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# Effect of anaerobic reactor process configuration on useful energy production

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ARTICLE INFO

*Article history:*
Received 30 June 2009
Received in revised form
7 January 2010
Accepted 14 January 2010
Available online 4 February 2010

*Keywords:*
Biological hydrogen production
Methane
Phased reactors
Staged reactors
UASB
Specific energy yield

ABSTRACT

The effect of reactor process configuration on anaerobic production of useful energy (hydrogen and methane) from a complex substrate was investigated for the following reactor systems: suspended growth, two-phase mixed, two-stage mixed, upflow anaerobic sludge blanket (UASB) reactor, and two-phase UASB. The mixed two-phase and two-stage configurations yielded the highest specific energy productions of 13.3 and 13.4 kJ/g COD fed, respectively. Reactor process configuration influenced microbial pathways in acidogenic reactors in that butyrate was the predominant volatile acid in phased configurations, whereas acetate was predominant in the staged configuration. The UASB reactor achieved the highest average daily energy production per reactor volume of 101 kJ/L reactor-d. All reactor configurations achieved high COD removals on the order of 99%. However, hydrogen represented only 3% of the total energy produced by the two-phase mixed and two-phase UASB configurations. Theoretical analysis revealed that the maximum specific energy production by the two-phase suspended-growth configuration is only 9% higher than that for a single-stage mixed reactor. Consequently, the production of hydrogen from complex substrates in these process configurations does not seem to be justifiable solely from an energy point of view. Instead, it is suggested that phased anaerobic systems should be considered primarily for improved process stability whereas resultant hydrogen production is of secondary benefit.



## 1. Introduction

Anaerobic biotechnology is realizing renewed interest due to its ability to produce useful forms of energy from wastewaters, municipal solid waste, manure, and various agricultural crops. Whereas anaerobic conversion of wastes to methane has been employed for decades, more recent work has focused on anaerobic production of hydrogen. Advantages of hydrogen include its ability to power conventional fuel cells, and to facilitate reduced nitrogen oxides ($NO_x$) emissions when blended with compressed natural gas (CNG) as fuel for internal combustion engines (U.S. Department of Energy, 2007). Indeed, application of blended hydrogen and CNG (which contains at least 90% methane) as a fuel source has been suggested as a bridge to a future hydrogen economy (U.S. Department of Energy, 2007). These advantages indicate that it may be desirable to obtain hydrogen from anaerobic waste biodegradation at the expense of reduced methane production. However, because hydrogen is readily consumed in methanogenic systems, it is necessary to segregate hydrogen production from methanogenesis.

Several strategies have been employed to enhance hydrogen production, such as application of reduced pH and low hydraulic retention time (HRT) to eliminate methanogens by "kinetic control" (Ghosh and Klass, 1978). Studies have determined that maximum hydrogen production rate (Oh et al.,

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0043-1354/$ – see front matter 
doi:10.1016/j.watres.2010.01.010

2004) or maximum hydrogen yield per unit of substrate (Zhang et al., 2003; Fang and Liu, 2002) are realized at pH of 5–6 using HRTs ranging from 6 to 24 h, depending on the nature of the substrate. Methanogenic activity can also be minimized by the use of chemical inhibitors, heat shock pretreatment of inocula, or pure cultures. However, these techniques may be prohibitive at an industrial scale due to significant costs that would be realized.

Selection of an appropriate process configuration is critical to successful operation and warrants detailed consideration (Speece et al., 2006). Pohland and Ghosh (1971) introduced the two-phase concept, which physically separates acidogenesis from subsequent fermentations and methanogenesis into different reactors. By segregating microbial groups, optimal environments can be provided by each reactor, and thus improve overall process efficiency, reaction rate, stability, and operational control (Ghosh and Klass, 1978; Dinopoulou et al., 1988). Others (Romli et al., 1994; Azbar et al., 2001; Kraemer and Bagley, 2005) have studied two-stage systems, which recycle biomass from the methanogenic reactor to the acidogenic reactor. Staged systems typically require less alkalinity for pH control (in the acidogenic reactor) compared to phased systems.

