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Biocells for biogas production: anaerobic plant for the energetic enhancement of biomasses and zootechnical slurry

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Abstract

The Italian countryside is characterized by many small farms, spread in the territory, which constitute a great potential of renewable energy. However renewable chains require large investments to ensure economic stability and technical feasibility of the same. The following study aims to analyze technical and economic feasibility of micro-anaerobic digestion plants for small farms.

Discontinuous charged digestion, commonly called batch, is characterized by a single feeding of the organic substrate in the reaction chamber, perfectly sealed, able to make the anaerobic conditions. The matter is ejected only at the end of fermentation process, when all the organic potential has been transformed into biogas. This technology is characterized by simplified features, with the possibility of setting up more digestion chambers, loaded with different types of biomass typically seasonal, then biogas will be valorized by an energy conversion system. The Biomass Research Centre, on loan from the Ministry of Agriculture and Forestry, inside the project ERAARZ (Renewable Energy for Farms derived from Zoo-technical Slurry), is developing in Umbria an innovative batch prototype plant with a nominal electricity power rating of about 50 kW. Chamber for biomass digestion will be undertaken using a machine for bagging corn in plastic bags, filled with a mix of different biomasses and zoo-technical slurry. The anaerobic processes activation will be improved through slurry spreading by valves at the top of the chamber. An hydraulic pump recycles at the top the slurry, after its heating made by heat produced into the energy conversion system, ensure the optimal conditions for bacterial growth inside the bio-cell.

Continuous monitoring of biogas will enable data collection that will be used to reach for the better working conditions and better system performance.
This plant, thanks to the lack of mechanization and push for lower costs, can be a solution also for developing countries.

Keywords

biogas, renewable, slurry, biomass, anaerobic, bagger, bags

Introduction

The anaerobic digestion process is a thermo-chemical process, that can be realized in lack of oxygen, able to transform organic matters in biogas composed by methane and carbon dioxide principally; this reaction starts naturally also in big heaps of organic matters, like agricultural biomasses.

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Methane rate goes from 50% to 80% according to the biomass used in the process and according to the typology of the process (see chapter 1.1); this percentage of methane comport a low heating value variable from 4.500 Kcal/m^3 to 6.500 Kcal/m^3.

The biomasses in input must have this characteristics:

- Moisture up to 50%;
- C/N value between 20 and 30;
- pH value between 6,4 and 7,2;
- Low value of ratio between lignin and cellulose;
- For zoo-technical slurry, lack of antibiotic elements deriving by medical care of the breeding;
- Lack of phenols [1].

These characteristics are fundamental for the development of the microorganism families necessary to start the process; water in input permit the microorganism to move inside the substratum and to develop itself, like an "house"; non optimal ratio between Carbon and Nitrogen may comport some problems of inhibition of the process according to the elevate percentage of Nitrogen ammoniac (urea of the slurry); pH is an index of the stability of the process; lignin isn't a biodegradable substance, then its elevate value comports a low efficiency of the plant [2].

Microorganisms families realize the anaerobic digestion by two steps: the first one is a transformation of complex substances in intermediate composts, like acetic acid and hydrogen, that will be the feeding for methanigen microorganisms families during the second step [3]. In figure 1 there is a scheme of all the stages of anaerobic digestion whit their products, feedings and bacterium.

