Influence of the ionic strength on H_2 production from the Organic Fraction of Municipal Solid Waste (OFMSW)

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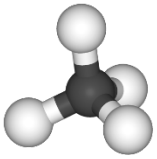
Anaerobic digestion processes : from past to present

Before Nowadays



CH_4 → Electricity & Heat

Waste

Wastewaters

Effluents

Digestate: used as fertilizer, composted or landfilled

What next ? AD next gen = the concept of Environmental Biorefinery

Multiple and various types of waste under a territorial context

Social, Economical & Environmental Services towards circular economy

Agro-industrial waste

Biowaste OFMSW

Agricultural residues

Urban sludge

New inputs (*eg.*, microalgae $H_{2\ (Power\ to\ gas)}$)

Under environmental and sanitary safety (contaminants - pathogens)

CH_4 & **H_2**

Heat
Electricity
Biofuel - Biohythane
NG grid

Platform molecules

Acétate, butyrate, éthanol, phénolic compounds, etc.

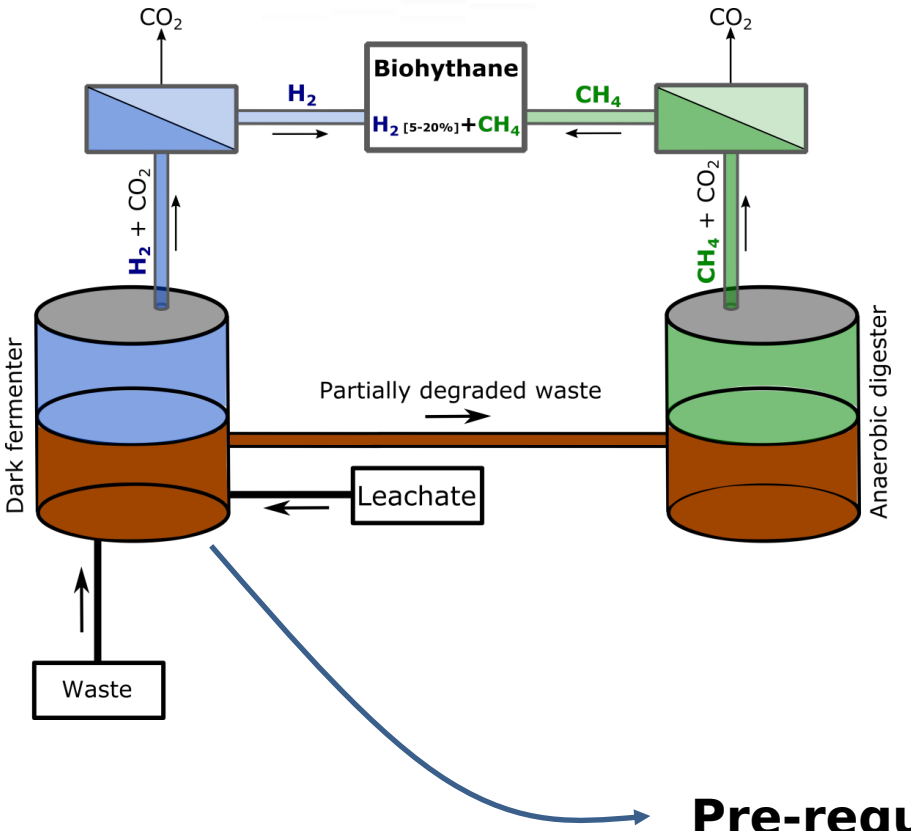
Digestate & fertilizers

N, P, K, oganic matter

H_2O

Water reuse

Two-step process for bioHythane (H_2/CH_4) production



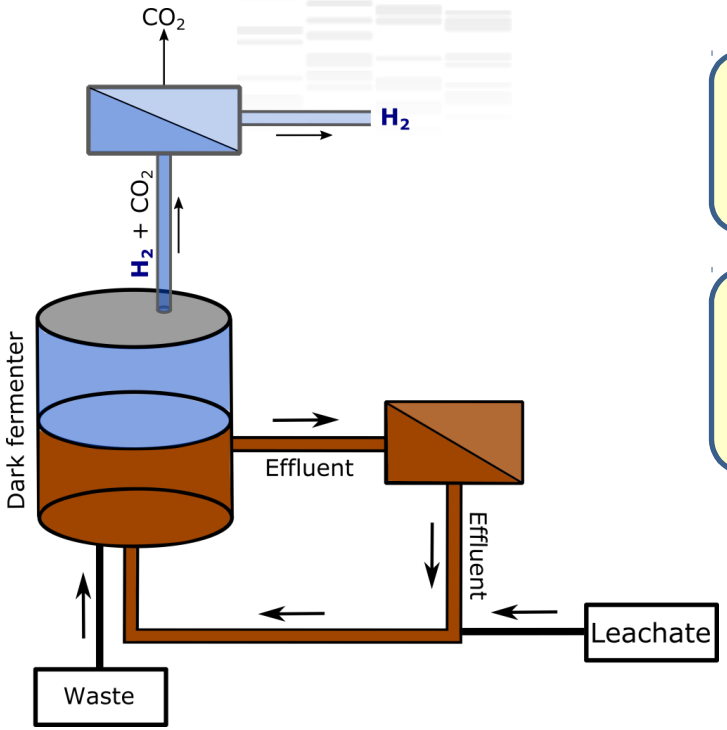
Benefits of a two-step process

- pre-hydrolysis of the substrate (better energetic yield)
- Easier maintenance on the digester
- Better combustion (if appropriate engine)

Pre-requisite for the fermenter = Low TS content (< 10%TS)

 Leachate recirculation

