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Mixing in digesters used to treat high viscosity substrates: The case of olive oil production wastes

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ABSTRACT

Olive pomace (OP) and olive mill wastewaters (OMW) are two residues that are derived from olive oil production. The high TS content and the presence of polymeric ligno-cellulosic compounds impart a very high viscosity value of about 180 cP to the OP–OMW mixture. In this condition, the Rushton impeller, which is normally used in digesters, is unable to guarantee a homogenous mixing of the reactor medium. Four different impellers have been tested with the aim of improving the mixing of the reaction medium: a Pelton Impeller, a Rushton impeller with six 45° inclined blades, a marine impeller (MI) with three blades and an anchor impeller (AI). The marine and the anchor impellers have permitted homogenization of the reaction medium and have consequently led to a good biogas production. Therefore, these two impellers have been used in combination with a two-stage AD configuration, based on the separation of the two distinctly different groups of bacteria (acidogens and methanogens), in order to reproduce the optimal operative conditions for the different microorganisms in each stage. The tests have demonstrated that an AI can be recommended for a one-stage configuration, while a MI is necessary for a two-stage configuration.

1. Introduction

Digesters fed with mixtures with a high TS content have a great potential for the efficient conversion of agricultural, municipal and household wastes into biogas [24]. Increasing the solids concentration in the digester, in fact, permits the size of the reactor to be reduced, and consequently the economics of the AD of these materials to be improved. However, the high viscosity caused by a high TS concentration can severely reduce the mass and heat transfer among the enzymes, bacteria and substrates in the digester. Adequate mixing is required to accelerate the diffusion processes and thus to improve the reaction kinetics for organic mixtures with high TS contents. Agitation is fundamental for many processes, and in particular for AD in order to mix the liquid, to permit the suspension of sedimentable solids, to degas the produced biogas bubbles and to promote the heat transfer from the heating surface. Agitation is influenced by the velocity of a liquid, the intensity of turbulence, the rate of energy dissipation and its distribution in the vessel, and finally by the viscosity of the reaction medium, all of which determine the fluid dynamics of the reactor [3].

Semi-solid OP and liquid OMW are wastes that are derived from olive oil production. OP is the solid residue that remains after oil extraction from cold-pressed olives. It is characterized by a high organic concentration (COD > 250 g/L), and in particular by high contents of TS and polymeric substances, such as lignin and cellulose, high electrical conductivity, a high concentration of polyphenols (0.1–5 g/L) and low pH (4–6) [4]. Olive mill wastewaters are liquid wastes from olive oil production. OMW is derived either from the water used for olive washing before oil extraction through the pressing operation, or from the water content in olive drupes. They present an acid pH, a browny -black color, a very low TS content (1–2% *w/w*) and consequently a COD concentration which usually does not pass 40 g/L. As it is mainly constituted by water, OMW has a density that is close to 1000 kg/m^3 [5].

Previous studies have demonstrated that the biogas performance of an OP–OMW mixture at a 10% *w/w* TS concentration can be improved by the addition of 5 g/L of $CaCO_3$ [6,20]. This pretreatment, in fact, makes it possible to pass from a biogas production of 0.4 NL/L to one of about 22 NL/L. It can explain the ability of calcium carbonate to promote the formation of a biofilm on lignocellulose materials, where the biomass growth increases. Moreover, Chen et al. [8] underlined that calcium is known to be

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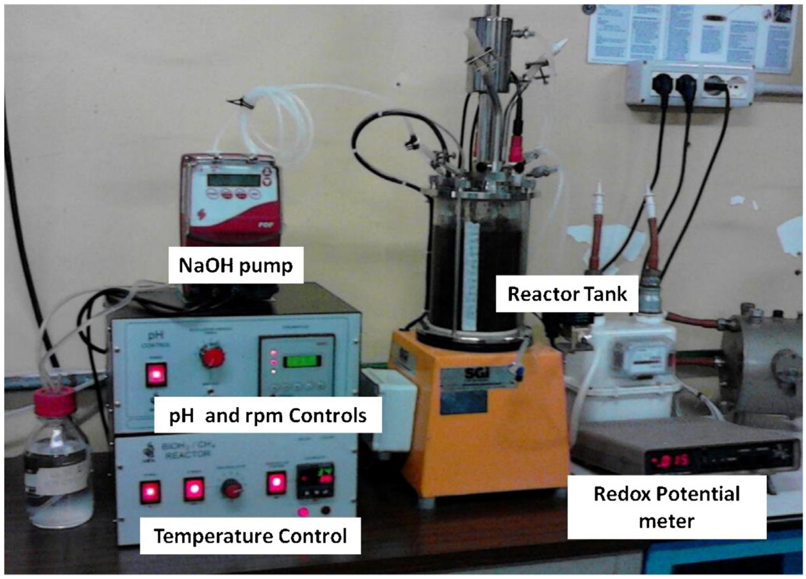

