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Digestate as bio-fuel in domestic furnaces

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ABSTRACT

This study investigates the use of the biogas power plants byproduct (digestate) as biofuel in an ordinary domestic air furnace. The digestate, disposed by a 1 MW biogas plant located in Italy, was dried out and pelletized in order to be used as fuel in a wood pellet furnace with 29 kW_{th} of nominal power, commonly installed in industrial HVAC systems. The first test was carried out starting from a heavily dried pellet called "digestate 0" characterized chemically and physically in order to obtain its composition, while its ashes were tested using an optical thermal dilatometer for the softening point evaluation. This first test outlined that the "digestate 0" pellets were not suitable for combustion applications even when mixed with an equal part of pure wood pellets. The research then focused on the raw digestate drying process through a set of physical and chemical tests. It was found that a temperature of 150 °C maximizes the higher heating value of the new "digestate 1" at 16.6 MJ/kg. However, to further avoid the ash sintering, "ultimate digestate" pellets were prepared mixing 50% of "digestate 1" and 50% of wood. The digestate obtained in such a way was experimentally tested through several runs of the air furnace. In these tests, the overall efficiency as well as the furnace emissions was measured.

1. Introduction

The anaerobic digestion of organic and/or waste matter produces a gas mixture known as "biogas" composed of about 50% of methane and 50% of CO_2. The process generates also a byproduct known as digestate [1,2]. The biogas is used for CHP applications after a process of filtration which eliminates little amounts of sulfuric gases; it can be also upgraded to bio-methane [3] for automotive fueling.

The digestate disposed by biogas power plants is composed of a liquid fraction and a solid fraction. The liquid part has a high level of nutrients while the solid fraction balances the humic equilibrium of the soil [4]; for this reason Italy is one of the countries where the digestate is categorized as agricultural byproduct with fertilizing properties [5].

On the other hand liquid and solid digestate from anaerobic digestion of manure contain high levels of nitrogen in organic and inorganic form [4]. This limits its application into soils as reported in the European "Nitrates Directive" which imposes the annual maximum spreading of 170 kg of nitrogen for hectare of soil in several sensible areas of the EU union [6].

This limit reduces feasibility and profit of biogas power plants which use manure as feedstocks, because farmers are often forced to buy or rent hectares of soil to spread the digestate. For these reasons, the utilization of digestate as fuel will lead to the combined advantages of exploiting a byproduct for energy purposes together with the reduction a common issue related to biogas plants. This paper investigates the behavior and characteristics of a pelletized solid digestate used as fuel in domestic furnaces.

Digestate disposal problem has become relevant in recent years only; this is the result of the great number of biogas power plant installed. Nevertheless, literature review showed little works about using combustion as a possible solution to this issue. Other researches focus on digestate composting or its disposal in landfills [7,8]. Contrary to these solutions, the combustion of digestate pellets in small air furnaces is easy to implement in situ.

The application of pelletized digestate as fuel in heat generators is presented by Kratzeisen et al. [9] where two different digestate pellets are tested in a biomass combustion facility. The pollutant emissions and combustion behavior are there evaluated and discussed. A further study, developed by Li et al. [10], investigates the combustion of digestate in order to increase the CHP efficiency of a biogas power plant. Reference [11] analyzes the feasibility of the combustion of manure digestate for district energy production. Further studies about digestate combustion are reported in literature [12–14].

The first attempt to exploit pure digestate into a furnace started from the solid byproduct obtained from the liquid–solid separator of the plant, dried and pelletized. During the drying process with hot air, the inorganic nitrogen (ammonia) evaporates and it can be converted into ammonia salts in an acid scrubber [4]. These salts can be used as fertilizer in agriculture.

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In addition, the high temperature of drying resulted into the torrefaction of the digestate. This phenomenon stabilizes the digestate properties and increases its energy density. The digestate was subsequently transformed in pellets and burned in a furnace; however the torrefaction process consumes the volatile part of the digestate and the further combustion becomes difficult.