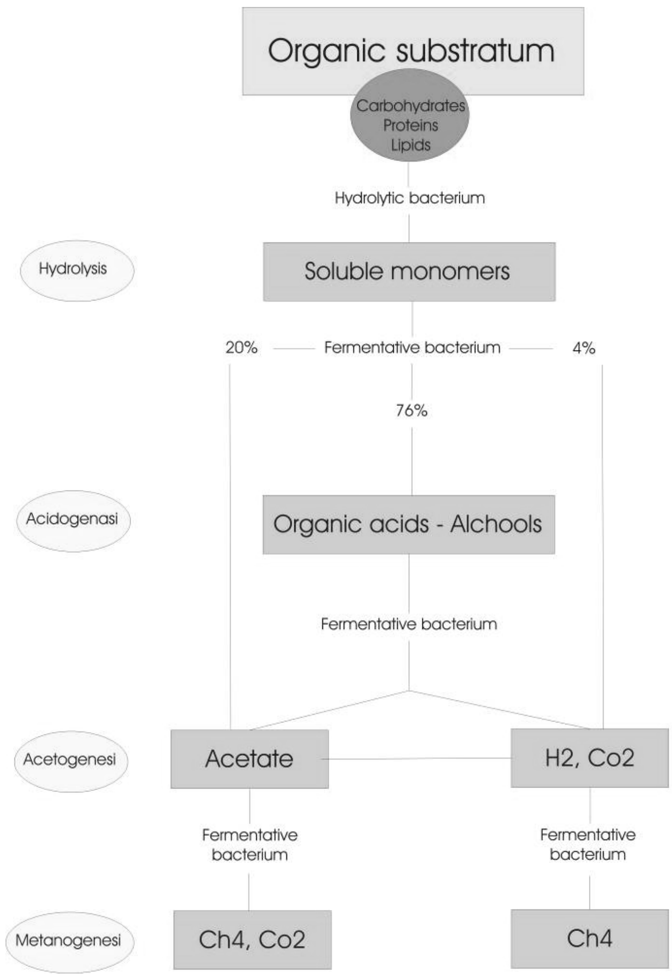

Figure 1: Stages of anaerobic digestion process

All the stages can be also realized in only one step using a digestor: in this case, the digester reactor will have a configuration too many complicated because you have to guarantee optimal condition of development for different microorganisms families [4].

Typologies of anaerobic process

Temperature is the main characteristic that influences the anaerobic process type because temperature of development is different for the microorganism families.

If the process temperature is between 15°C and 25°C there is the development of psicrophilic batters, between 25°C and 45°C mesophilic batters, between 45°C and 55°C thermophilic batters.

The different types of processes have different retention times: between 30 and 90 days for psicrophilic process, between 15 and 35 days for mesophilic process, about 15 days for thermophilic process [5]. Naturally, different processes have different technologies, costs and efficiency; table I is about the characteristics of mesophilic and thermofilic process.

Table I: Characteristics of mesophilic process and of thermophilic process.

Process type	Management costs	Efficiency (biogas/ substratum)	Organic input
Mesophilic	Medium	Medium	Medium
Thermophilc	High	High	High

Another significant difference between processes types is about the percentage of dry matter contained in the substratum; we speak about "dry digestion process" when this percentage is more than 20%, "wet digestion process" when dry matter is less than 10%, "half-dry digestion" in the other cases [6].

Digester plants technologies

Based on quantity and on typology of biomass in input, based on the process type, there are many solutions to build an anaerobic plant.

The simplest technologies solutions are tanks or lagoons, warm or not warm; the main difference between tanks and lagoons is that the second one can be realized directly on terrain, without civil buildings, upon waterproofing, but whit bigger dimensions.

Tanks can be realized on the ground or partially buried. Biogas is catch by floating PVC cloths or using pipes combined whit a compressor to make the pipes on negative pressure and then guarantee the picking up of biogas (see figure 2).

These types of reactor have many problems deriving by the lack of agitation mechanical system, necessary to homogenize slurry and maximize the process efficiency, and by the lack of heating system whit great efficiency, especially for the lagoons technologies, owing to the big size of reactors. Therefore solid contained in slurry can solidify and become a rigid coating whit a consequently block of leak of biogas, in the worst hypothesis.

A second type of digester reactor is the CSTR (Completely Stirred Reactor – see figure 3) make by a cylindrical tank, dimensioned on the quantity and type of biomass used, where a mechanical agitation system guarantees an homogenization of chemical characteristic of the organic matters in the tank. In this case, anaerobic digestion takes place in only one stage; consequently, the plant is cheaper but it has a lower efficiency and more problems in the purification of zootechnical slurry.

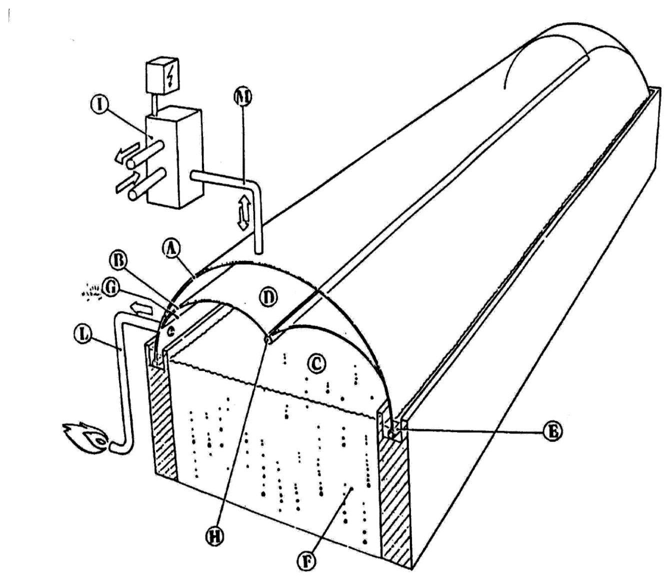

Figure 2: Tank anaerobic digester plant: A) waterproof covering; B) separation membrane; C) biogas chamber; D) air chamber; E) anchorage; F) slurry tank; G) connection between membrane and cover; H) membrane ballast; I) air pump; L) biogas exit; M) air pipe (source Ecomembrane)