Fig. 1. The 2 L CSTR reactor used for the screening tests.

essential for the growth of certain strains of methanogens and for the formation of microbial aggregates. Jackson-Moss et al. [13] observed that Ca^{2+} concentrations of up to 7 g/L have no inhibiting effects on anaerobic digestion, although $CaCO_3$ guarantees a buffering action that prevents the acidification of the reaction medium as a consequence of VFA production in the acidogenic phase [20]. Finally, $CaCO_3$ has been shown to significantly reduce the inhibiting polyphenol concentration in the reaction medium [6].

In their test, the OP–OMW mixture was digested in continuous mode in a 2 m^3 pilot reactor [5]. In spite of a good biogas production of 1.4 NL/Ld, the test was affected by a mixing problem due to the high reaction medium viscosity of the high concentrations of sedimentable solids and organic polymeric compounds. The Rushton impeller, which was used to mix the reaction medium, was not completely adequate for the homogenization of the total volume of the reaction medium. The present work has the aim of optimizing the stirring system of the OP–OMW mixture by testing four different impellers: a Rushton turbine with 45° inclined blades, a Pelton turbine, a marine impeller and an anchor one. Taking into account the obtained results, the best two impellers have been combined with a two-stage anaerobic digestion configuration, which is known to improve the robustness of the system, facilitate a better control and optimize the overall anaerobic digestion process [21].

2. Materials and methods

This work has been divided into three sections. The first one, "Screening Tests", deals with two tests that have had the aim of proving the difficulties of mixing the OP–OMW mixture with a traditional Rushton turbine during anaerobic digestion. The first test has been named "Zero Test" (ZT) and it demonstrates how a high reaction medium viscosity, due to the high TS concentration and to the presence of polymeric organic compounds, can inhibit the fermentation process. In the second test, called "Destoned Test" (DT), the OP–OMW mixture was filtered in order to remove the sedimentable solids and consequently to decrease the viscosity of the reaction medium, thus improving the performance of the Rushton turbine. The second section, called "Impeller Tests", presents four tests in which the OP–OMW mixture was fermented using four different mixing systems while the rotational velocity of the impellers was kept constant. Finally, the third section, "Two-stage Configuration Tests", represents an attempt to improve the biogas production of the two best tests of the previous section, by combining them with a two-stage anaerobic digestion configuration. All the tests dealt with in the three sections were conducted in triplicate.

Table 1
Chemical characteristics of OP and OMWW.

	OP	OMW
Density (kg/m^3)	969.50 ± 41.2	989.40 ± 5.31
pH	6.75 ± 0.05	4.86 ± 0.01
TS content (g/l)	331.33 ± 6.81	12.04 ± 0.02
VS content (g/l)	305.60 ± 6.18	7.49 ± 0.21
Low heat value (kJ/kg)	25.504 ± 52	negligible

2.1. Screening tests

2.1.1. OP, OMW and inoculum characteristics

The OP and OMW both originated from Melendugno, a little town located near Lecce in the south of Italy. The OP was derived from the olive production operations. These operations include a three-phase centrifugation, which is used to separate the solid phase, oil phase and aqueous one as well as the OMW from previously pressed olives. Table 1 summarizes the main characteristics of the OP and OMW, which were evaluated experimentally at least three times.

In order to guarantee the presence of methanogenic bacteria in the reaction medium, bovine manure was used as an inoculum, following the suggestion of Shigematsu et al. [22], who reported that bovine manure is one of the most efficient methane bacteria source producers. The initial conditions of the inoculums were: pH 7.3, density = 888.4 Kg/m^3, TS = 221.4 g/L and VS = 183.76 g/L.

2.1.2. The experimental apparatus and the preparation of the OP–OMW mixture

The two tests mentioned in the first section were conducted in a 2 L volume CSTR reactor (Fig. 1). The reactor, thermostated at 35 °C, included pH, rH and temperature monitors and was also equipped with a condenser to remove water from the biogas flow. Mixing was guaranteed by the presence of a Rushton impeller, which was