OPERATIONAL RESULTS OF THREE BIOGAS PLANT IN ITALY

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1 INTRODUCTION

This paper presents the results of monitoring of three biogas plants with conversion to electrical energy carried out in the context of the project EU LIFE "Seq-Cure - Integrated systems to enhance sequestration of carbon, producing energy crops by using organic residues" (www.crpa.it/seqcure) lasting for about one year.
The organic substrates traditionally used for biogas production have very low total solid content, varying from 3 to 6% in the pig slurry to 8 to 12% in the cattle slurry (CRPA, 2001). In the co-digestion plant however, other substrates with high energy density are used in addition to the livestock effluent, deriving typically from energy crops and/or residues of the agro-food industry which have total solid content of between 15 to 35% and with 80 to 96% of volatile solids (CRPA, 2008; CRPA, 1996).

The purpose of the co-digestion is to increase the production of biogas per volume unit of the digester and hence the profitability of the investment (Soldano, 2007). In addition to the obvious benefits deriving from increased productivity however, the increase in the organic load radically alters the management approach that has to be adopted in running the plant. The stability of the process becomes more difficult to maintain because of the increased intensity of the various processes characteristic of anaerobic digestion and the balance that has to be achieved between them (acidic hydrolysis vs. methanogenic activity). Care in maintaining the composition of the mixture loaded, pH control and possible recycling to balance the load are thus of fundamental importance. As a consequence of the above it is not always possible to achieve the theoretical yields identified in laboratory tests, typically carried out in batch reactors allowing the obtaining of the maximum methanogenic potential (BMP).

It is also necessary to consider that not only may biogas production be interrupted but also its transformation into electrical energy and transmission to the national grid may be halted because of break-downs on ordinary or extraordinary maintenance. This is why the extended monitoring of biogas plant is of great importance for all those considering making an investment in farm energy (Soldano et al., 2008). Knowledge of production dynamics and actual average yields over extended periods makes it possible to obtain a realistic picture of actual production yields.

2 MATERIALS AND METHODS

The project monitored three plants differing from each other in the technology applied and the organic substrates used:

- CSTR, pig slurry (215 kWe installed);
- CSTR, dairy cow slurry, agro-industrial residues and energy crops such as maize and triticale silage (355 kWe installed);
- Plug flow + CSTR, beef slurry, energy crops such as maize and sorghum silage, and agro-industrial residues (845 kWe installed).

2.1 Description of the monitored plants

The biomass for the first biogas plant was slurry supplied by a pig fattening farm where pigs were housed on fully slatted floor and pit underneath. The slurry produced was removed on a continuous basis and his house retention time was about 10 days. The second biogas plant was loaded with dairy cattle slurry and agro-industrial residues (potato, onion, sugar beet pulp). The third plant was loaded with beef cattle slurry, maize and sorghum silage and agro-industrial residues. Table 1 shows the characteristics of the related farms and biogas plants.

TABLE 1 **Characteristics of farms and biogas plants**

Parameter	**First Plant**	**Second Plant**	**Third Plant**
Type of farm	Fattening pig farm (1000 t lw)	Dairy farm (110 milking cows)	Beef farm (2000 heads)
Substrate (% of OLR)			
- slurry	100	9	5
- energy crops	-	24	74
- agro-industrial residues	-	67	21
Reactor type	CSTR	CSTR	PFR+CSTR
Reactor volume (m^3)	2 x 1370	2 x 1050 + 850	1000 + 2 x 2400
Hydraulic retention time (days)	23	60	95
Process temperature (°C)	35-40	35-40	38-42
OLR (kg $VS \cdot m^{-3} \cdot day^{-1}$)	1	2.5	1.9
CHP (kWe)	210	355	845

lw: live weight

CSTR: Continuously stirred tank reactor; PFR: Plug flow reactor

2.2 Monitoring plan

The purpose of the monitoring plan was to check the efficiency of the biomass conversion and to measure the functioning parameters. The activities were carried out over a period of about 12 months. The main parameters measured were the following:

- quantity of solid and liquid biomass loaded (t·d-1);
- the chemical characteristics of the biomasses loaded (pH, total and volatile solids, total and ammonia nitrogen, total organic carbon, phosphorous and potassium and COD);
- quality of the biogas produced: methane concentrations (% vol), carbon dioxide, (% vol), hydrogen sulphate (mg·Nm-3), ammonia (mg·Nm-3);
- average gross electrical power (kW) produced, used by the auxiliaries, used by the digesters and accessories;
- characteristics of the digestate: pH, total and volatile solids, total and ammonia nitrogen, total organic carbon, phosphorous and potassium, COD, volatile acidity and total alkalinity.