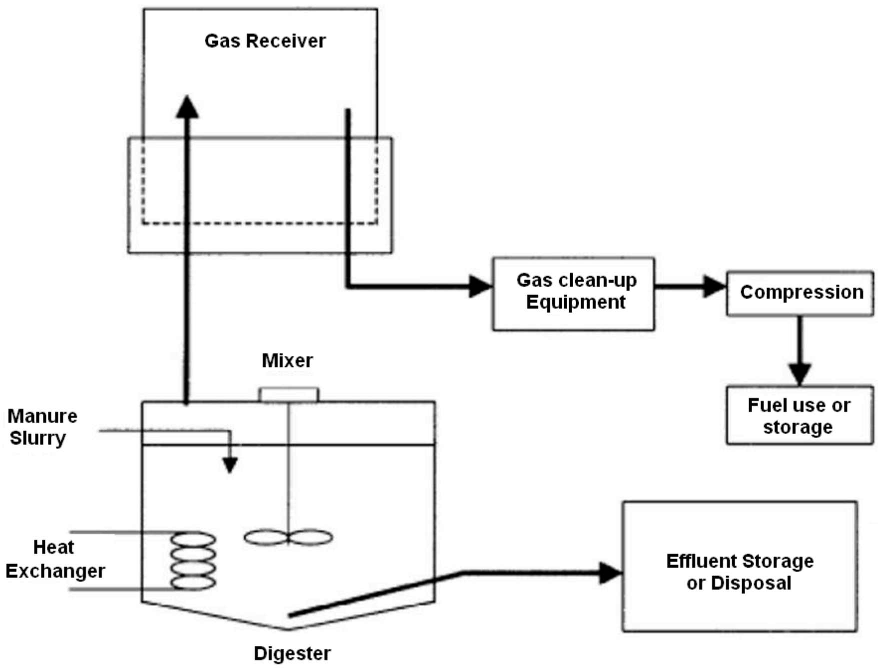

Figure 3: Digester CSTR

The last reactor solution mono-stage is represented by plug-flow reactor (PFR), composed by a prismatic tank whit length bigger than others dimensions (see figure 4).

Figure 4: Digester PFR

Table II: Characteristics of biomasses in input (% of dry substance)

Material	Dry Substance (%)	Organic Substance (% d.s.)	Biogas (m^3/tons o.s.)
Breeding			
Bovine sewage	6 - 11	68 - 85	200 – 260
Bovine manure	11 – 25	65 – 85	200 – 300
Swine sewage	2,5 – 9,7	60 – 85	260 – 450
Swine manure	20 – 25	75 – 90	450
Bird sewage	10 – 29	75 – 77	200 – 400
Bird manure	32,0 – 32,5	70 – 80	400
Agriculture			
Maize	34	86	350 – 390
Grass	26 - 82	67 - 98	300 - 500
Straw	85 – 90	85 – 89	180 – 600
Pole of maize	86	72	300 - 700
Agro-industry			
Vegetal rejects	5 – 20	76 – 90	350
Molasses	80	95	300
Whey	4,3 – 6,5	80 - 92	330

PFR is the reactor with the biggest efficiency and can use slurry whit high percentage of solid elements; this reactor doesn't need a mechanical agitator system because the organic matter must to go away slowly to guarantee a constancy in all the sections of the reactor of nutritive matters and bacterium concentrations, gradually variable until the optimal conditions on the last section.

If the solid elements percentage is minor than 13%, we can find PFR technologies combined whit mechanical agitator systems.

The pilot plant object of the project REACS is an evolution of PFR digesters whit shortest dimensions and better efficiency (double stage co-digestion reactor).

Some examples of biomasses in input

Using different material we will have different efficiency both in quantity both in quality of biogas produced by anaerobic digester.

In this paragraph we will present you the evaluation of biogas produced by different types of biomasses in the anaerobic digestion process (see tables II and III).