Two-step process for bioHythane (H_2/CH_4) production



Recycling leachate could cause inhibition by ions (eg. NH_4^+ inhibition of AD and H2 fermentation*,)**

AIM = Evaluate the impact of the ion concentration on fermentative hydrogen production from OFMSW

AGV (g/L)	*Acétate*	*Propionate*	*Butyrate*	*Valérate*	*Caproate*
	0,77±0,01	0,14±0,00	0,05±0,00	0,07±0,00	0,05±0,01
Anions (g/L)	Cl^-	NO_2^-	NO_3^-	PO_4^-	SO_4^-
	2,73±0,58	-	-	0,10±0.09	0,02±0,02
Cations (g/L)	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}
	2,55±0.60	4,02±0,79	1,64±0,34	0,19±0,02	0,29±0,14

** Nielsen HB, Angelidaki I (2008) Strategies for optimizing recovery of the biogas process following ammonia inhibition. Bioresour Technol 99:7995–8001.*

*** Salerno MB, Park W, Zuo Y, Logan BE (2006) Inhibition of biohydrogen production by ammonia. Water Res 40:1167–72.*

Methodology

1 - Freshly prepared synthetic OFMSW

Average composition of the OFMSW collected in France (MODECOM 2016)

Category	Elements	% w/w
Food waste	Meat	7.0
	Coffee grounds	3.9
	Rice	4.3
	Potatoes	20.9
	Bread	5.1
	Yogurt	2.0
Garden waste	Grass	5.0
Paper	Paper	35.1
Cardboard	Cardboard	16.7

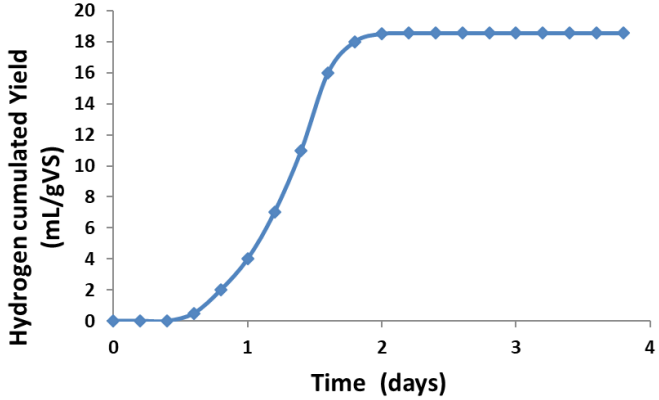
Methodology

2 - Batch tests on OFMSW diluted with leachate

pH : 6
T°C : 37°C
TS : 3%
NH_4^+ **stripped** leachate

- Biogas analysis every 2 h with automated µ-GC
- VFAs analysis by HPLC (end)
- Microbial community analysis (end)

