,42	0,22	0,21	08/08/2023	3,9	78,74	0,46	0,18	0,16
14/08/2023	18/09/2023	4,94	81,68	0,61	14/08/2023	2,99	78,01	0,35	0,25		14/08/2023	1,37	64,74	0,13	0,47		14/08/2023	4,2	79,58	0,50	0,10	
					22/08/2023	2,78	75,45	0,31	0,29	0,27	22/08/2023	3,66	79,01	0,43	0,17	0,32	22/08/2023	3,17	76,68	0,36	0,24	0,17
29/08/2023	03/10/2023	4,28	77,51	0,50	29/08/2023	2,53	72,32	0,27	0,41		29/08/2023	2,93	76,78	0,34	0,35		29/08/2023	2,6	74,64	0,29	0,39	
					05/09/2023	3,67	78,18	0,43	0,25	0,33	05/09/2023	3,23	77,26	0,37	0,31	0,33	05/09/2023	3,58	78,17	0,42	0,26	0,33
12/09/2023	17/10/2023	4,81	72,85	0,53	12/09/2023	3,18	75,74	0,36	0,24		12/09/2023	3,46	67,85	0,35	0,25		12/09/2023	3,42	83,13	0,43	0,18	
					19/09/2023	3,55	73,01	0,39	0,22	0,23	19/09/2023	3,24	73,16	0,36	0,25	0,25	19/09/2023	3,54	74,88	0,40	0,21	0,19
26/09/2023	31/10/2023	4,52	84,46	0,57	26/09/2023	3,58	75,71	0,41	0,09		26/09/2023	3,26	75,94	0,37	0,13		26/09/2023	3,33	75,25	0,38	0,12	
					03/10/2023	3,3	71,39	0,35	0,14	0,12	03/10/2023	3,21	72,29	0,35	0,15	0,14	03/10/2023	3,81	75,87	0,43	0,06	0,09
10/10/2023	14/11/2023	5,7	81,47	0,70	10/10/2023	3,39	77,71	0,40	0,13		10/10/2023	3,22	77,41	0,37	0,15		10/10/2023	3,36	76,56	0,39	0,14	
					17/10/2023	3	76,99	0,35	0,18	0,15	17/10/2023	2,68	76,05	0,31	0,22	0,19	17/10/2023	2,82	75,64	0,32	0,21	0,17
24/10/2023	28/11/2023	5,58	80,74	0,68	24/10/2023	3,86	70,58	0,41	0,16		24/10/2023	4,23	79,16	0,50	0,07		24/10/2023	3,98	82,34	0,49	0,08	
					31/10/2023	2,78	77,11	0,32	0,25	0,21	31/10/2023	3,98	79,25	0,47	0,10	0,08	31/10/2023	3,82	78,47	0,45	0,12	0,10
07/11/2023	12/12/2023	4,6	86,3	0,60	07/11/2023	3,06	81,99	0,38	0,32		07/11/2023	3,5	76,9	0,40	0,29		07/11/2023	3,02	76,87	0,35	0,35	
					14/11/2023	3,32	73,48	0,37	0,33	0,33	14/11/2023	3,66	80,58	0,44	0,25	0,27	14/11/2023	2,64	84,88	0,34	0,36	0,35
21/11/2023	26/12/2023	4,79	83,28	0,60	21/11/2023	3,81	78,92	0,45	0,22		21/11/2023	3,06	78,31	0,36	0,32		21/11/2023	3,37	78,63	0,40	0,28	
					28/11/2023	2,33	76,85	0,27	0,41	0,32	28/11/2023	2,42	73,27	0,27	0,41	0,36	28/11/2023	2,42	77,72	0,28	0,39	0,34
05/12/2023	09/01/2024	5,16	84,49	0,65	05/12/2023	2,9	77,67	0,34	0,26		05/12/2023	2,67	77,23	0,31	0,29		05/12/2023	3,36	79,73	0,40	0,19	
					12/12/2023	3,89	74,9	0,44	0,16	0,21	12/12/2023	4,38	76,76	0,50	0,09	0,19	12/12/2023	4,43	80,92	0,54	0,06	0,13
					19/12/2023	3,93	77,61	0,46	0,14		19/12/2023	4,36	77,5	0,51	0,09		19/12/2023	3,92	79,33	0,47	0,13	
					27/12/2023	4,08	75,16	0,46	0,14	0,14	27/12/2023	3,92	78,77	0,46	0,14	0,11	27/12/2023	4,12	79,69	0,49	0,11	0,12
					02/01/2024	4,34	79,53	0,52	0,14		02/01/2024	4,23	80,19	0,51	0,15		02/01/2024	4,22	75,93	0,48	0,17	
					09/01/2024	3,65	78,47	0,43	0,22	0,18	09/01/2024	4,66	81,06	0,57	0,09	0,12	09/01/2024	4,4	79,95	0,53	0,13	0,15