Table III: Biogas yield for volume unit

Material	Volume (m^3)	Weight (tons)	Biogas (m^3)
Bovine sewage	1	1	15
Bovine manure	1	0,3	10,1
Swine sewage	1	1	15,6
Swine manure	1	0,3	23,5
Bird sewage	1	1	44,5
Bird manure	1	0,3	29,3
Maize	1	0,625	67,6
Grass	1	0,5	89
Straw	1	0,04	12
Pole of maize	1	0,4	123,8
Apple rejects	1	0,3	2,6
Molasses	1	0,3	68,4
Whey	1	1	15,3
Vegetal rejects	1	0,4	14,5
Olive Mill Water	1	0,5	357

As you can see, the biogas yield of zootechincal slurry is not the biggest one: compared whit biogas from maize, the yield of slurry is about half quantity. However, it’s not possible to make an anaerobic process using only maize because substratum doesn’t have the right characteristics for the development of microorganisms families, whit a consequently increase of activation time of digestion process.

From literature data, we can underline the elevate yield of Olive Mill waste Water (OMW), rounded 360 m3 of biogas for 1 m3 of OMW; using this substance in anaerobic process, there will be some problems deriving from the presence of phenols and from the seasonal supply, estimated around 90 days for years.

Moreover, at the end of anaerobic digestion process, the substratum has an elevate percentage of Nitrogen that you must pulling down using traditional metodologies; this problem bind to build a plant so much complex than other plants dedicated to different input biomasses [6].

The Bio-cell technology

Biomass Research Centre elaborate a project for a prototype biogas plant, based on batch reactor technology named "bio-cell", as the result of an accurate design developed with the following objectives:
- environmental savings;
- environmental protection;
- maximization of biogas production.

The technology is innovative, simple and replicable. The figures 5-6-7 shows different views of the plant, with the components within. In the following section we will describe the main section and running system of the bio-cell.

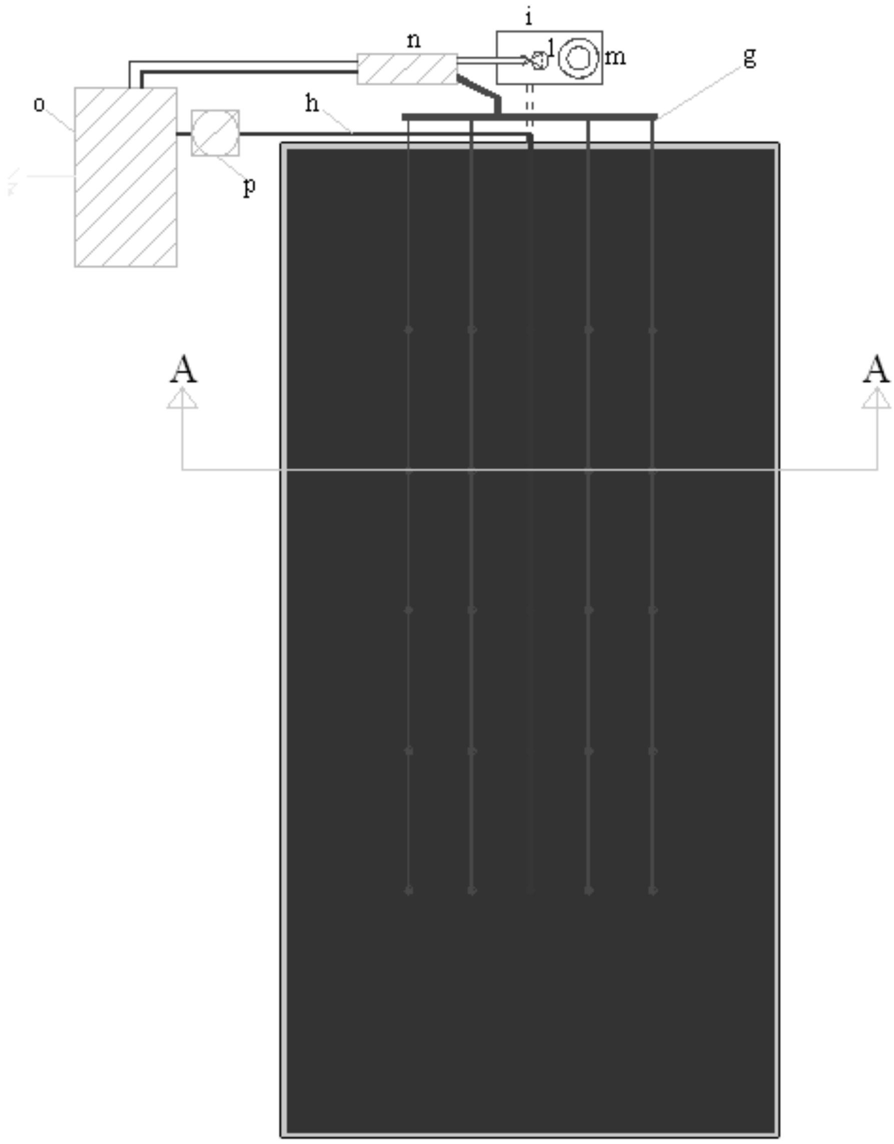

Figure 5: Plan of Bio-cell plant.

