Efficient hydrogen fermentation for 2 - stage anaerobic digestion processes: Conversion of sucrose containing substrates

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Introduction

In order to optimize the conversion of biomass in a biogas plant one possibility is to setup a 2 - stage anaerobic digestion process. In the first stage H_2, CO_2 and fatty acids are the main products. The fatty acids are converted into CH_4 and CO_2 in the second stage. So the hydrogen fermentation provides not only easy convertible fatty acids for the following steps, but also H_2 which can be used as well. According to theoretical calculations the 2 - stage process has a 6% higher energy recovery than a one stage process. The real values can be even higher because of the improved substrate conversion. The energy recovery in the real process could be increased up to 22% as seen in Fig. 1. Another positive aspect are the better combustion properties of the hydrogen enriched biogas regarding to CO_2 and NO_X emissions.

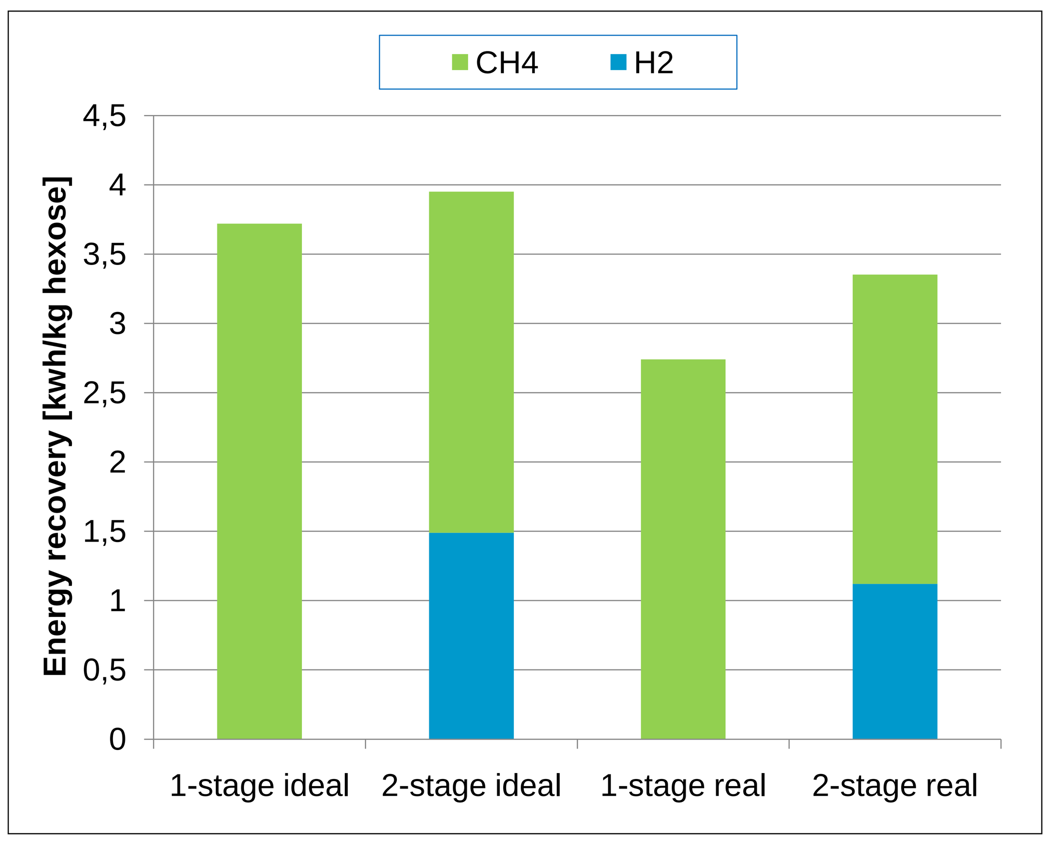

Fig. 1 Energy recovery in 1-stage and 2-stage processes (ideal and real)

This study deals with the thermophilic hydrogen fermentation step in a new bioreactor system with 2 sucrose containing substrates: thick juice, a pre-product of sugar production and molasses, a by- product of it. The conversion of sucrose resulting in the highest hydrogen yield has only H_2, CO_2 and acetate as products according to following formula:

$$C_{12}H_{22}O_{11} + 5H_2O \rightarrow 8H_2 + 4CO_2 + 4CH_3COOH$$

Thermophilic fermentation has 3 major advantages:

- ❖ Higher product yields
- ❖ Sanitation and therefore elimination of pathogenes
- ❖ Avoidance of hydrogen consuming organisms like methanogenes

Experimental Setup

A new designed carrier based bed reactor (CFTB) with a total volume of 30 L was applied for these experiments. It was operated at a temperature of 80 °C and a pH of 6.5 (adjusted with 2M NaOH). The hydraulic retention times in these tests were 20, 15, 12 and 10 h which are equal to organic loads between 0.5 and 1 g/L/h (10 g/L sucrose). A co-culture of the extreme thermophiles *C. saccharolyticus* and *C. owensensis,* which were pre-cultured in a stirred tank reactor were used as inoculum. However, the fermentations were conducted in an auto selective mode. For the process monitoring gas volume and gas composition as well as acids and sucrose in the liquid phase were determined.

Results

Generally this new bioreactor configuration resulted in an effective immobilization of the hydrogen producing microorganisms providing a very stable process, which could be easily recovered after power failure or leakages. Sucrose in the substrate was completely consumed and converted to acetate, lactate and small amounts of ethanol. The acids formed are displayed in Fig 2a. Lactate concentration stayed nearly constant at about 1.8 g/L with both substrates.