The different colours in the table indicate the correlations between the Volatile Solids entering the digestion lines with the average of the two Volatile Solids analyses carried out on the digestate over the following 35 days.
Analyses that took place in the period from July to January in which the retention time of the biomass in the digesters was 35 days were taken into consideration.
By averaging the data by column, the following table is then obtained.

BIOMASSES	DIGESTATE								
	MICRO-AERATION			CAVITATION			REFERENCE		
kg VS for each load of 15 kg)	kg VS	kg VS reduction	% reduction	kg VS	kg VS reduction	% reduction	kg VS	kg VS reduction	% reduction
0,61	0,39	0,23	37%	0,39	0,22	36%	0,42	0,19	31%
	M-A vs Refer		**118%**	Cavitation vs Refer		**115%**			

A reading of the table confirms that cavitation is 15% more efficient than the reference also in terms of Volatile Solids reduction.
Micro-aeration appears to be the most efficient pre-treatment in terms of Volatile Solids reduction, with +18% compared to the reference and +3% compared to Cavitation.
This does not contradict the lower efficiency of micro-aeration in terms of biomethane production, but rather provides a possible explanation.
In the micro-aeration process, it seems logical to state that the concentration of oxygen present in the biomass favours aerobic bacterial colonies that transform it into methane gas or other gases (notably carbon dioxide), which are not conveyed to the gas analysis system and therefore are not counted, but at the same time reduce the nourishment of anaerobic methanogenic bacterial colonies in the subsequent digester.
This increased efficiency of the micro-aerator in its ability to reduce Volatile Solids is a feature that could be exploited in other fields, such as sewage treatment. However, it is a result incidental to the purpose of our industrial research, which would merit further analysis especially of the biogas produced in the micro-aerator. However, such analyses are beyond the scope of this project, and therefore in the following, micro-aeration will no longer be considered as an implementable pre-treatment technology in the planned small-scale biomethane production plant.

Energy Consumption

With regard to the energy consumption of the Cavitator in comparison to the energy produced contained in the biomethane, at the level of the Pilot plant, it is not possible to make a direct comparison between overall consumption (heater, mixer + cavitator) between the two Reference lines and the Cavitator, because the various energy-consuming components (heater and mixer) are oversized in terms of power compared to the plant's needs. On the other hand, further miniaturising each of these components, compared to the minimum size components on the market, would not have added much to the analysis, other than disproportionately increasing the cost of the Pilot itself.

We then carried out an indirect analysis of the energy consumption of the installed cavitator per kg of biomass treated and used compared to the energy content of a slurry/bovine manure with a dry matter content of 15%; which is the situation usually found in our stables.
From the count carried out, which I report in the table below, it appears that the cavitation of biomass consumes about 4.5% of the energy contained in the biomethane that can be produced.

weekly load	kg	90
average daily load	kg	12,86
days from 11/07/23 to 1/2/24	giorni	197
total biomass treated	kg	2533
Kwh used for cavitator	kWh	68,95
Cavitated biomass used	%	75%
one NCM CH4 enrgy content	kWh/Nmc	11,3
kWh used for cavitated biomass	kWh	51,71
kWh used for cavitation	kWh/kg	0,020
kWh producible per kg manure 15% dry matter	kWh/kg	0,45
Cavitation energy consumption on producible energy	**%**	**4,5%**

