

Continuous Bioethanol and Biogas Production from Food Processing Waste

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1. Introduction

The necessity to reduce CO₂ emissions and oil consumption has been determining a new interest in bio-energy and bio-fuels in recent years (Farrell et al., 2006). The most promising of these fuels is bio-ethanol, which can be used with a clean combustion, has a high octane number (103), is chemically stable, non-toxic and biodegradable. Further, it can be used for vehicles transport as a mixture with oil or pure; in fact, as mixture does not require specific changes on the engine, while when used pure only small changes are requested. Finally, the CO₂ emission produced by the bio-ethanol combustion is “environmental friendly”, because deriving by renewable energy sources. However, the actual production of bio-ethanol based on corn starch is not long sustainable because of ethical, environmental and economical constraints and a second generation of bio-ethanol from ligno-cellulosic materials is growing (Galbe and Zacchi, 2007), the so called LC-ethanol. Another important option for the production of bio-ethanol is the use of bio-waste rich in sugars or starchy materials (Mahro and Timm, 2007). The main advantages of this option are related to the reduced demand for pre-treatments and hydrolytic steps and the abundance of C6 sugars. These materials are produced in large amount in Europe and can be considered an important feedstock for biofuels production: the generation of food-processing waste has been estimated in 222 millions tonnes per year, vegetable and fruit being at 140 million of tonnes/year (Waldron, 2007).

In this study we considered the bio-ethanol production through the fermentation of waste from the pastry and confectionery industry, which are particularly rich in fermentable sugars. Important aspects of the study were the use of continuous reactors (without and with biomass recycling) and the use of the yeast *Saccharomyces cerevisiae* EC1118 without sterilisation of the treated material.

Further, in order to enhance the use of the raw material also the anaerobic digestion for methane production was implemented in the process according to the scheme reported in figure 1.

2. Materials and methods

The raw waste treated in the experimentation showed COD concentrations of some 600 g/L with large abundance (up to 90%) of glucose, sucrose and fructose. This was diluted (10:1) to reduce mixing problems. Bio-ethanol fermentation was carried out in a continuous anaerobic stirred reactor (15 litres volume), without sterilisation, working at 35°C. At the beginning of the work the reactor was inoculated with *Saccharomyces cerevisiae* (strain EC1118). The following parameters were monitored: biogas

production, ethanol, sucrose, glucose, fructose, glycerol, lactic acid, the volatile fatty acids (from C2 to C7) and biomass (on selective and no-selective Petri plates).

The first part of the study was devoted to the study of the system working as a continuous stirred tank reactor (CSTR) at different dilution rates (0.1; 0.2; 0.3; 0.5; 0.67; 0.75 and 1.33 d⁻¹) while in the second part, according to the results previously gained, the dilution was fixed at 0.5 d⁻¹ and the biomass recycle was operated. Proved solid retention times were 2, 5, 10 and 15 days. After a steady state was reached, it was maintained for at least 4 HRTs and the mass balances were calculated. The biogas generated from the downstream of the fermentation process was estimated via BMP tests (Angelidaki et al., 2007). The BMP tests were run for the best reactor conditions: CSTR with biomass recycling at 0.5 d⁻¹ and with SRT of 10 days. The distillation bottom samples were obtained from distillation of the liquid phase coming from the fermentation on a glass distillation column (lab-scale).

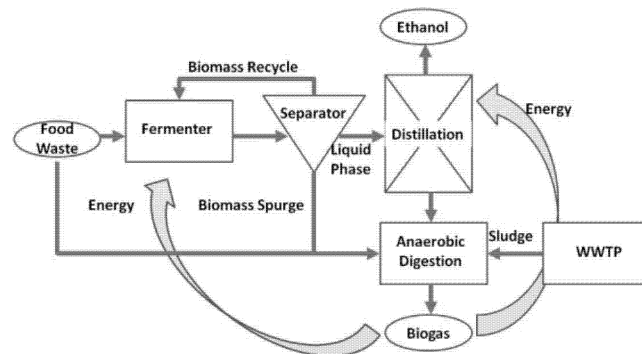


Figure 1-Scheme of the Plant for the production of bio-ethanol and biogas from food waste

3. Results and Discussion

3.1 Continuous fermentation trials at different dilution rates without recycling

The continuous fermentation tests were carried out operating at dilution rates in the range 0.1; 0.2; 0.3; 0.5; 0.67; 0.75 and 1.33 d⁻¹ and feeding the reactor with a solution at some 60 g/L as COD. From the mass balance on carbon (fig. 2) one can note how at low dilution rates (0.1-0.2 d⁻¹) the system completely used the influent substrate (carbon was the limiting compound for growth); then, 45% of influent carbon was converted into ethanol and a high fraction of sugars was converted into undesired by-products (VFA, lactic acid, glycerol etc...). About 15% of the influent carbon underwent to by-products transformation. In this condition, carbon was the limiting element as shown by the biomass concentration at dilution rates of some 0.1 d⁻¹.

In a ideal CSTR the dilution rate and the kinetic constants are linked by the formula

$$D = \mu - k_d$$

where, D is the dilution rate, k_d the decay constant and μ the growth rate, all with units, d^{-1} .

In this system, when at $D = 0.1 d^{-1}$ the two parameters showed similar magnitude and decay became an important factor because of the substrate scarcity.

On the other hand, when the dilution rate increased (greater than $0.3 d^{-1}$) part of the sugars was not used and the fraction of carbon converted into ethanol progressively reduced while by-products disappeared. During all the periods analysed the fraction of carbon converted into glycerol was below 3%.

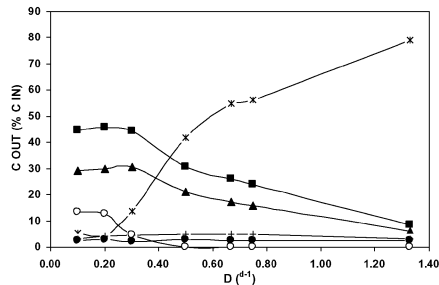


Fig. 2 Carbon mass balance for the single CSTR system

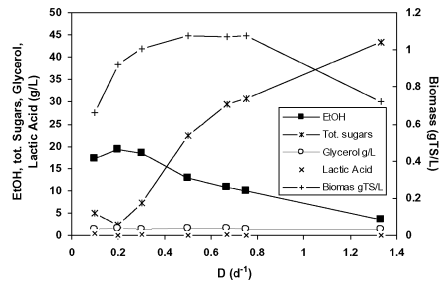


Fig. 3 The main parameters of the single CSTR system

When the dilution rate increased over $1 d^{-1}$ the biomass concentration decreased again since the value of D was similar to the maximal growth rate ($D \approx \mu_{max}$) as the system achieved the condition of wash-out. This fact was well explained by the ratio between the ethanol produced and the biomass produced (g/g): figure 4 shows that this ratio reached a pick at 25 g/g for dilution rates of some ($0.6-0.8 d^{-1}$) and values of some 20 g/g for dilution rate of some $0.5 d^{-1}$ while it reached values of some 5 g/g at dilution rates of $1.33 d^{-1}$. In addition, the maximum ethanol/utilized sugars ratio and the maximum specific productivity were obtained for a dilution rate of some $0.8 d^{-1}$; however, in that condition, the sugars used where only 50% of the influent. So, in order to optimize the process yields, it was decided to operate with a dilution rate of $0.5 d^{-1}$ and biomass recycling.

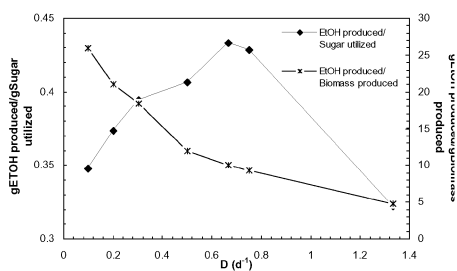


Fig. 4 EtOH produced/Sugars utilized and EtOH produced/Biomass produced for a single CSTR reactor

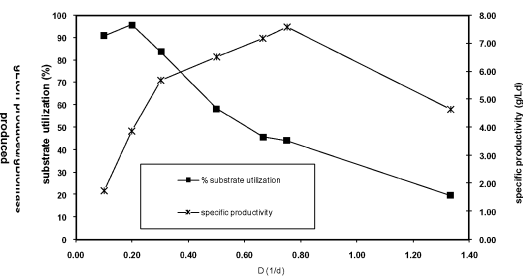


Fig. 5 Substrate utilization and Specific productivity for a single CSTR reactor

3.2 Continuous fermentation trials at different dilution rates with recycling

In the second part of the study the system was operated as a CSTR with biomass recycling at a dilution rate of 0.5 d^{-1} . The solid retention time (SRT) was varied between 2 and 15 days. Figure 6 shows the plot of the main parameters (sugars, ethanol and biogas) for different SRT: the ethanol concentration in the reactor increased with the solid retention time from 2 to 10 days and then remained constant at some 25 g/L when increasing the SRT from 10 to 15 days. On the other hand, the biogas production increased linearly with the SRT, passing from 10 to 40 L/day.

The mass balance for carbon is shown in figure 7: it turns out evident how, increasing the SRT, that is, increasing the biomass concentration in the reactor, the fraction of carbon converted to ethanol increased from 20 to 50%, the biogas increased from 10 to 40% while the effluent sugars disappeared, passing from 20 to less than 5%. By-products remained constant along the experimentation representing some 5% of the influent carbon.

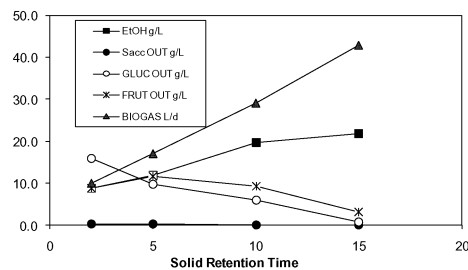


Fig 6 The main parameters for the system working like a reactor with biomass recirculation at constant dilution rate (0.5 d^{-1}) and a different SRT

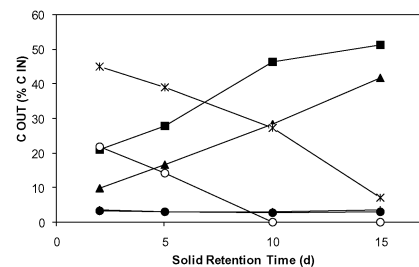


Fig.7 Carbon mass balance for the system working like a reactor with biomass recirculation at constant dilution rate (0.5 d^{-1}) and a different SRT

With specific reference to the ethanol/utilized sugars ratio (figure 8), this showed a trend similar to the ethanol concentration, presenting a maximum for solid retention times of some 10-15 days when the substrate utilisation was some 90% (figure 9). In those conditions the yield reached values of some 0.5 g/g, a value similar to that reported by Tao et al. (2005) who found in a recent research that it was possible to obtain some 0.488 g ethanol/g glucose operating under no-sterile conditions.

As for the specific productivity for ethanol (see figure 9), this increased from 4 to 10 $\text{g/L}\cdot\text{d}$ for a SRT of some 10-15 days. Also this value was in good agreement with literature data where reported productivities are in the range 5 – 20 $\text{g/L}\cdot\text{d}$ with CSTR with biomass recycling and ethanol concentrations in the reactor are between 20 and 70 g/L (Sanchez and Cardona, 2008).

The concentration of active yeast biomass was monitored along the experimentation by means of microbiological control. In particular, that was evaluated via selective and no-

selective Petri plates: the concentration of active biomass remained constant at some 2.5×10^8 CFU/mL despite the variation in dilution rates and solid retention times.

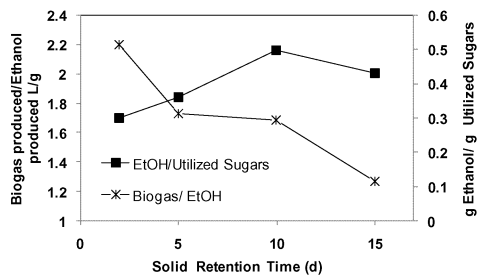


Fig. 8 EtOH produced/Sugars utilized and EtOH produced/Biomass produced for the system working like a reactor with biomass recirculation at constant dilution rate (0.5d⁻¹) and a different SRT

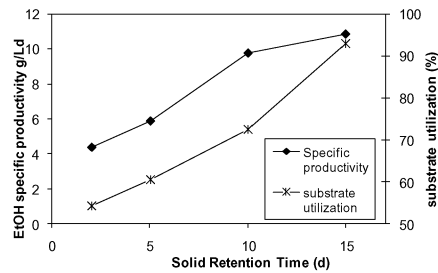


Fig. 9 Substrate utilization and Specific productivity for the system working like a reactor with biomass recirculation at constant dilution rate (0.5d⁻¹) and a different SRT

3.3 BMP tests

In order to gain the maximal energy revenue from the treated waste, both the biomass spurge and the residual fraction after distillation were tested for biogas production. The BMP tests, conducted under mesophilic and thermophilic conditions, showed the very high digestibility of the treated material. The biomass spurge of the fermentation and the distillation bottom stream reached values of 0.43-0.47 L biogas/g VS(biomass spurge) (Fig. 10) and 405mL biogas/gCOD (fig. 11) respectively distillation bottom stream. The maximum biogas production was reached in just few hours (less than 3 days) as the substrate is soluble and readily biodegradable.

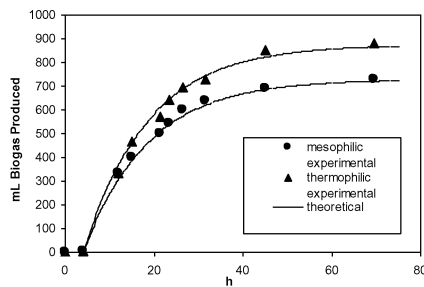


Fig. 10 BMP tests conducted on distillation bottom stream in mesophilic and thermophilic condition

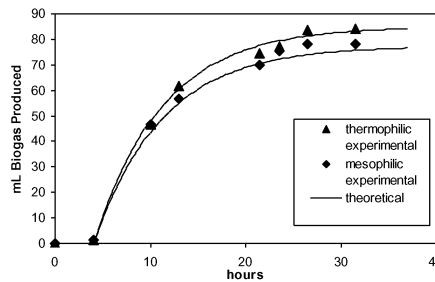


Fig 11 BMP tests conducted on biomass spurge in mesophilic and thermophilic condition

4. Conclusions

The following remarks can be derived from the study:

- food processing waste can be easily fermented in continuous anaerobic reactors working in mesophilic conditions without sterilisation. The process was able to show good yields (up to some 0.5 gEtOH/gused sugar) but with low substrate conversion when operating with dilution rates of some 0.5 d⁻¹;
- to improve these results a biomass recycle was introduced. In this situation the system was able to convert up to 90% of the sugars with ethanol specific productivity of some 10 g/L·d when operating with a dilution rate of some 0.5 d⁻¹ and a solid retention time of 10 days.
- Batch tests for biogas production carried out both in mesophilic and thermophilic conditions showed the possibility to produce some 0.4-0.5 m³ of methane per kg of volatile matter fed. This biogas can be then conveniently converted to thermal and electric energy to improve the energy balance of the system.

5. References

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