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Fermentative hydrogen production from food – industry wastes in a CSTR-type reactor: The influence of Hydraulic Retention Time

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Renewable Energy Resources

- Growing energy demands
- Decreasing reserves of fossil fuel resources
- Environmental problems

→ Renewable Energy Resources

BIOMASS : Biological (organic) material that can be converted into ***biofuels*** (CH_4, H_2, bio-ethanol, bio-diesel).

↓

agricultural residues
forest residues
livestock residues
energy crops
municipal and industry wastes and wastewaters

Food Waste

- Uneaten food and food preparation leftovers from residences, commercial establishments and institutional sources.
- Food industry wastes (out of date products, leftovers from the production processes, etc)

Food industry wastes used in this study

- The mixture of seven out of date solid baby foods at different flavors

Rich in carbohydrates, which are an ideal substrate for fermentative hydrogen production.

Food waste has been proven to be highly desirable substrate for anaerobic fermentation due to its high digestibility and well balanced carbon and nutrient contents.(*Zhang et al., 2007*)

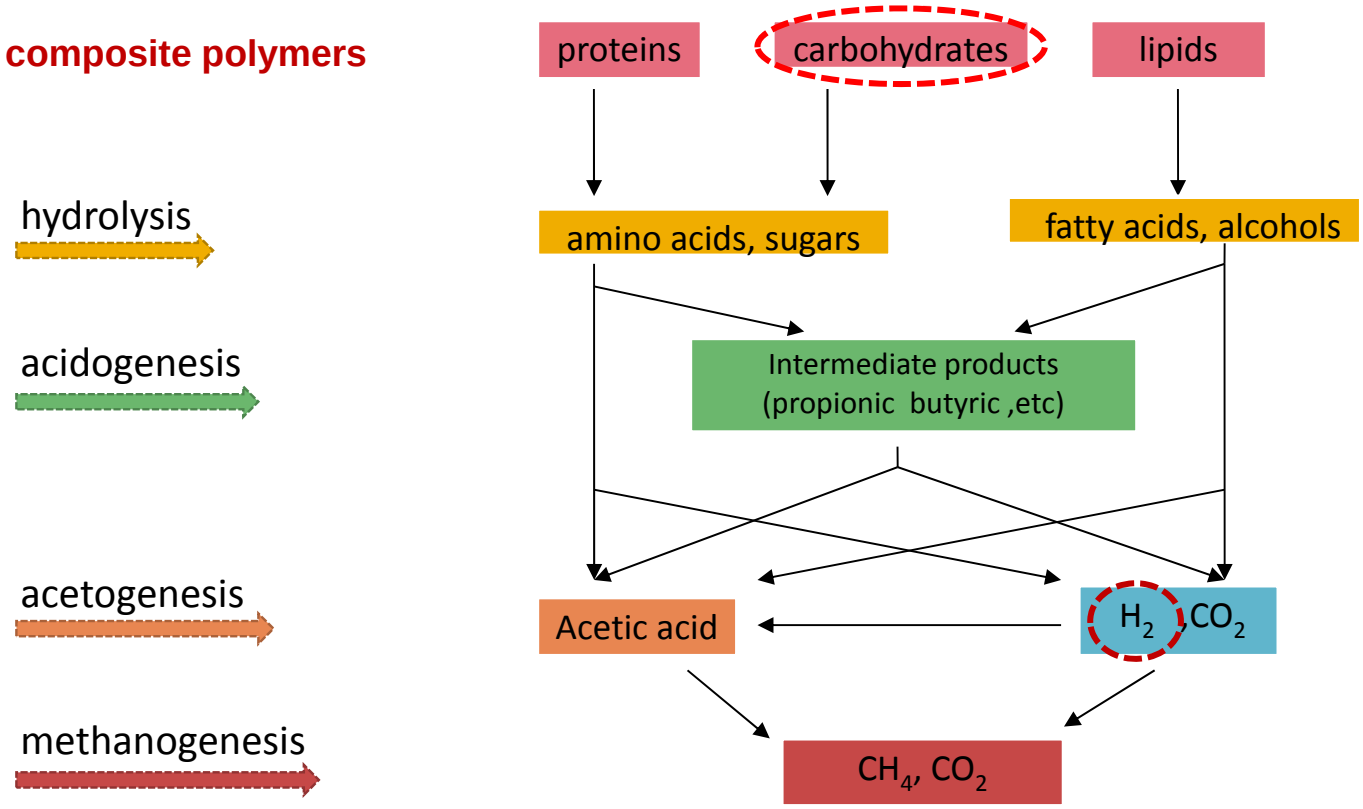
Zhang et al., Bioresource Technology 98 (2007) 929 - 935

Aim of this study

- The investigation of the influence of the Hydraulic Retention Time (HRT) on fermentative hydrogen production using as substrate the solid waste streams of a food industry in a CSTR – type reactor.