Data analysis : Gompertz model

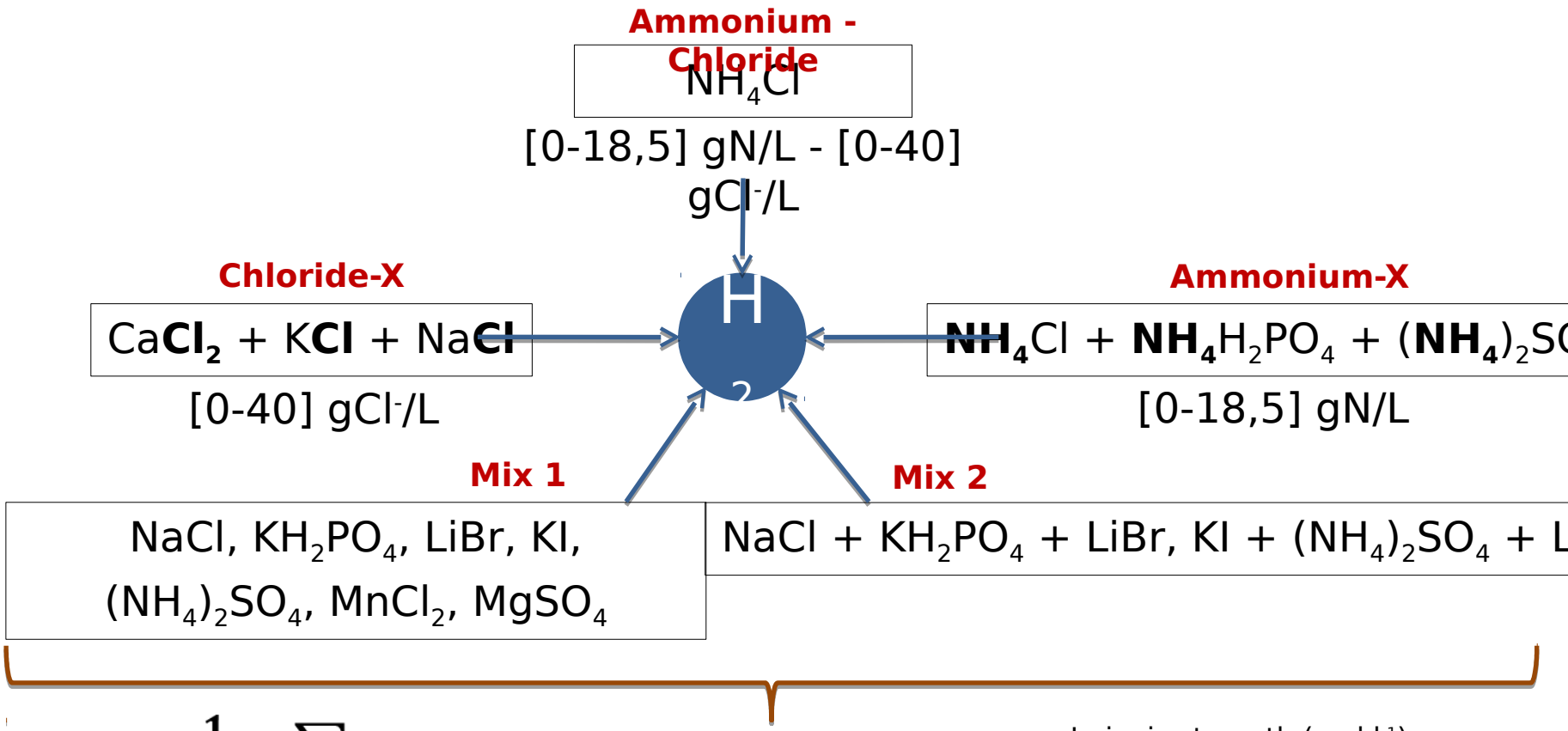


$$H(t) = P exp\left\{-exp\left[\frac{R_{m.e}}{P}(\lambda - t) + 1\right]\right\}$$

λ : Lag phase (d)
Rm : Maximal hydrogen production rate (m
P : Hydrogen production potential (mL/gVS)
H : Cumulative hydrogen (mL/gVS)

