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A batch digester plant for biogas production and energy enhancement of organic residues from collective activities

Franco Cotana[a], Alessandro Petrozzi[a*], Gianluca Cavalaglio[a], Valentina Coccia[a], Anna Laura Pisello[a], and Emanuele Bonamente[a]

[a]CIRIAF-CRB – Biomass Research Centre, University of Perugia, Via G. Duranti sn, 06125 Perugia, Italy

Abstract

An innovative little-sized batch biogas plant has been recently developed by the Italian Biomass Research Centre. It was fed by the residual biomass (agriculture residues and zootechnical wastes) produced by a farm located in the countryside of Perugia, Italy. The successful experience allowed the research group to design an upgrade of the existing plant, making it replicable to every communitarian activity such as Conference Halls, Schools, Condos, where organic biomass is produced as waste. Biomass recovery from markets, canteens and little food companies represents an opportunity for the installation of new residues-powered plants, achieving the production of both electricity and thermal energy for house heating and industrial processes. The collected biomass could also be integrated with pruning or residual biomass from the maintenance of the green and the neighbouring municipal wastewater from a septic tank. The simplicity, automaticity, and the cost-effectiveness of the plant, together with the incentives from electric energy injection to the grid, made the investment payable in a few years, allowing the operator to gain from renewable sources. Little sized biogas plants solves the problem of harvesting and disposal of the organic waste, reducing its transportation costs and producing green energy. The paper presents the preliminary design of the plant.

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Keywords: biogas, batch digester, waste, residual biomass.

1. Introduction

The Umbria Region, as the majority of the regions in of central Italy, is characterized by little farms spread over a rural territory and for which it is difficult to organize a complete and integrated chain for the collection and the energy enhancement of the residual biomass.

* Corresponding author. Tel.: +39-075-585-3806; fax: +39-075-515-3321.
E-mail address: petrozzi@crbnet.it.

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An innovative small-sized biogas plant, structured in biocells digesters, was designed and implemented to serve a rural facility [2-3]. It represents also an opportunity to other farmers to produce renewable energy by residual biomass, swine or bovine manure and straw, extremely abundant in our region [4], avoiding the high costs for their disposal. The Italian incentives for electric energy from Renewables injected to the grid is more advantageous for smaller biomass plants; therefore the economic return of the investment is guaranteed in a reasonable time if compared to the plant lifetime.

Nomenclature

CRB	Italian acronym for Biomass Research Centre
CHP	Combined Heat and Power
LEED	Leadership in Energy and Environmental Design

2. The former biocell biogas plant

The prototype experimented by CRB was developed with the goal to reduce the investment costs and to simplify the plant operation, by optimizing the economic feasibility. To this aim, low-cost technologies were implemented such as the huge polyethylene bags used as digesters and filled with solid and liquid animal manure and seasonal biomass (olive husk, straw, marcs). This batch pilot plant, renamed “biocells plant”, was experimented using different biomass mixes and in different thermal conditions [5].

Digesters were filled with solid biomass; slurry is heated and loaded to the bag providing the thermal conditions for mesophillic anaerobic bacteria growth to produce biogas. Biogas is loaded to the 30 kW powered CHP engine by a blower and its combustion produces electricity and heat. It is estimated half of the produced heat is needed to maintain the thermal conditions inside the digester. All the plant is automatized by a Programmable Logic Controller system dialoguing with the data provided by temperature and pressure sensors that continuously monitor the different components. When the biogas yield ends, the slurry and biogas piping is removed and attached to another polyethylene bag filled with fresh biomass. In summertime, the exhausted bags are ripped and the digested matter is removed and spread over the fields as fertilizer; the polyethylene can be harvested and recycled. The chain is completely closed and sustainable.

3. The upgraded plant prototype

The plant was upgraded after testing different biomass and using different kinds of bags, modifying technology and optimizing the chain, e.g. using high albedo paintings of the plastic skin, can help the plant to maintain the optimal temperature [6-7], allowing to increase the heat recovered for the users.

CRB was also tasked, through a research project supported by the Italian Ministry of Environment, to restore a historic building close to the plant, providing an environmental sustainable design, based on renewable energy use and optimized passive solutions for energy saving and reduced environmental impact. The building is the “Sant’Apollinare” fortress, edified in X century and composed by an U-shaped complex with a floor area of about 1,000 m^2, and an adjacent building which was edified for stable use. This building is the object of the retrofit intervention. It will be converted into office and labs facilities, conditioned by the biogas plant. The goal is to achieve the International LEED certification label for the stable, by a refurbishment based on innovative and sustainable solutions grouped into categories such as sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor quality, innovation and design process, regional priority.

The requirements to accomplish were: to preserve the aesthetic status of landscape maintenance, to reduce the land-use caused by the lack of space on the top of the hill, to use the organic waste produced from the canteen and sewers for recovery and energy enhancement, to use the heat output for the stable air conditioning. The need to achieve all of these goals led CRB to modify the design of the biocell plant, integrating it into the sewerage system and using underground biocells as digester (see Figure 1) instead of the polyethylene bags. In this way the visual impact and the emission of odors are safeguarded. The novelty compared to previous plant, is the digester: it is composed of a concrete tank with three cubic volumes, 12 cubic meters each, the first stadium is used for hydrolysis, the second for methanization, the third for digested matter recovery, drying and extraction. The digester, such as many plants designed by CRB, was chosen and dimensioned by a digital model created by the *Aspen plus* software, defining and simulating the flows and the hydraulic retention time, temperatures and biological processes. The first and the second volumes are heated by hot water recovered by the CHP engine through the same principle of the experimented big plastic bags plant.

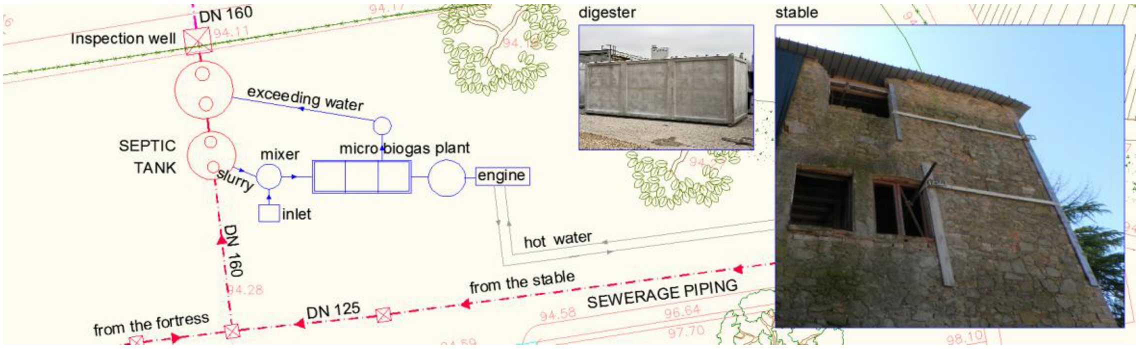

Fig. 1. The layout of the plant, integrated to the sewerage piping system

3.1. The building

The refurbishment of the building was aimed at energy saving. The ground floors and the roof were restructured using thermal-insulation techniques, such as ventilated interspaces and insulating materials. [8]. The walls and fixtures allow to create a continuous envelope without thermal bridges. The air conditioning of the stable is provided by fan coils supplied with hot or cold water depending on the season. In winter, the heat recovered from the CHP is sent through the distribution network directly to the fan coils; in summertime heat is fed to an absorption chiller. The fortress is used as Conference Hall for winter and summer University schools, its attendance is concentrated in a few months, in a continuous way, during both summer and winter months.

3.2. The available biomass

Biomass feeding the plant is generally represented by pruning from the green areas surrounding the fortress, recovered by the green maintenance and soft straw collected from the plain at the base of the hill.

The fortress full capacity is 40 guests; the production of effluent of such persons may be estimated as 190 g/day for each person, producing 220 kg per month [9]. Another biomass source is represented by the canteen waste. The activity of 40 meals a day produces more than 120 kg per month of residual material to be disposed. The resulting material will be shredded through a special machine and poured into the piping: all the solid biomass are converted and directly injected to a mixing well, mixed with liquid biomass and loaded inside the first volume of the digester. Regarding the liquid biomass, it constitutes the sludge separated from the 3.4 cubic meters septic tank for the waste collection produced from the fortress. The digester plant is inserted to the sewer piping as a bypass: the sludge is loaded in, the flowing water is disposed along the sewer. Table 1 summarizes the biomass flows.

Table 1. A summary of the available biomass

Biomass	Daily amount (*kg*)	Monthly amount (*tons*)
Straw and pruning	-	30 t
Slurry from sewer	7.6	0.23
Food waste	4.0	0,12

3.3. The energy requirement and production

The stable is set in climate zone E, with 2289 degree days. A dynamic analysis of the energy needs was performed to estimate the energy requirements. The thermal power is 23 kW; the power of the absorption chiller is 20 kW. The biocell plant works for a total of 4,000 hours per year, evenly distributed along the critical seasons. Considering a thermal output recovered by CHP of about 50 kW, half power is absorbed to maintain the temperature of the digesters. The energy produced is sufficient to cover all the users' requirements.

4. Economics

According to the last Italian Decree on Renewable, biogas plants powered under the threshold of 30 kW can be financed with a total feed in tariff of 0,236 € per electrical produced kWh. Operative costs can be considered void because the complete automatization of the plant. The total investment costs, about 150,000 € can be paid in 9 years by the yearly revenue of 17,500 € for 20 years.

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