In two-reactor systems, hydrogen and methane can be collected separately; therefore, the two-phase and two-stage configurations are attractive from an energy perspective. By contrast, a single-stage system provides essentially all of its useful energy in the form of methane.

Historically, comparative studies between reactor configurations have been completed with respect to substrate removal, effluent quality, and organic loading rate. However, no comparisons between several reactor configurations were identified that evaluate proportionate hydrogen and methane production. Therefore, the work described herein was undertaken to investigate the effect of reactor process configuration on the proportion of useful energy production in the forms of hydrogen and methane during anaerobic biodegradation of a well-defined, complex substrate.

## 2. Materials and methods

Fig. 1 is a schematic of the process configurations, which included a suspended-growth (Sus), two-phase suspended-growth (2PSus), two-stage suspended-growth (2SSus), an upflow anaerobic sludge blanket (UASB), and a two-phase UASB (2PUASB) system. All reactors were maintained at 35 °C. A complex substrate (Ensure®) was chosen as the carbon source for the preparation of synthetic wastewater used in this study. Ensure® is marketed as a liquid diet food intended to supply a significant portion of daily human nutrition requirements. Ensure® provides 6 g total fat, 40 g total carbohydrates, 9 g protein per 240 mL, plus vitamins and minerals. In addition to Ensure® (120 mL/L), the components employed for synthetic wastewater were as follows (g/L): $K_2HPO_4$ $3H_2O$ (0.35), $MgSO_4$ (0.20), $FeCl_2$ $4H_2O$ (0.01), $CoCl_2$ $6H_2O$ (0.007), $NiCl_2$ $6H_2O$ (0.007), tap water (880 mL/L). The synthetic wastewater COD was $40 \pm 1$ g/L and was prepared in 10-L batches every 10 days and was stored at 4 °C to minimize biological growth.

### 2.1. Reactor design and start-up

Table 1 provides a summary of influent volumetric and COD mass flow, reactor volume and solids retention times (SRT).

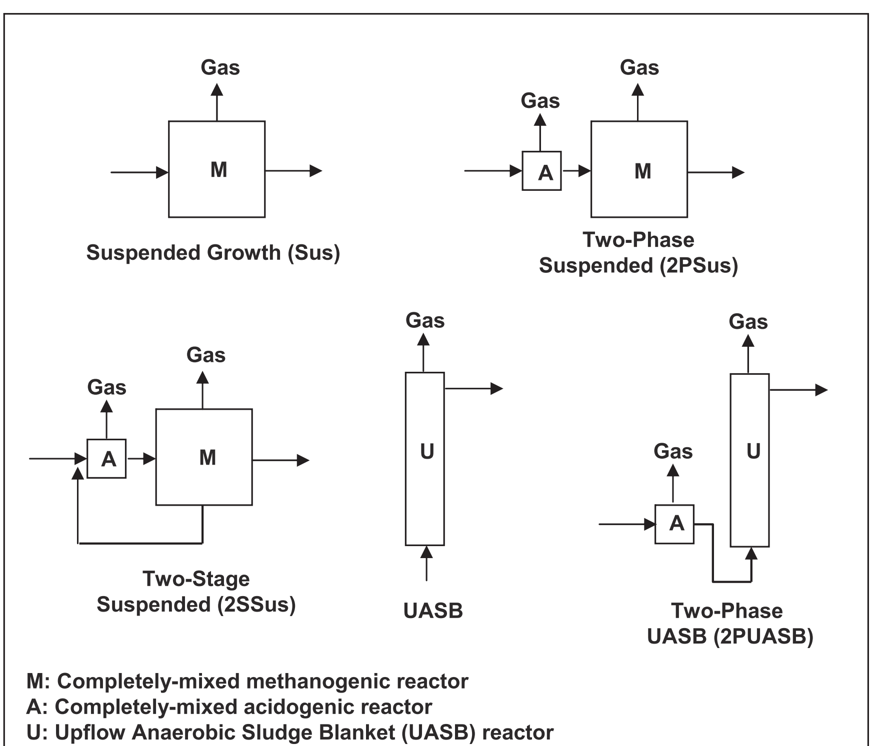


**Fig. 1 – Schematic of reactor process configurations.**