Methodology

3 - Use of different mixtures of ions at a wide range of concentrations

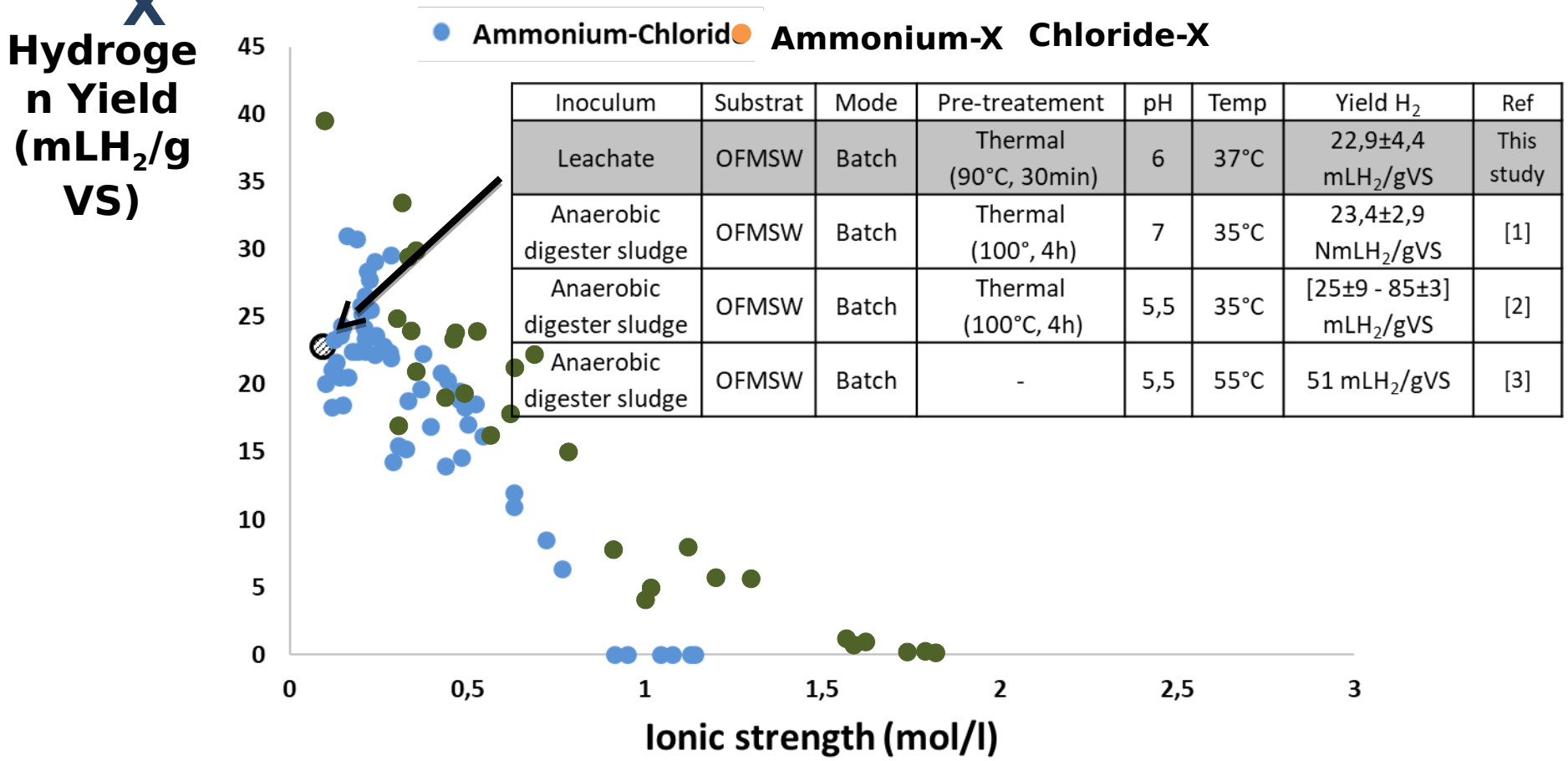


$$I = \frac{1}{2} \times \sum C_i Z_i$$

Ionic strength (0-3M)