Fermentative hydrogen production

- It is carried out in the **dark**, under **anaerobic** conditions
- It is directly related to the **acidogenic** stage of anaerobic digestion process.



- It is well founded, that **carbohydrates** are the main source of hydrogen during fermentative processes.

Fermentative Hydrogen Production

Metabolic pathways - reactions

Production of acetic acid:

- $C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2$

Production of butyric acid:

- $C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2$

Production of propionic acid:

- $C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2H_2O$

Production of lactic acid:

- $C_6H_{12}O_6 \rightarrow 2CH_3CHOHCOOH$
- $C_6H_{12}O_6 \rightarrow CH_3CHOHCOOH + CH_3CH_2OH + CO_2$
- $2C_6H_{12}O_6 \rightarrow 3CH_3COOH + 2CH_3CHOHCOOH$

Production of ethanol:

- $C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$

Fermentative Hydrogen Production

Hydraulic Retention Time (HRT)

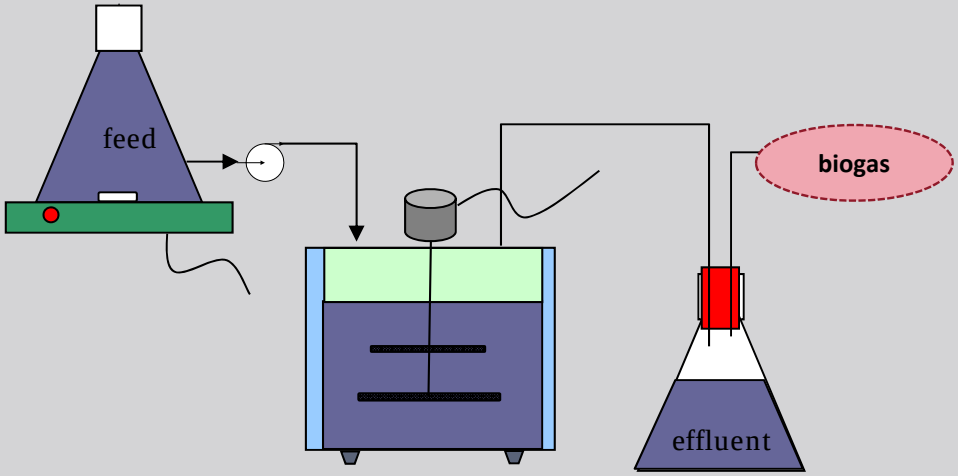
Reactor volume

$$HRT = V/Q$$

Volumetric feeding rate

important parameter that influences the hydrogen production rate and operational stability of a hydrogen-producing reactor.

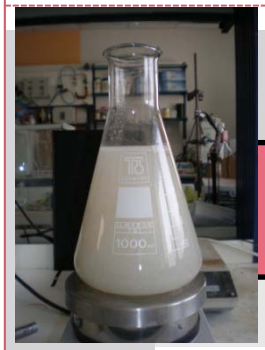
Experimental procedure - Reactor



- CSTR – type reactor
- V = 0.4 L
- T = 35°C
- **HRTs = 12, 8, 6 and 4 h.**

- **Start - up:** 2 d as a batch reactor.
- **Inoculum:** indigenous microbial species, contained in the substrate
- **Inoculum characteristics:**
  - TSS = 10.57 g/L
  - VSS = 10.56 g/L
  - pH = 6.87
  - TCOD = 22.6 g/L

Experimental procedure - Feed



Feed characterization

Aqueous solution of the mixture of the seven solid baby foods.

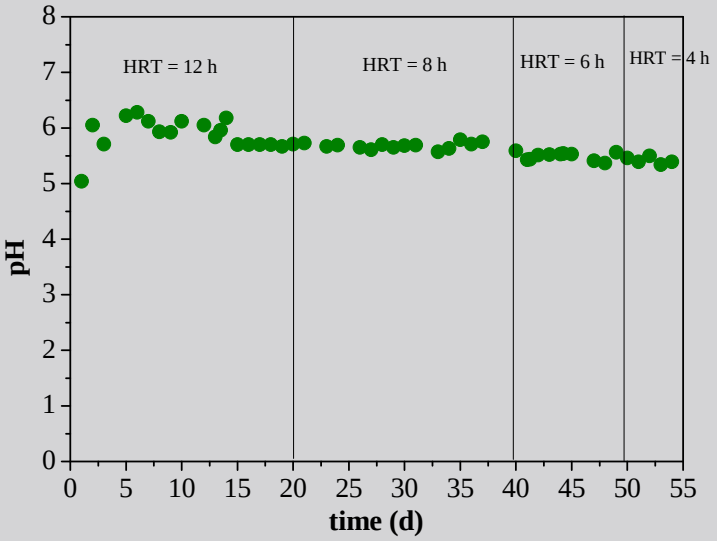
pH	11.61 ± 0.44
TSS (g/L)	13.4 ± 1.05
VSS (g/L)	10.8 ± 0.42
Total Carbohydrates (g/L)	**12.43 ± 0.73**
Soluble Carbohydrates (g/L)	7.94 ± 0.35
Total COD (g/L)	21.30 ± 4.07
Soluble COD (g/L)	12.85 ± 1.90