The biomass is fed into a sealed chamber, covered on top with a waterproof sheet (d) supported by a system of weights of support (f), a hydraulic system for the support and insulation (e) to recreate the conditions of anaerobics. Biogas that saturate the environment flows through the systems of uptake (h) to desulfurization (p) and to an internal combustion engine (o) by which there is production of electricity and heat cogeneration used for utilities and to heat through exchanger (n) the digestion chamber itself.

The bio-cell consists principally of a chamber made by soil and completely waterproofed by as basal layer of compacted clay (b) linked with a polyethylene film (a). Inside the digester, through the access ramp (q), we will be able to feed the plant whit solid biomasses, needed for digestion process, like straw bales, maize silage, etc. After feeding, the bio-cell will be covered using another waterproofed polyethylene film. Through special diffusers (g) placed at the top of the cloth, the liquid biomass (m) is load by a pump (l), from a pre-load well (i) into the digester. On the bottom of bio-cell, we find some drainage pipes able to collect liquid biomass into pre-load tank; so, the hydraulic system also perform the re-circulation of liquid inside the digester. On the top of digester, there also are jets for biogas extraction; every jet is equipped by a barrel for biogas storage. All barrels are connected whit a grid to reach co-generation system.

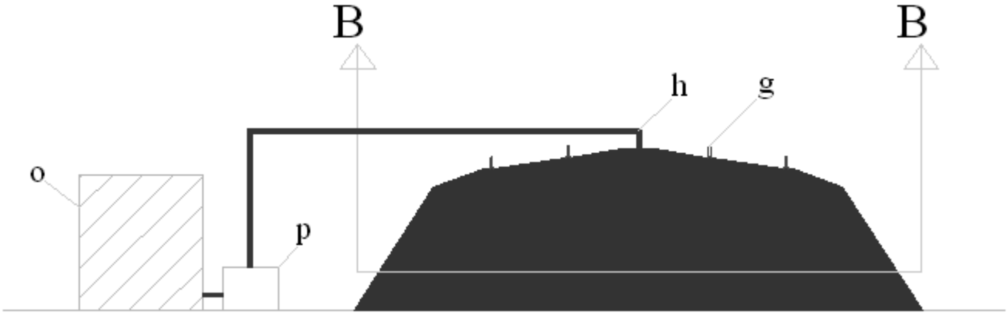

Figure 6: Elevation of Bio-cell plant.

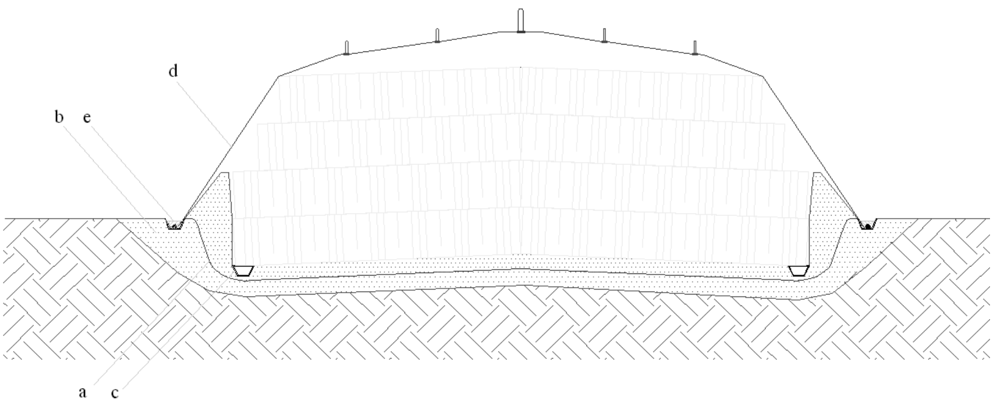

Figure 7: Section A-A of Bio-cell plant.

Prototype plant realization

The Biomass Research Centre, on loan from the Italian Ministry of Agriculture and Forestry, inside the project called ERAARZ, acronym for Renewable Energy for Farms derived from Zoo-technical Slurry, has developed in Umbria, near Sant'Angelo di Celle (Perugia) an innovative batch prototype plant.

CRB is running this project to develop bio-cell technology and make it customized.

The beginning design of the plant, shown upper, was modified to realize a simpler plant layout, whit more efficiency on biomass degradation. We decide to develop project using the technology for bagging biomass in plastic bags, technology developed in agricultural field. On the figure below (figure 8), you can find the general layout of the plant.