I : ionic strength ($mol.l^{-1}$)
Ci : ion concentration ($mol.l^{-1}$)
Zi : ion charge state

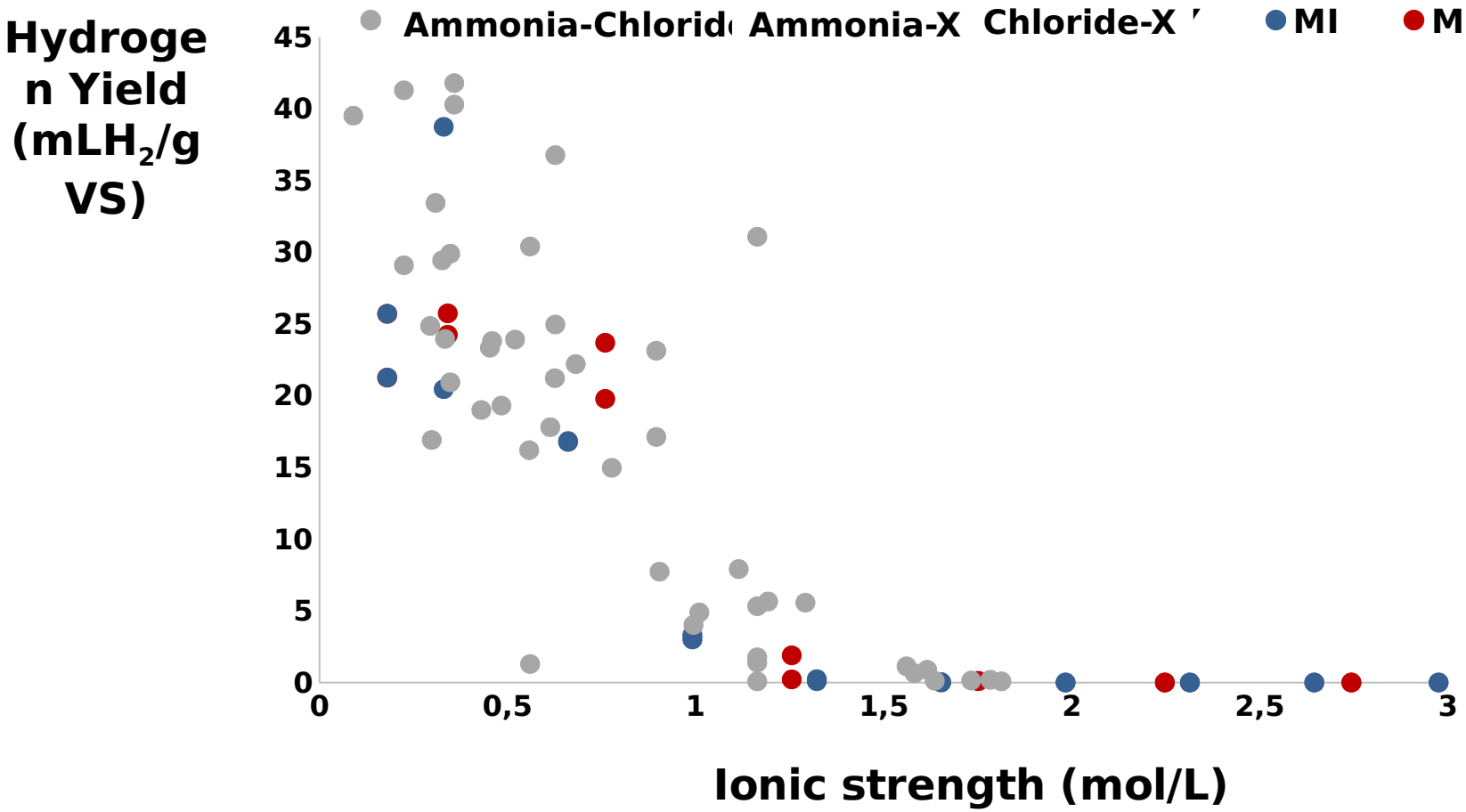
Results : effects of $NH_4^+Cl^-$ / NH_4^+-X / Cl^- X



