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Combination of decentralized waste drying and SSF techniques for household biowaste minimization and ethanol production

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ABSTRACT

The results of the demonstration of an innovative household biowaste management and treatment scheme established in two Greek Municipalities for the production of lignocellulosic ethanol using dehydrated household biowaste as a substrate, are presented within this research. This is the first time that biowaste drying was tested at a decentralized level for the production of ethanol using the Simultaneous Saccharification and Fermentation (SSF) process, at a pilot scale in Greece. The decentralized biowaste drying method proved that the household biowaste mass and volume reduction may reach 80% through the dehydration process used. The chemical characteristics related to lignocellulosic ethanol production have proved to differ substantially between seasons thus; special attention should be given to the process applied for ethanol production mainly regarding the enzyme quality and quantity used during the pretreatment stage.

The maximum ethanol production achieved was 29.12 g/L, approximately 60% of the maximum theoretical yield based on the substrate's sugar content. The use of the decentralized waste drying as an alternative approach for household biowaste minimization and the production of second generation ethanol is considered to be a promising approach for efficient biowaste management and treatment in the future.

1. Introduction

Waste management still remains a challenge for the growing world. From the total amount of Municipal Solid Waste (MSW) produced a 40–50% of it is considered to be biological waste. This percentage is higher in low and middle income countries according to the World Bank (2012).

The main environmental threat from biowaste is the production of methane during their decomposition in landfills. It is estimated that landfills are the third most important source of methane emissions in the United States of America (USA) (World Bank, 2012).

In the USA the strategy is to capture the landfill methane through the Landfill Methane Outreach Program (EPA, 2012). In the European Union (EU), the Landfill Directive (Directive 1999/31/EC) obliges Member States to reduce the amount of biodegradable municipal waste going to landfill by 35% of 1995 levels by 2016 (for some countries by 2020) which is expected to significantly reduce the problem. Moreover, Directive 2009/28/EC «on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC» obliges member states to use renewable energy resources. The fact that there is an ongoing economic crisis in many EU countries while, the predominant method of waste management and treatment is still landfilling, constitutes a significant problem for reaching legally-binding targets set by the EU legislation. The fact also, that the EU has set a 7% cap on biofuels produced from food crops in transport fuels, obliges member states to use alternative resources in order to reach the targets set. The already existing technologies, in many cases, need further optimization while they are unable to treat biowaste due to the fact that the raw material will biodegrade, loosing critical substances, if not treated ontime. Moreover, many biowaste treatment processes used today, are considered to be complicated and problematic and need to be further optimized.

European policy focuses on actions taken towards resource efficiency, circular economy and climate change adaptation and mitigation. A concrete strategy on circular economy and resource efficiency has not been elaborated up until now, while targets set by the European Commission (EC) policy in regard to the drastic

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reduction of greenhouse gases (GHGs), that play an important role in the negative impacts of climate change, have not been defined per sector.

Decentralized household biowaste drying for the production of fully dehydrated lingo-cellulosic biomass out of household biowaste and the subsequent production of second generation of ethanol, by using its carbohydrate content with the use of the SSF process (Sun and Cheng, 2002) constitutes a waste management and treatment option that has never been tested at any scale in the past.

The SSF process involves the simultaneous batch acid hydrolysis and fermentation of the lignocellulosic substrate, while it can also operate as a fed-batch process which is considered to provide substantial benefits to the whole environmental and economic viability of the process. The process is used for the treatment of different types of lignocellulosic materials (Olofsson et al., 2008) such as agricultural products and waste. The already existing processes use raw household biowaste material and their efficiency remains low, due to lack of stability in the substrate used on the one hand, and microbial activity that intercepts the enzyme activity during the fermentation process on the other hand, thus they do not operate at full scale worldwide (Sotiropoulos et al., 2015).

The fact that the mass and volume of the raw material is significantly reduced with relatively low energy consumption (0.9 kW h/$kg_{wet\ substrate}$) along with the fact that the carbohydrate content of the dehydrated material is preserved (Sotiropoulos et al., 2015), while the ethanol yield produced seems to be satisfying when compared to bibliography, constitutes a most promising and concrete, regarding its results, option for household biowaste management and treatment.