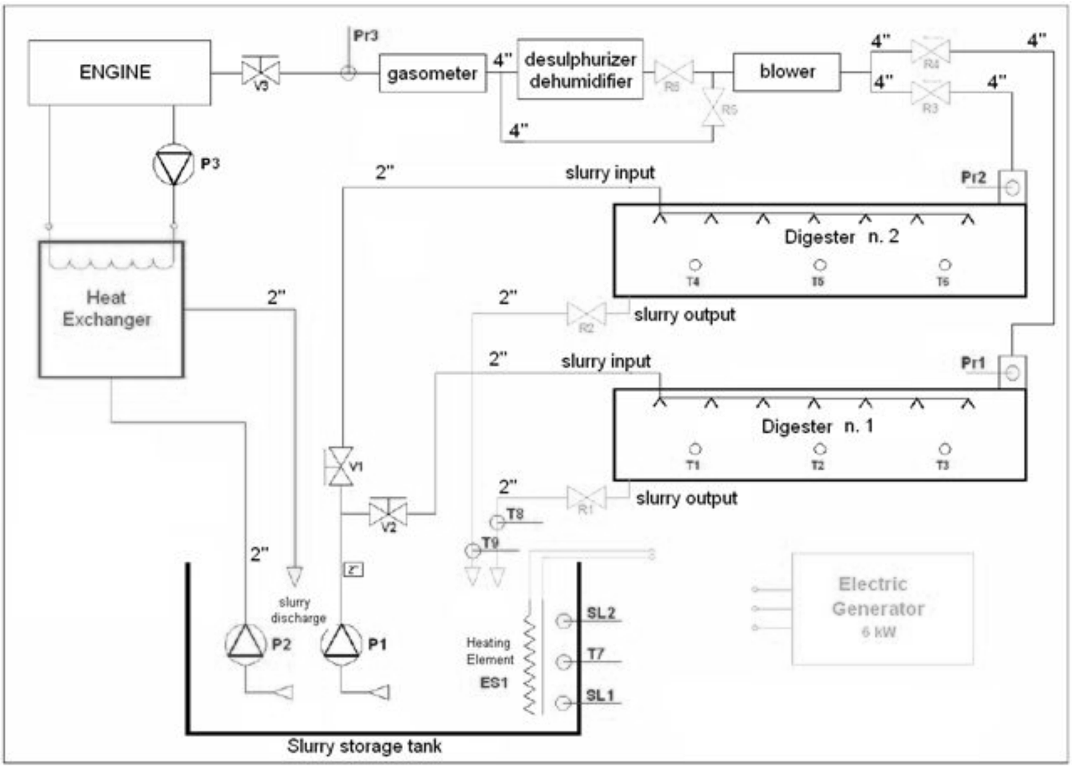

Figure 8: Layout of new Bio-cell prototype plant.

Figure 9: The bagging machine.

Figure 10: The biomass loading.

Figure 11: The straw-launching machine.

Figure 12: The three biocells.

Running test phase, we decided to realize three bio-cells filling it with different biomasses matrix: solid manure in the first, 10 m long, straw and manure in the second bio-cell, 5 m long, and the third bio-cell feed only with straw, 10 m long (see figure 12). The realization of the bio-cells was improved using a straw-launching machine fed with straw-bales (see figure 11). The separate straw was directly loaded inside the bagging machine (figure 9-10), equipped with a conveyor belt. Biomass is pushed inside the plastic bags by two horizontal cochlea positioned on the other side respect feeding zone. The machine allowed the insert of two drainage pipes inside the bag, to collect the percolate.

Bio-cells will be equipped with temperature and pressure sensors, all collected with a PLC control panel. A special software permit to see all sensor's values, open valves, put on liquid recirculation pumps and biogas aspiration system, start co-generation system, etc.

All the flows are shown in the synoptic scheme, report in figure 13.

We decide to load liquid slurry only on the second and on the third bio-cell because the first one is already charged with manure and so it is able to perform anaerobic digestion process by itself.

The anaerobic processes activation of bio-cells number 2 and 3 is realized by liquid slurry charging from percolate storage tank (figure 14). The slurry is first of all heated by an electric resistance positioned inside the storage tank (figure 15) and then loaded from injection system on the top of bio-cell; all injectors all linked to charging pump by an hydraulic ring system.

A second pump, switch on after bio-cell activation, permits to charge slurry into the heating system fed by thermal energy recovering of co-generation system, able to ensure the optimal conditions for bacterial growth inside the bio-cell.

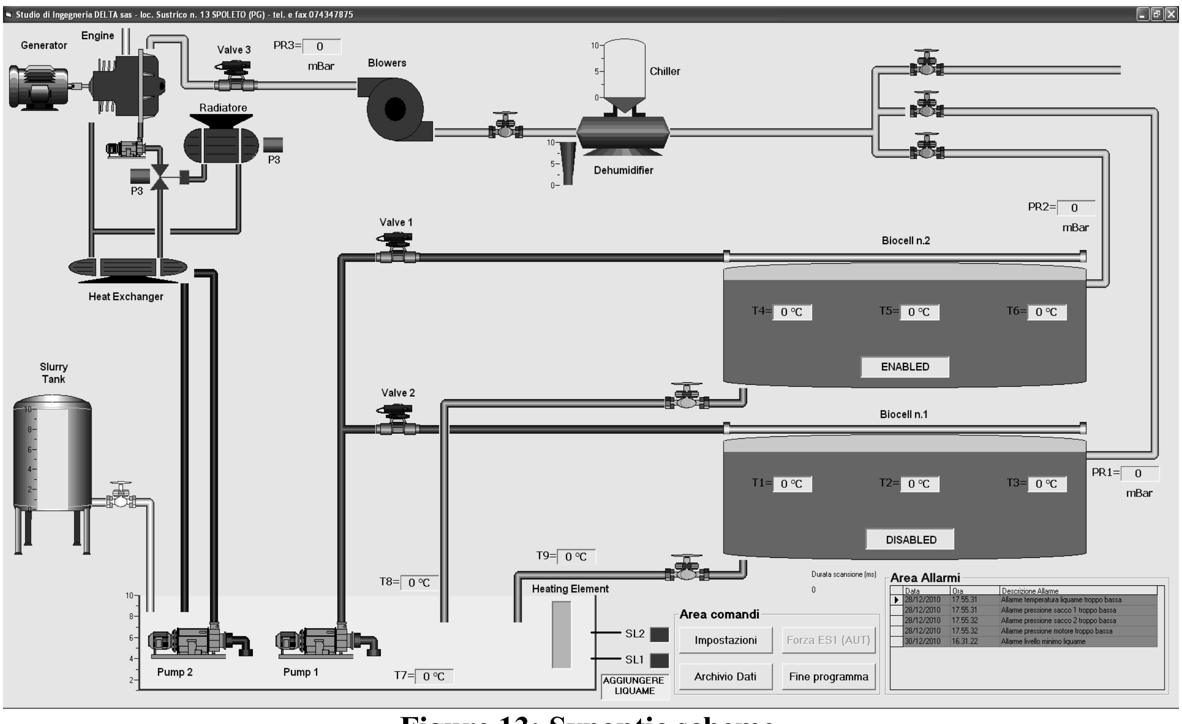

Figure 13: Synoptic scheme.

At last, biogas is up taken by the top of bio-cells and, after a dehumidification process, converted in electric and thermal energy by a co-generation system of 30 kW net electric energy power.

Monitoring and conclusions

This plant is a prototype based on biological processes, so running times are closely related to environmental conditions of operation, including the most important one, temperature.

In addition to temperature and pressure sensors, we will use to analyzer: the first is for biogas composition analysis, to know how much methane we find on biogas mix and consequently evaluate when reaction is over; the second is for exhaust gases from co-generation system to verify the respect of maximum limit in atmosphere pollution emission.

Figure 14: The well and pipes conveying in/out.

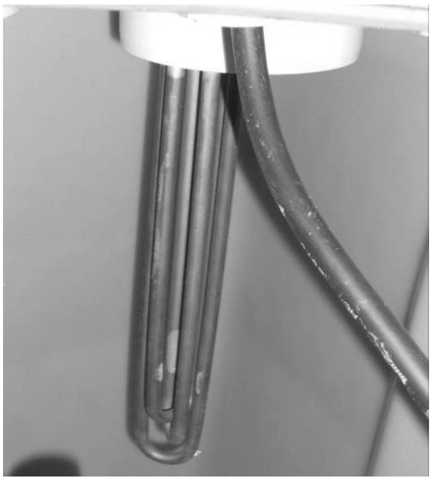

Figure 15: The heating element.