Inoculum	Substrat	Mode	Pre-treatement	pH	Temp	Yield H_2	Ref
Leachate	OFMSW	Batch	Thermal (90°C, 30min)	6	37°C	22,9±4,4 mLH_2/gVS	This study
Anaerobic digester sludge	OFMSW	Batch	Thermal (100°, 4h)	7	35°C	23,4±2,9 $NmLH_2/gVS$	[1]
Anaerobic digester sludge	OFMSW	Batch	Thermal (100°C, 4h)	5,5	35°C	[25±9 - 85±3] mLH_2/gVS	[2]
Anaerobic digester sludge	OFMSW	Batch	-	5,5	55°C	51 mLH_2/gVS	[3]

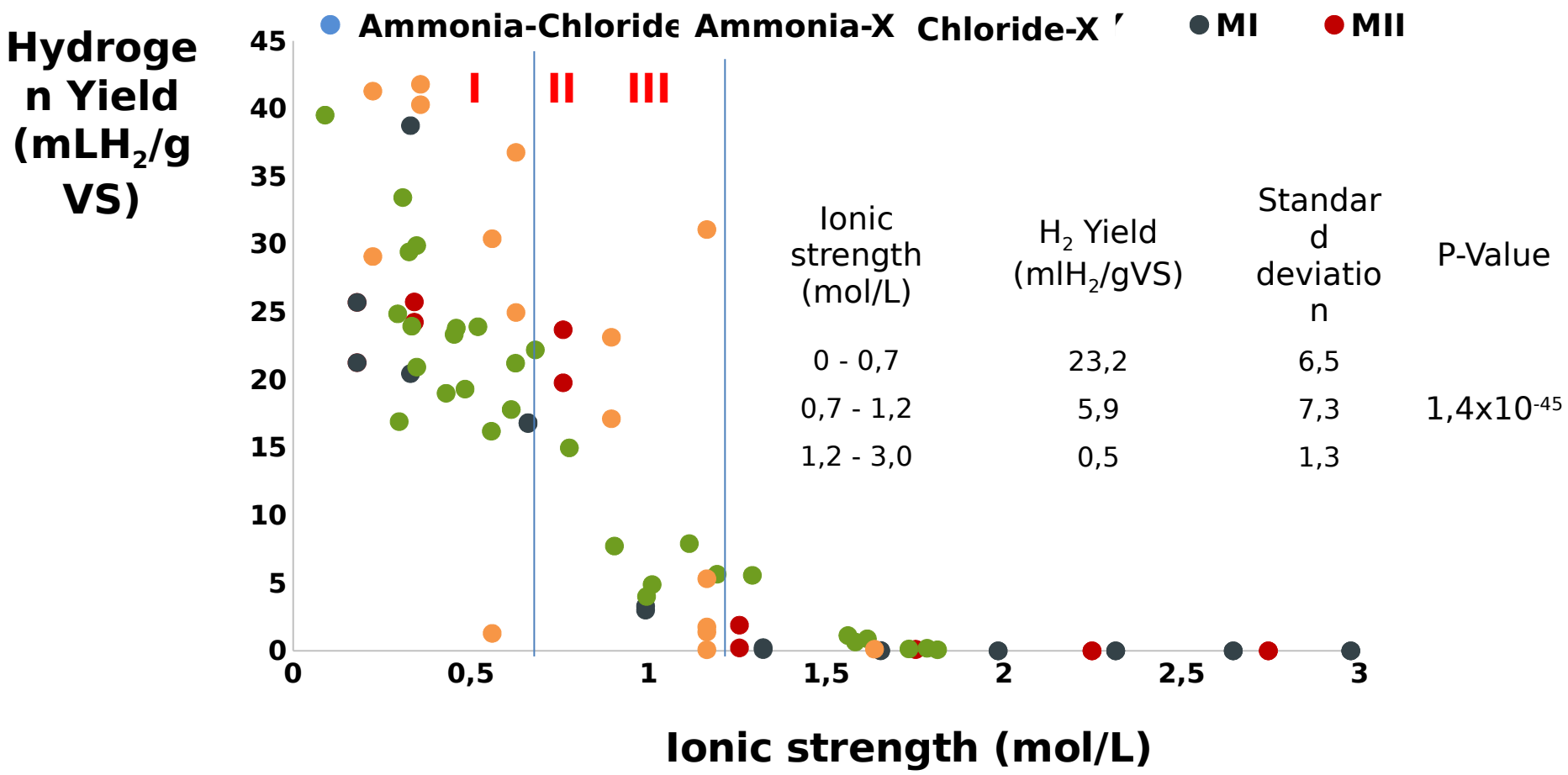
[1] : Favaro L et al. Effects of inoculum and indigenous microflora on hydrogen production from the organic fraction of municipal solid waste. Int J Hydrogen Energy 2013;38:11774–9.
[2] : Alibardi L et al. Composition variability of the organic fraction of municipal solid waste and effects on hydrogen and methane production potentials. Waste Manag 2014;36:147–55.
[3] : Tyagi VK et al. Enhancement in hydrogen production by thermophilic anaerobic co-digestion of organic fraction of municipal solid waste and sewage sludge--optimization of treatment conditions. Bioresour Technol 2014;164:408–15.