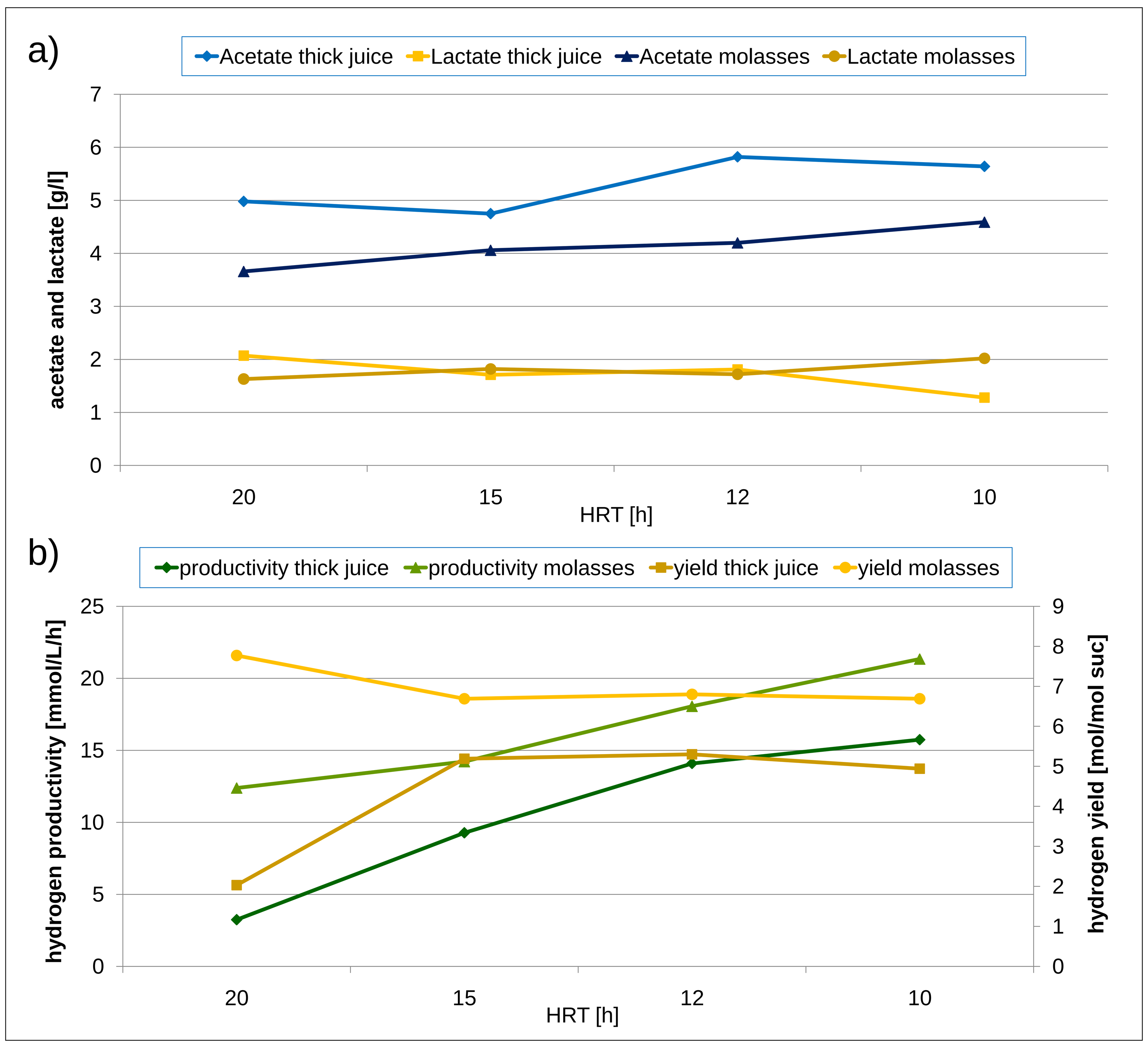

Fig. 2 a. Formed acids, b. Hydrogen productivity and yield during the fermentation in a CFTB reactor (Co-culture C. saccharolyticus and C. owensensis). Average data from long term fermentations

The concentration of acetate during the thick juice fermentation was 4.9 - 5.8 g/L, during the tests with molasses 3.7 - 4.5 g/L, whereby the theoretical maximum is 7 g/l. The hydrogen productivity and yield (Fig. 2b) were higher during the molasses fermentation than using thick juice though less acetate was produced. This was most probably due to the composition of the different substrates. Molasses contains additional proteins and amino acids which can be converted to hydrogen as well. This falsifies the relation between acetate and hydrogen production The H_2 - productivity increased in both tests with decreasing HRT and ranged from 2.7 - 15.1 mmol/L/h with thick juice and 12.2 - 22.7 mmol/L/h with molasses. The hydrogen yield stayed nearly constant around 4.5 - 5.5 mol/mol sucrose in both fermentations at a HRT of 15, 12 and 10 h corresponding to 55 – 69% of the theoretical maximum. Methane was never detected.

Fig. 3 The CFTB reactor

Conclusion

These tests revealed that sucrose based substrates can be efficiently converted to H_2 and acids. Although the reached hydrogen productivities and yields were more than acceptable with both substrates, additional fermentations with shorter HRT and higher organic loads will be performed with molasses which is more complex and needs therefore less additional nutrients.

The aim of HYVOLUTION is to develop a blue-print for non-thermal decentral hydrogen production process using local biomass. HYVOLUTION is an integrated project, funded by Framework Programme 6 of the EC.

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