+ 5 g/L NaOH
+ 6.8 g/L KH_2PO_4
+ 2g/L urea
+ 0.5 g/L yeast extract

+ $(NH_4)_2HPO_4$ (7.21 g/L)
+ $FeSO_4 * 7H_20$ (0.7 g/L)
+ trace metals

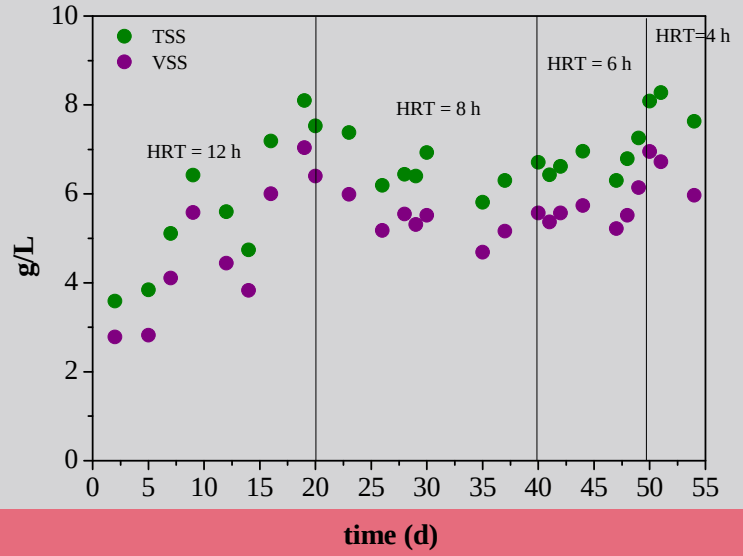
10 mL/ L feed

Results

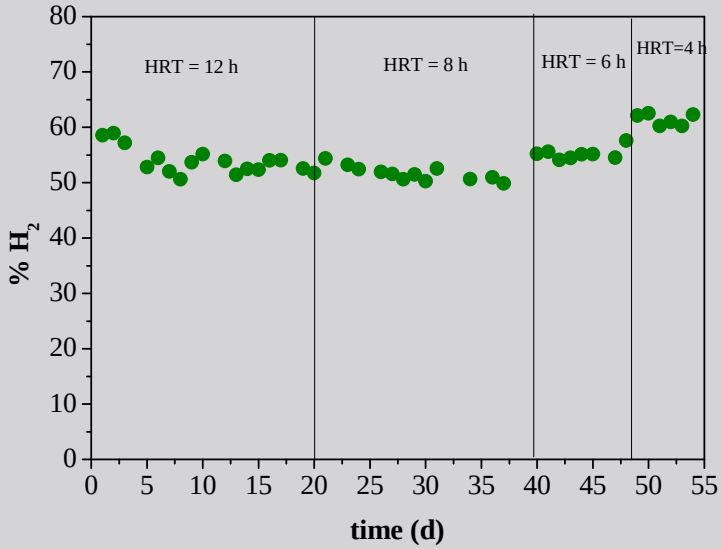


pH lied between 5.5 – 5.7

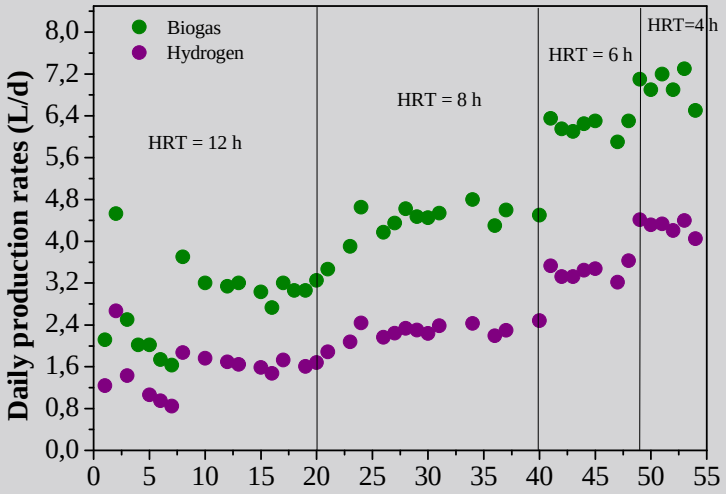
TSS = 6.5 – 7.9 g/L
VSS = 5.3 – 6.7 g/L



Results



Hydrogen content in the gas phase lied between 50 -60 %



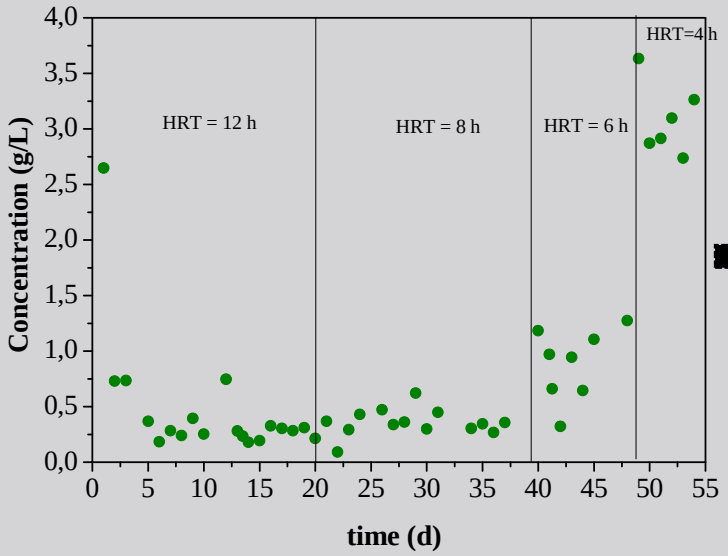
Higher H_2 production rate for HRT= 4 h

4.3 ±0.1 L H_2/d

or

85.7 ± 1.7 L H_2/Kg waste

Results

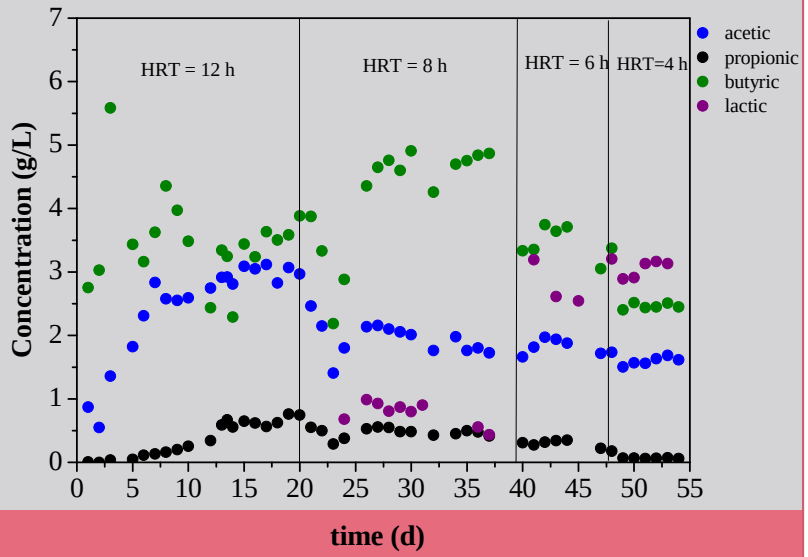


HRT =12 and 8 h ➡ complete carbohydrates' consumption

HRT = 6 h ➡ a slight increase in their concentration

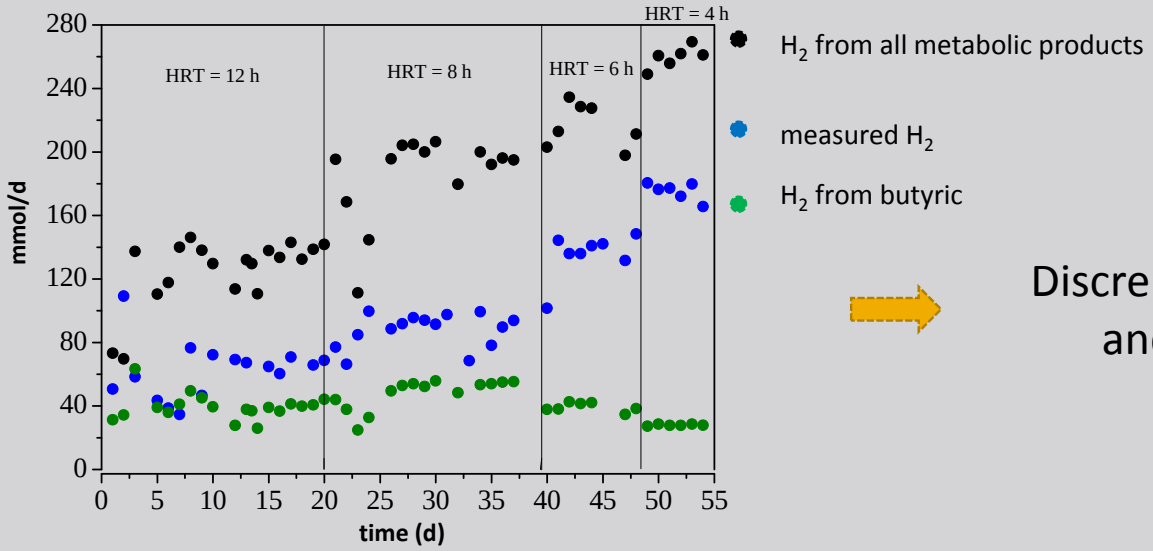
HRT = 4 h ➡ carbohydrate accumulation

Main metabolic products:
Acetic acid
Propionic acid
butyric acid
lactic acid



Results

H_2 balance taking into account the concentrations of acetic, butyric and propionic acids.



Discrepancy between predicted and measured hydrogen production rates

$C_6H_{12}O_6 + 2H_2O \rightarrow \mathbf{2CH_3COOH} + 2CO_2 + \mathbf{4H_2}$

$C_6H_{12}O_6 \rightarrow \mathbf{CH_3CH_2CH_2COOH} + 2CO_2 + \mathbf{2H_2}$

$C_6H_{12}O_6 + \mathbf{2H_2} \rightarrow \mathbf{2CH_3CH_2COOH} + 2H_2O$

$C_6H_{12}O_6 \rightarrow 3CH_3COOH$

Results

Characteristic	Value			
	HRT = 12 h	**HRT = 8 h**	**HRT = 6 h**	**HRT = 4 h**
Content in hydrogen (%)	52.43 ± 1.03	50.95 ± 0.75	55.70 ± 1.34	61.47 ± 1.06