2. Material and methods

In this work, digestate pellets from the anaerobic digestion of a feedstock composed of manure, maize flour and straw are characterized through physical and chemical analyses. In order to evaluate the overall efficiency of the furnace, the machine performance was first evaluated using a "ENplus A1" pellets in accordance with the European regulation "EN 14961-2". Then "digestate 0" pellets were tested under two different conditions: pure digestate combustion (that failed due to sudden ash sintering) and 50% (in weight) digestate pellets and 50% certificated "ENplus A1" wood pellets combustion. In addition, the influence of the drying temperature on the properties of the digestate was evaluated by experimental analyses. Finally a new pellet, called "ultimate digestate", was produced and investigated. It is composed by a mix of an half of "digestate 1" and an half of sawdust wood obtained from the previous "ENplus A1" wood pellets. "Ultimate digestate" was characterized both chemically and physically. During its combustion test emissions were also investigated and compared with that of certified "ENplus A1" pellets.

2.1. Combustion facility

The facility used in this work is a commercial air furnace of 29 kW_{th} of nominal power. The fuel enters into the furnace through an auger connected to a hopper which is weighted during each tests in order to evaluate the fuel consumption. Before leaving the furnace, the exhausts pass through a heat exchanger increasing the temperature of an air flow. After the exchanger, the exhausts leave the air furnace through a chimney, while the hot air is directed into a channel where an Extech HD300^{TM} anemometer is placed. This instrument measures and records the air velocity through a blade anemometer and the air temperature through a K type thermocouple. The facility described before is reported in Fig. 1. A combustion test generally consists of 40 min (2400 s) at max power, and data acquisition starts when furnace exhausted temperature was stabilized. The exchanger blower is activated when air raised over 37 °C. The fuel is fed into the brazier with a 10 s of auger run and 15 s of stop. The overall efficiency of the air furnace in case of "digestate 0"–"ENplus A1" pellets co-feeding was calculated by the Eq. (1).

$$\eta_{tot} = \frac{\rho_{air} c_{p,air} w A \Delta T}{\dot{m}_{bio} HHV_{dig} f_{dig} + \dot{m}_{bio} HHV_{wood} f_{wood}} \quad (1)$$

where $\rho_{air} = 1.225$ [kg m^{-3}] is the density of the ambient air, $c_{p,air} = 1.005$ [J kg^{-1} K^{-1}] is the specific heat of the ambient air, w [m/s] in the average air flow velocity, $A = 0.0314$ [m^2] is the section of the outlet duct, ΔT [K] is the air temperature increase, $\dot{m}_{bio}$ [kg/h] is the biomass consumption, HHV_{dig} [MJ/kg] is the higher heating value of the type "digestate 0" pellets, f_{dig} is the mass fraction of the "digestate 0" pellets in the fuel, HHV_{wood} [MJ/kg] is the higher heating value of the wood pellets and f_{wood} is the mass fraction of wood pellets in the fuel. Eq. (5) is adaptable in case of single feeding with pure digestate or pure wood considering equal to zero the mass fraction of wood or digestate.

2.2. Chemical analysis

In order to obtain the average dry-ash-free (*daf*) composition of the digestate pellets, a sample of "digestate 0" and of "ultimate digestate" pellets was tested in a EA 1110 CHNS-O analyzer. In addition, the pellets were reduced to ash by heating them in a stove at 550 °C for 4 h [15] to estimate the ash content *ASH* [%]. The average "as-received" (*ar*) composition of the pellets was then calculated using Eqs. (1)–(6) [16]. The moisture of the pellets *M* [%] is almost zero as a result of the heavy drying process.

Fig. 1. Combustion facility.

$$C_{ar} + H_{ar} + N_{ar} + S_{ar} + O_{ar} + M + ASH = 100 \quad (2)$$

$$C_{ar} = \frac{C_{daf}(100-M-ASH)}{100} \quad (3)$$

$$H_{ar} = \frac{H_{daf}(100-M-ASH)}{100} \quad (4)$$

$$N_{ar} = \frac{N_{daf}(100-M-ASH)}{100} \quad (5)$$

$$S_{ar} = \frac{S_{daf}(100-M-ASH)}{100} \quad (6)$$

$$O_{ar} = \frac{\left(100-C_{daf}-H_{daf}-N_{daf}-S_{daf}\right)(100-M-ASH)}{100} \quad (7)$$