The biogas production was calculated on the basis of electrical energy and the rated electrical yield of the cogenerators. None of the plants included a measuring system for the biogas produced. All parameters identified were processed to calculate typical efficiency indices for biogas plant: Organic load rate ($kgVS \cdot m^{-3} \cdot d^{-1}$), hydraulic retention time (d), gas production ($m^3_{biogas} \cdot m^{-3}_{reactor}$, $m^3_{biogas} \cdot kg\ VS^{-1}$), specific Energy conversion rate ($kWh \cdot kgVS^{-1}$).

3 RESULTS AND DISCUSSION

3.1 First plant

Average pig slurry production was 120 $m^3 \cdot d^{-1}$, that is, the equivalent of about 42 $m^3 \cdot t_{lw}^{-1} \cdot year^{-1}$. If this production is related to the digester's useful volume, this means an average hydraulic retention time of about 23 days. On the basis of the chemical analyses of the loaded pig slurry, the organic load rate can be estimated at 1 $kgVS \cdot d^{-1} \cdot m^{-3}$. The digestion type effected was mesophilic: the average temperatures in the primary digesters were 36.6°C, and those of the secondary digester were 39.5°C. The average methane concentration in the biogas produced was 67$\%_{vol}$ (59-72$\%_{vol}$), while that for carbon dioxide was 31.1$\%_{vol}$ (26-36$\%_{vol}$). The hydrogen sulphate concentration was however very high (about 1,992 ppm), typical of pig slurry but an indication of low efficiency in the desulphurisation system. The biogas produced was used in a cogenerator. Table 3 indicates total annual production. The electrical energy produced over the whole period amounted to 1,043 MWh. The consumption of auxiliaries and the anaerobic digestion plant amounted to 217 MWh, representing 20.8% of the gross electrical energy produced. The plant transformed volatile solids loaded with a yield of 0.423 $Nm^3 \cdot kgVS^{-1}$. The volumetric production, referring to each cubic metre of useful space in the reactor was 0.433 $Nm^3 \cdot m^{-3}$.

3.2 Second plant

Over the monitoring period a total average of about 18,000 t of organic substrates was loaded, equivalent to about 3,160 t of organic material. 23.6% of the organic material loaded was from farm silages and 67% from the agro-industrial residues with the remaining 9.4% coming from livestock cattle slurry. 73.4% of the organic materials from the agro-industrial residues was represented by potatoes (entire, pieces and mashed), about 8.1% was made up of residues from tomato processing and 7.5% from fruit residues. The additional material bringing the whole up to 100% was residues from beet, cereals, onions, beans and pumpkins. The organic material content of the loaded biomass (residues and energy crops) was always 90% or more of the dry material. In the cattle slurry, however, volatile solid represented about 80% of the total solid. Volatile solids represented on average, 91% of dry matter of the mixture loaded. The average concentration of total solids in the mixture loaded was about 19% while the organic loading rate, also considering the volume of the first covered storage tank in the calculation, was about 2.5 $kgVS{\cdot}m^{-3}{\cdot}d^{-1}$. The high organic load in the plant was in part made possible by the homogenising and balancing effect of the recycling of part of the digestate present in the second anaerobic reactor and/or in the first storage tank. The high concentration of starches was due to the extensive use of potatoes and silages. Their intense hydrolytic action lead to a high production of volatile acidity which, if not sufficiently blocked by cattle slurry and end-of-process digestate, was in danger of lowering pH excessively and inhibiting the action of the methanogenic bacteria. The average hydraulic retention time, with the inclusion of the first covered storage tank in the calculation, was about 60 days. The production of biogas, calculated by reference to the cogenerators' official yields and the percentage of methane in the biogas, amounted to 119,436 $m^3{\cdot}month^{-1}$, equivalent to 1,430,000 $m^3{\cdot}y^{-1}$. On the basis of the methane percentage present on average in biogas (53%) this means that the production of methane was about 760,000 $m^3{\cdot}y^{-1}$. The specific production of biogas was thus about 450 $Nm^3{\cdot}tVS^{-1}$ loaded, while the methane yield was about 240 $Nm^3{\cdot}tVS^{-1}$ loaded. Specific biogas production per unit of volume unit was however, on average, 1.331 $Nm^3{\cdot}m^{-3}{\cdot}d^{-1}$.

3.3 Third plant

The monitoring period saw an average loading of 60.8 $t{\cdot}d^{-1}$ in which the predominant material was that of farm sorghum silage (37.9% of the load) followed by a mixture of fruit residues (28.1%), then followed by the secondary substrates. The solid biomasses represented about 73.6% of the total solid load. A total of 22,196 t of all substrates was loaded, equivalent to average hydraulic retention time of 95 days. On the basis of the chemical analyses of the biomasses used the organic material load was about 4,270 t of volatile solids, equivalent to 1.95 $kgSV^{-1}{\cdot}d^{-1}{\cdot}m^{-3}$. The digestion was the mesophilic type. The temperatures in the primary digester were on average 41° C. Fluctuation over the last period were contained within an interval of ± 4° C. In the same way, in the two secondary digesters, the temperature of the slurry was maintained at 42.4° C for the first and 41.3° C for the second. Turning then to the quality of the gas produced, methane concentrations were found on average to be 53.1% vol (51.8 to 55.6% vol.), carbon dioxide concentrations were 46.6% vol (44.6 to 47.8% vol), hydrogen concentrations were 83 ppm (23 to 180 ppm), while concentrations of hydrogen sulphate sent to the cogenerator were 38 ppm (13.6 to 59.9 ppm). The biogas produced is entirely used in a cogenerator for the production of electrical energy transmitted to the national grid. Part of the electrical energy is used by the plant for the various internal components (mixers, loaders, sorting pumps for loading and unloading). Table 3 sets out electrical production over the period under consideration. It was possible to estimate biogas production on the basis of the rated value of the electricity production of the installed co-generator and hence the yield indices. The plant allowed the processing of volatile solids loaded into biogas at a yield of 0.672 $Nm^3{\cdot}kg\ VS^{-1}$. Volumetric production compared with cubic metres of useful space in the reactor was calculated at 1.38 $Nm^3{\cdot}m^{-3}_{reactor}$.

Table 2 shows the differences identified between monitored plants. Energy production in the first plant was highly dependent on the live weight of the animals. On the other plants production was much more regular due to the higher co-fermentation rate between the energy crops and agro-industrial residues. Table 3 sets out electrical production of the three plants over the period under consideration.

TABLE 2 **Results of monitoring activity**

	First plant	Second plant	Third plant
Volumetric production (m^3 biogas · m^{-3} reactor)	0.45	1.33	1.38
Biogas yield (Nm^3 · kg VS^{-1})	0.42	0.45	0.67
Methane yield (Nm^3 · kg VS^{-1})	0.28	0.24	0.36
Electric energy yield (kWhe · kg VS^{-1})	0.99	0.80	1.48

TABLE 3 **Summary of energy production parameters of the three plants monitored**

Parameter		First	Second	Third
Gross electrical production	MWh·y^{-1}	1,018	2,527	6,578
Average electrical power produced	kW	119	287	742
	% installed power	59	80.8	87.7
Cogenerator auxiliaries consumption	% gross energy production	4.2	3	3.99
Digestion plant consumption	% gross energy production	14.5	5.5	3.27

4 CONCLUSIONS

In the agricultural and livestock sector the production of biogas and its subsequent transformation into electrical energy has by now become a well-established practice. The substrates which can be used include both animal manure on its own and in a mixture with energy crops and/or agro-industrial residues. In both cases however, correct plant design must take account of the specific characteristics of the matrices to be used is indispensable to ensure that it functions well.

In the case of plant using prevalently energy crops, the uniform nature of the product makes it possible to construct more reliable, even if more complex, plant. The addition of agro-industrial residues brings with it problems relating to continuity of supply and variable quality. These problems can be mitigated if the matrices can be subjected to ensilage or if the main load remains energy crops. In the case of animal slurry however, the variable nature of these matrices means that the plant designer and subsequently the manager, must take all necessary measures to limit the effects on biogas production that may be caused by load variation.

Finally, in economic terms, it is important to remember that organic materials coming from the use of animal manure are free while agro-industrial residues and energy crops have to be paid for and the management of the digestate represents an additional cost item.

REFERENCES

CRPA (edited by) 2001. Liquami zootecnici- Manuale per l'utilizzazione agronomica – Edizioni L'informatore Agrario, pages 320

CRPA (edited by) 2008. “Energia dal Biogas” – publisher AIEL (Associazione Italiana Energie Agroforestali), pages 103

CRPA (edit by) 1996. Biogas e cogenerazione nell'allevamento suinicolo – Manuale pratico. ENEL spa, pages 208,

Soldano M, Fabbri C, Verzellesi F, Piccinini S 2008. Biogas, monitorare un impianto per migliorare le rese produttive – Supplemento a *L'informatore agrario*, vol 38, pp 35-38

Soldano M, Fabbri C, Piccinini S 2007. Co-digestion plant in dairy cattle farm in Emilia Romagna region- Proceeding International conference “Progress in Biogas”, Stuttgart, 19-21