2. Materials and methods

2.1. Description of the case study areas

The Municipalities in which the innovative household biowaste (dried at decentralized level) to ethanol waste management scheme was established and implemented were Papagos-Cholargos and Aspropyrgos Municipalities. Both of the Municipalities belong to the Attica region in Greece. The total amount of Municipal Solid Waste (MSW) generated in Papagos-Cholargos Municipality in 2014 was 17,986 t $year^{-1}$ (392.3 kg cap^{-1} year) this quantity is less by approximately 8% than the one recorded by Sotiropoulos et al. (2015), which could be accredited to the ongoing economic crisis in Greece which has contributed to the significant reduction of MSW produced by the civilians (civilians throw less). In Aspropyrgos Municipality the quantity of MSW produced for 2014 was 16,114 t $year^{-1}$ (534.3 kg cap^{-1} year). In both Municipalities, the MSW generated are sent to the landfill of Ano-Liosia in Attica region, while a recycling system which includes the source separation of packaging waste using 610 blue bins for the case of Papagos-Cholargos and 450 for the case of Aspropyrgos Municipality (in both case the capacity is 1.100 L) has been established at a small scale. The collected recyclables in both cases, are transferred to the Mechanical Biological Treatment (MBT) plant of Ano-Liosia in Attica, in order to be recycled. Both of the Municipalities did not produce biofuels at any scale at the time this research started.

The selection of the participating households was performed on a voluntary basis by providing the necessary publicity and awareness raising campaigns in both Municipalities. In total 82 residencies (251 civilians) participated the demonstration of this innovative waste management scheme while more than 160 residencies showed willingness to participate to this research.

2.2. Training of the participating households/implementation of the innovative household biowaste to ethanol management scheme

Training seminars in the Municipalities and door to door for the civilians were implemented. The seminars main target was for the participating civilians, to provide pure substrate, for the bioconversion process of the dehydrated material, to take place. The seminars included: (a) introduction of the civilians in source separation techniques, (b) information on the environmental and socioeconomic benefits of the proposed household biowaste management scheme for both Municipalities, (c) presentation of the source separation guide to the civilians, and (d) presentation of the data that should be recorded during the implementation of the pilot program.

For the implementation of the innovative household biowaste management and treatment scheme, the following equipment was distributed to the participating householders: (1) a 23 L commercialized kitchen waste bin that was placed in the householders' kitchens for the collection of their biowaste, (2) a 120 L brown bin for the collection of the source separated household biowaste outside the participating households and (3) a source separation manual with guidelines for the proper separation of the generated household biowaste.

The waste material that should be disposed in the waste bins were: Kitchen waste which included all waste produced in kitchens in every form (cooked and uncooked) such as: pasta, rice, flour, cereals, meat, fish and bones, dairy, fruits and vegetables, including kitchen paper waste and garden waste in order to achieve higher cellulose content to our substrate.

The source separated household biowaste were transferred at the National Technical University of Athens (NTUA) facilities by the Municipalities waste authorities, 3 times per week for a period of 12 months (1 year) in order to be further treated. The waste were manually sorted by the research staff in order to define its purity levels while, it was further treated with the use of a commercialized biomass dryer in order to reduce its mass and volume and simultaneously preserve the incoming substrate's characteristics (Sotiropoulos et al., 2015). The main parts of the drying method used can be seen in Fig. 1:

The waste drying system used was a drum dryer with an agitation system used for crushing and pulverizing the material to 1–2 mm diameter. The specific model used was GC-100 of GAIA Corporation. The drying temperature was 175 °C while the dryer operated for an 8 h period in order to completely dehydrate 50 kg of wet substrate. Two trials were performed on a daily basis (16 h operation). The final dry product, having approximately 1–2 mm diameter was further enzymatically treated with the use of a pilot scale bioconversion facility installed at the NTUA premises. The main parts of the facility used for the bioconversion process are illustrated in Fig. 2:

The waste management scheme and its full operation is described in the Waste2bio project DVD film (Waste2bio Project DVD film, 2015)

2.3. Evaluation of the waste management scheme

Extended physicochemical characterization of the source separated household biowaste was performed by measuring a wide variety of parameters, related to the assessment of the effectiveness of the waste management scheme and the bioconversion process used.

The assessment of the innovative waste management scheme was implemented through the evaluation of the following parameters: