Methane production from process water of the hydrothermal carbonization of food waste and sewage sludge: Impact of substrate to inoculum ratio and hydrochar addition

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INTRODUCTION

Hydrothermal carbonization (HTC) has gained interest as an attractive waste management strategy to harness energy from wet and low-value biomass with the additional benefit of avoiding prior energy-drying step. The main product of the carbonization process is a carbon enriched solid material (hydrochar) with a high energetic density and caloric value (29 MJ/kg) that can be used as a solid fuel among many other industrial and environmental applications. Besides the solid phase, it also produces a small fraction of a gaseous phase and a high-strength liquid phase. Depending on the HTC operational condition and the raw biomass composition, high amount of organic and complex refractory compounds (i.e., phenols, furans, acetic acids, propionic acid, formic acid, pyrazines, aromatic amines, pyrimidines, aldehydes, esters, etc.) are usually found in the liquid phase resulting in high chemical oxygen demand and total organic carbon (Berge *et al*., 2011; Villamil *et al*., 2018). Thus, further valorization needs to be usefully accomplished before final dumping. Since the liquid phase contains several minerals (i.e., nitrogen, carbon and phosphorus compounds) and dissolves organics, it can be an interesting substrate for anaerobic digestion (AD) to reduce the organic matter content and to produce an extra energy by means of biogas production. In this work the effect of different substrate to inoculum ratio on the methane yield and the organic matter degradation of different HTC-liquid fraction from mixed biomass (sewage sludge, food waste and pruning waste) was investigated as well as the effect of sewage sludge + municipal solid waste-derived hydrochar addition on the methane yield and the specific methane production rate of two HTC-liquid fractions from mixed biomass.

MATERIALS AND METHODS

To carry out the experiments, five different liquid fractions (LFs) from HTC (220˚C and 1h) were used as substrates for AD (i.e., the liquid fraction of 100% sewage sludge (LF 100SS), the liquid fraction of 100% municipal solid waste of the metropolitan region of Chile (LF 100MSW_M), the liquid fraction of 32% sewage sludge + 68% municipal solid waste of the north region of Chile (LF 32SS + 68MSW_N), the liquid fraction of 22% sewage sludge + 78% municipal solid waste of the metropolitan region of Chile (LF 22SS + 78MSW_M) and the liquid fraction of 28% sewage sludge + 72% municipal solid waste of the southern region of Chile (LF 28SS + 72MSW_S)). The anaerobic digestion set-up consisted of the realization of two treatment Series (I and II) at mesophilic condictions (35 ± 2 °C). In the treatment Series I, the effect of three different substrate to inoculum ratio (SIR) (i.e., 1:1; 1:2, 1:3, based on g $tCOD_{substrate}$: $gVSS_{inoculum}$) was investigated by using five different liquid fractions from HTC as substrates. In the treatment Series II, the effect of SS + MSW_M-derived hydrochar obtained in the HTC was evaluated in the AD of two liquid fractions (LF 32SS + 68MSW_N and LF 22SS + 78MSW_M) at six different concentrations (i.e., 1, 5, 10, 15, 20 and 25 g/L).

RESULTS AND DISCUSSION

Figure 1 shows the cumulative methane production and total COD removal efficiency for each HTC-liquid fraction at three SIR (i.e., 1:1, 1:2 and 1:3) along the AD experiments. A very low methane production (4 – 44 $NmLCH_4$/g $tCOD_{added}$) was observed for all LFs treated at SIR=1:3 in agreement with the low tCOD removal efficiency (6 – 9%), probably due to substrate limitation (Figure 1 c, f). Higher pH values were also attained for SIR=1:3 ranging from 7.59 to 8.10 in comparison with those obtained for 1:1 (7.48 – 7.74) and 1:2 (7.47 – 7.93). This is in agreement with the TAN concentrations found in SIR=1:3 (i.e., 1235 mg/L average) at the end of the experiments which were higher than those found in 1:1 and 1:2 (increased by 11% and 9%, respectively). Although SIR=1:2 obtained better performance for some liquids, the rest of the residues showed similar behavior in methane yields at each SIR, being the LF of only MSW_M who always reached the lowest yield.

The effect of SS + MSW_M-derived hydrochar in the methane yield of the LFs of 22SS + 78MSW_M and 32SS + 68MSW_N was also assessed. For all treatments, the cumulated methane yields ranged from 52 to 157 $NmLCH_4$/g $tCOD_{added}$. It was observed that the addition of hydrochar substantially improved the methane production.

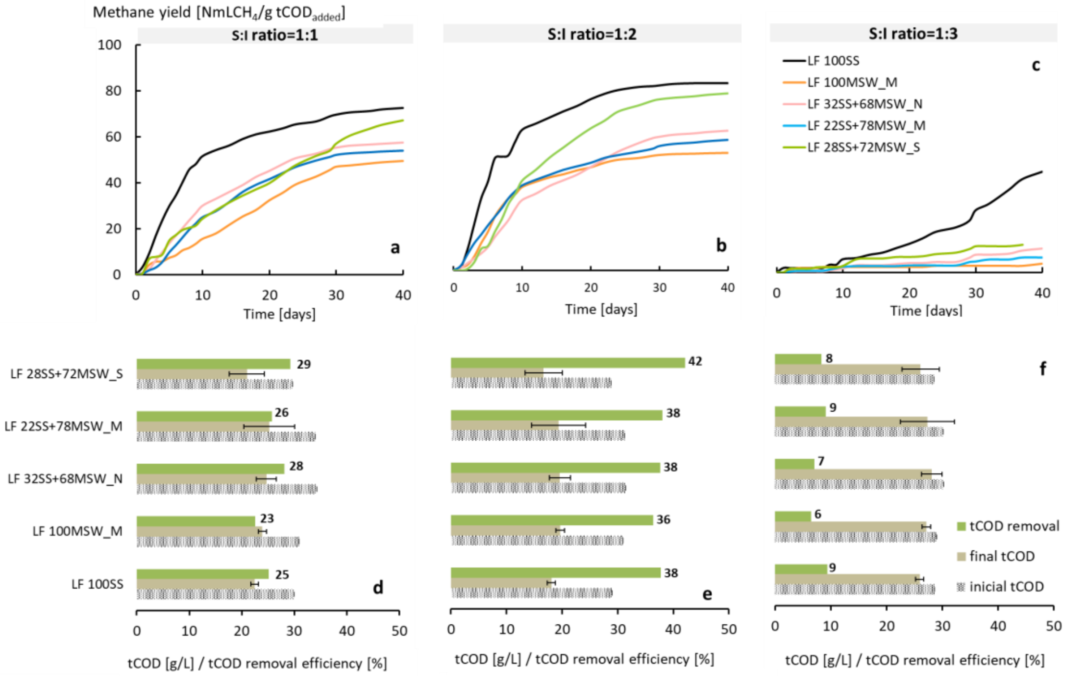

Figure 1. Cumulated methane yield (a, b, c) and total COD removal efficiency (d, e, f) for the HTC-liquid fractions at each substrate to inoculum ratio (SIR)

For the LFs of 22SS + 78MSW_M the methane yield increased from 52 up to 153 NmLCH$_4$/g tCOD$_{added}$ increasing the methane yield between 26% and up to 195% while for the LFs of 32SS + 68MSW_N there was an increase from 61 to 157 NmLCH$_4$/gtCOD$_{added}$ archiving an increment between 18 and up to 159% in comparison with the reactor without hydrochar. In this study, since more methane yield was produced from treatments with hydrochar than controls without hydrochar, it is assumed that hydrochar could facilitate the degradation of some reduced organic compounds commonly present in the HTC liquid fraction such as hydroxymethylfurfural (HMF), phenols, furans, butyrate, propionate, formic acid, etc. which are hard to degrade and remain at the end of the process (evidenced by the low tCOD removal discussed in figure 1). This may be due to the role of hydrochar to promote direct interspecies electron transfer (DIET) between bacteria and methanogenic communities in a metabolically and thermodynamically more efficient way. Syntrophic partners can attach to the char surface and utilize it to interchange electrons in biochemical reactions. Thus, it is presumable that hard-degraded compounds present in the spent liquors were metabolically favored by the presence of hydrochar. Results also showed that kinetics of the methanogenesis phase was also improved by leading to an early peak in the maximum methane production rate and shorting the lag phase for lower hydrochar dosages (i.e., 1, 5 and 10 g/L) (data not shown). The combination of HTC-AD technologies could add a safer waste management system with an additional energy recovery while a plus economic value is added to hydrochar by expanding its chain value.

CONCLUSIONS

The SIR had a significant impact on the methane yield and the tCOD removal efficiency of HTC-liquid fraction coming from different mixtures of SS + MSW. SIR of 1:3 reduced methane production while SIR of 1:2 obtained the best results. Additionally, the presence of SS + MSW_M-derived hydrochar (220 °C, 1 h) in the AD of the LFs obtained from the HTC of mixtures from sewage sludge, food waste and pruning waste significantly improve the methane yield (up to 195% more than control reactor), with the highest improvement archived at 15 g/L for both LFs studied as substrates (i.e., LF 22SS + 78MSW_M and LF 32SS + 68MSW_N). This work showed the feasibility of using the HTC-liquid fractions of mixed biomass to produce methane in a combined HTC-AD system.

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