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Economic feasibility study of a small-scale biogas plant using a two-stage process and a fixed bio-film reactor for a cost-efficient production

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Abstract

European and Italian incentive schemes promote small-scale biogas plant distribution using different types of biological and agricultural wastes as feedstock. A feed in tariff system is used in most of the European Union countries, and the incentive is paid on top of the market price capped at a maximum amount sold.

The proposed study explores the feasibility of two-stage biogas plants for small-scale CHP, based on a two-phase bio-film process partially tested during the Biowalk4Biofuels (B4B) FP7 project implementing an Anaerobic Digestion (AD) based on a rotating biological contactor thus able to combine significant yields and reduced volume. The project developed a small pre-industrial biogas plant implementing a recovered 45 kWel CHP unit with 95 kWth thermal power. In the two-stage process, a high-temperature hydrolysis phase was followed by a continuously stirred methanogenesis bioreactor equipped with a rotating biological contactor. Main process performances were related to Organic Load Rate (OLR) up to 15 kg VS/m3; the overall reactor volume was 70 m3 for expected biogas production of 25 Nm3/h.

Specifically, the aim of the present article is to address the use of the results and outcomes from some laboratory tests verified by the B4B system to model an overall feasibility evaluation. This allows to explore theoretical and economic feasibility of two ideal plants characterized by a 50 and 150 Nm3/h biogas production based on the overall system performances implementing a fixed biofilm for enhancing methanogenesis process. The feasibility study for the 50 Nm³/h biogas plants (equivalent to 100 kWel) shows profitable results, as well as evaluation of the 150 Nm³/h plants (300 kWe), that represent the biggest size for Italian incentives aimed at "small size" biogas plants.

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Keywords: RBC; biofilm; anaerobic digestion; hydrolisys; small scale plants; biogas; CHP; feed in tariff

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1. Introduction

Italian legislation has proposed an incentive scheme for the production of renewable energy from biogas that rewards the creation of small size plants [1]. The attention is focused on small- and medium-sized agricultural districts powered by agricultural waste. The aim of the Italian Directive on promotion and incentives for energy production from renewable sources [1] is to mitigate the environmental impact of crop-based energy production pathways of industrial plants from an overall sustainability perspective.

Feed-in tariffs (FIT) are one of the well-known and widely implemented renewable electricity (RES-E) support mechanisms in European countries. Nevertheless, there is a large range of individual FIT policies and ways of applications [2] like:

- Fixed-price vs. premium tariff (Denmark, Cyprus);
- Cost allocation;
- Cost containment (Cyprus, Estonia, Ireland, Latvia, Portugal, and Spain);
- Contract duration;
- Tariff amount;
- Digression rate.

In Latvia, for instance, RES-E is promoted within the feed-in tariff system involving a complex support system, which also includes elements of a quota system and tenders [3]. The FIT is calculated differently depending on the type of RES sources (i.e. biomass, biogas, wind and solar) and type of technology (mainly addressed to maximal capacity limitations). The FIT support level is implicitly considering natural gas tariff approved by the Regulatory Authority of Latvia [4].

The main environmental and economic hot-spots to be mitigated can be identified as follows:

- High consumption of water resources;
- Use of synthetic chemical fertilizers;
- Optimization and lowering of energy footprint for biomass cultivation and harvesting;
- Discharges of nitrogen compounds in areas adjacent to the plant;
- Transition from agricultural crops to energy crops.

Several LCA studies point out that the use of biological and agricultural waste instead of dedicated energy crops is beneficial for the overall environmental sustainability of bio-energy conversion roots [5, 6].

Nevertheless, the technology for these types of installations is not fully exploited in the market; the main problems are related to difficulties encountered when plants are fed mainly by waste biomass instead of conventional energy crops, or very specific wastes, such as cattle manure. Specifically, compatibility problems arise when biomass characterized by high nitrogen content and biomass characterized by high lipid content is used [5, 6].

In order to seriously improve biogas technology with the aim to reduce environmental impacts and to match the needs of small systems to be installed in small to medium size agricultural districts, the key problems of complex biomass disposal must be solved. A possible solution for these needs can be given by the use of technologically advanced systems able to maximize the biological activity and yield of anaerobic digestion processes.

This study presents the results of a system that combines two of the most technologically advanced solutions: two-stage AD process (instead of one stage) and methanogenesis process realized in a Continuously Stirred Tank Reactor (CSTR) equipped with a Rotating Biological Contactor (RBC) [7].

A hydrolytic thermal pre-treatment prior to methanogenesis is beneficial to solubilize suspended solids, reducing the volatile solids from 1.9 % up to 6 % in comparison with the conventional monophasic systems [8]. The effect of a hyper-thermophilic (70 °C) pre-treatment step on the thermophilic (55 °C) anaerobic digestion resulted in a 12 % higher organic suspended solid removal than the one-step thermophilic process [9]. Volatile Fatty Acids (VFA) and dissolved solids are more easily assimilated by methanogenic bacteria with respect to original molecules, increasing the entire biogas production process yield. It has been demonstrated that the two-stage biomethane production process is 11 % higher when treating primary sludge, and up to 37 % higher when treating secondary sludge [10].