Acetic acid (g/L)	2.94 ± 0.12	2.00 ± 0.17	1.83 ± 0.10	1.57 ± 0.05
Butyric acid (g/L)	3.19 ± 0.52	**4.71 ± 0.19**	3.46 ± 0.16	2.45 ± 0.05
Propionic acid (g/L)	0.63 ± 0.08	0.50 ± 0.05	0.26 ± 0.08	0.07 ± 0.00
Lactic acid (g/L)	-	0.77 ± 0.20	2.89 ± 0.36	3.03 ± 0.14
Soluble COD measured (g/L)	15.59 ± 0.69	17.10 ± 0.30	15.60 ± 0.48	16.98 ± 0.36
Soluble COD theoretical (g/L)	10.58	12.95	13.09	12.79

Results

Characteristic	Value			
	HRT= 12 h	HRT= 8 h	HRT= 6 h	HRT= 4 h
L H_2/L reactor/d	4.13 ± 0.14	5.63 ± 0.15	8.72 ± 0.32	10.79 ± 0.21
L H_2/ kg waste	96.27 ± 3.36	87.60 ± 2.40	101.75 ± 3.71	83.94 ± 1.63
L H_2/ kg VS waste	98.24 ± 3.43	89.40 ± 2.45	103.84 ± 3.79	85.67 ± 1.66
mol H_2/mol consumed carbohydrates	0.71 ± 0.03	**0.73 ± 0.03**	0.56 ± 0.03	0.49 ± 0.02

When the concentration of butyric acid maximized

Conclusions

- The influence of the hydraulic retention time was investigated during fermentative hydrogen production of food industry wastes in a CSTR–type reactor.

- The reactor operated at HRTs of 12, 8, 6 and 4 h, using indigenous microbial species.

- The maximum hydrogen production yield was obtained for the HRT of 8 h and was 0.73 ± 0.03 mol H_2/mol consumed carbohydrates which corresponded to 87.60 ± 2.40 L H_2/kg waste.

- It was demonstrated that solid wastes of food industry can be exploited for hydrogen production in continuous bioreactors, in a viable and effective process.

Thank you for your attention !!!