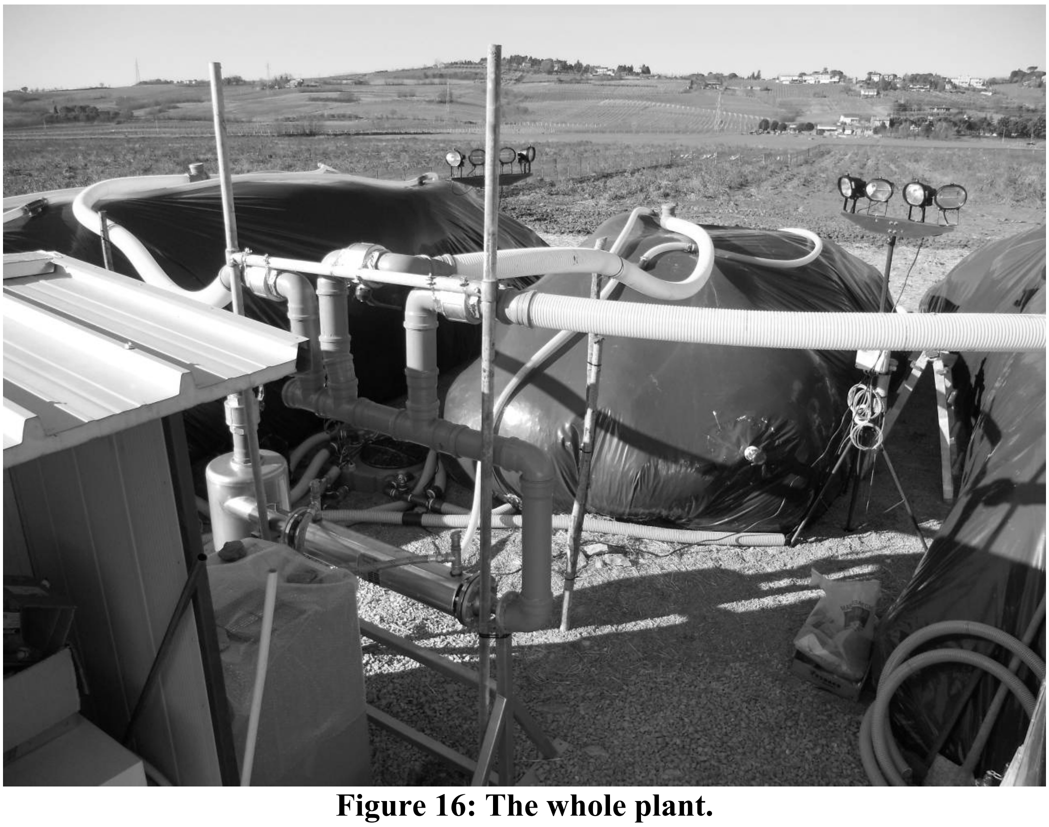

Figure 16: The whole plant.

During experimental time, we will feed bio-cell with different type of biomasses, both virgins and residuals, based on agricultural cycles.

The monitoring will determine what is the type or mix of biomasses allowing the better production of biogas.

Monitoring and testing are also performed on the residue of digestion, the digestate, which before being used for fertilization, will be analyzed and understand its characteristics, such as nutrient content.

All data collected will be carefully cataloged in order to create a useful database for the subsequent implementation of a computational model that allows to define precisely the mechanism of operation of the anaerobic digestion process in cells.

The mechanism of anaerobic digestion inside cells, has different development in time from the most common digester with continuous feeding. The produced biogas flow has a discontinuous pattern during the time, like a bell shaped, with an increase, a maximum, and a reduction. The main goal to customize plant is to combine the biogas production with the biogas demand for cogeneration system consumptions (figure 17).

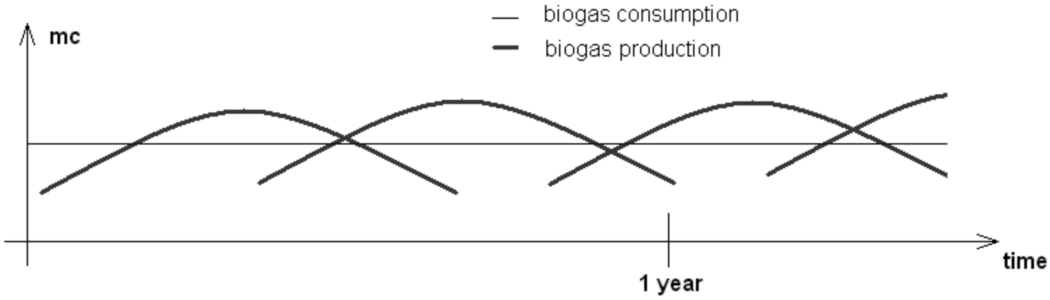

Figure 17: Biogas production and consumption.

Therefore, we can realize the condition of perfect response to the demand by adjusting the load time and the functioning of cells by liquid biomass loading regulation. The objective is to identify the right mix between different types of biomass, liquid and solid, the temperature conditions. Working on this way it'll be possible to obtain the maximum production efficiency in terms of biogas and then electricity energy and heat, realizing a good renewable chain adjustable to small size farm.

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