It can therefore be said that it is confirmed that there remains a higher efficiency of Cavitation over Reference even after subtracting the higher energy expenditure for the operation of the cavitator.
This net increase in efficiency is around 10%.
In previous reports, an estimated cavitation energy consumption of 11% was indicated.
The difference to the current calculation of 4.5% depends on two different calculation methods.
In the case of the previous reports, it was assumed that the electrical energy required to operate the plant is produced by a cogeneration system at the plant, and therefore the energy consumption is calculated on the chemical energy taken from the biomethane divided by the electrical energy yield of a cogenerator.
In the second case, however, counting is simply done on the electrical energy consumed divided by the chemical energy contained in the biomethane produced.
Assuming a cogenerator efficiency of 39%, the two differently calculated figures are reconciled.

Indeed:

$$4,5\% / 39\% = 11,5\%$$

5 Evaluation of results to date

WPS 2.2 - MOSTCH4 monitoring started in March 2023 with the start-up of the biodigesters by filling them with inoculum from a sewage sludge digestion plant.
Starting from 25 April, the loading of biomass slurry from the Mezzana barn began. In a first period until the end of May, a dry matter content of 2% was maintained by loading 20 kg twice a week. During this period, the functionality and reliability of the system was ascertained. From June onwards, the dry matter content was increased to 4-6% and from the beginning of July, the biomass loaded into each digester was increased to 3 weekly 30 kg loads, corresponding to a retention time of 35 days.

Since July '23, therefore, the loading conditions of the digesters have been at full capacity.

The biomethane production of the three lines has steadily increased over the period of measurement, slowing down in the last two months (horizontal asymptote)
In the last two months of the biomethane production measurement campaign, the following results were recorded:

1) The cavitation line shows a higher biomethane production than the reference line by at least 15%.
In contrast, the micro-aeration line produces about 50% less than the reference line

2) Analysis of the reduction of volatile substances over the entire period shows:
- A higher degradation capacity of volatiles of about 15% of the cavitation line compared to the reference line.
- An even greater degradation capacity of volatile substances - around 18% - of the micro-aeration line compared to the reference line.
- If in the first case, it can be assumed that the 15% greater degradation of SV resulted in greater biomethane production - confirming the production efficiency figure -, in the second case, on the other hand, it can be stated that the degradation of SV occurred due to aerobic bacterial colonies in the micro-aerator, which reduced the feeding of anaerobic and methanogenic colonies in the subsequent digester.

3) The measurement period for the initial 4 months of the herd's absence for moving to alpine pasture (summering) was conducted with previously stored biomass. In this way, it was shown that biomethane production can also take place in the case of herds summering.

4) The pilot plant proved to be relatively easy to operate and reliable, providing valid data for 95% of the days of the monitoring period

5) Albeit with an indirect calculation, it can be stated that the higher consumption of cavitation compared to the reference line is approximately 4.5% compared to the energy contained in the biomethane produced. Thus, a positive efficiency differential of more than 10% remains between the net energy production in an anaerobic digestion process preceded by biomass cavitation, compared to one without such pre-treatment.

6 Next steps

WPS 3 is currently underway, which concerns the design and construction of the NOSES pilot digester to be put in series with the MOSTCH4 pilot.

The design of NOSES has already been carried out and the selection of the supplier to be contracted for the construction is in progress.

The schedule of the WPS 3 activity foresees the testing of the NOSES pilot by the end of December 2024.

From January 2024 until June 2026, the monitoring activity (WPS 4) is planned to verify the efficiency and reliability of the digestion system consisting of the pre-treatment identified with the MOSTCH4 monitoring and the new NOSES digester.

7 National and international cooperation

The project was performed with the support of SUPSI BET, which managed the monitoring activities together with Laborex personnel. In addition, the SUPSI BET laboratory carried out the analysis of the biomass input and digestate.

All data from the Pilot PLC and the laboratory were collected and validated by SUPSI BET.

Maurizio Cavalli, PhD, a collaborator of Laborex's Italian branch, was involved in the analysis and processing of the data.

Dr. Maurizio Cavalli, PhD, has extensive experience in agricultural biogas plants gained in Italy and in research gained at the University of Milan.