Results : effects of ion mixtures



Very similar inhibition trends whatever the ionic species

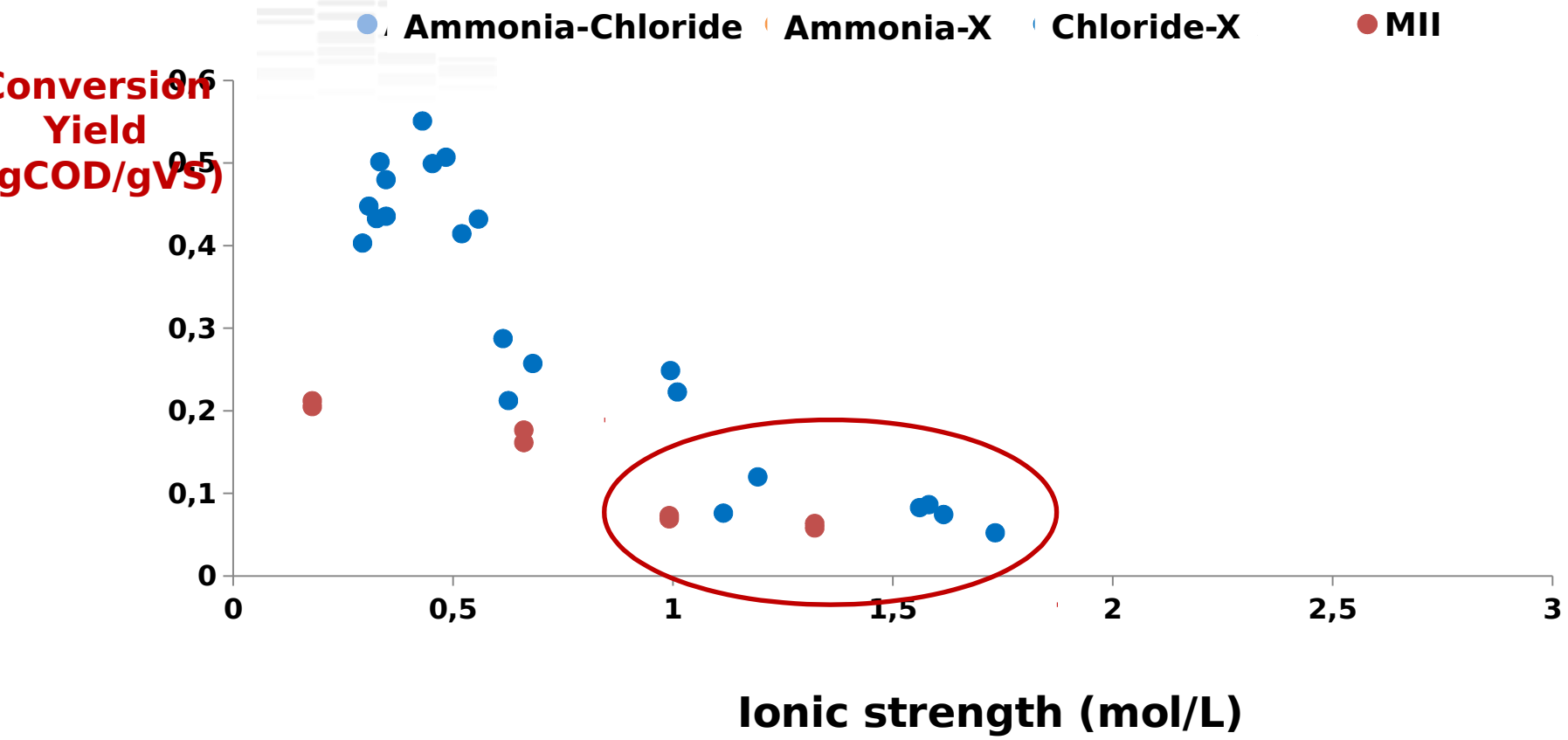
Results : statistical analysis



Ionic strength (mol/L)	H_2 Yield (mlH_2/gVS)	Standard deviation	P-Value
0 - 0,7	23,2	6,5	
0,7 - 1,2	5,9	7,3	$1,4x10^{-45}$
1,2 - 3,0	0,5	1,3	

Three statistical zones were identified

Results : Impact on microbial activity



Microbial activity shifted to other metabolisms

Results : microbial community analysis

Relative abudances of microbial families (in %)

Family	Ionic strength							
	0.25 mol/L	0.35 mol/L	0.53 mol/L	0.63 mol/L	0.72 mol/L	0.95 mol/L	1.02 mol/L	1.13 mol/L
Clostridiaceae	40	47	31	13	9			
Enterococcaceae	34	30	53	44	31			
Pseudomonadaceae	5	5	4	5		31	28	32
Lachnospiraceae				8	19			
Oceanospirillaceae						11	3	3
Halomonadaceae						10	9	12
Alcaligenacea						5	3	4
Others (<2%)	21	18	12	30	41	43	29	48

High impact on HPB (eg. *Clostridiaceae)* and emergence of halotolerant species

Trivedi VD et al. Insights into metabolism and sodium chloride adaptability of carbaryl degrading halotolerant Pseudomonas sp. strain C7. Arch Microbiol 2017;199:907–16.
Jolliffe LK et al. The energized membrane and cellular autolysis in Bacillus subtilis. Cell 1981;25:753–63.

Conclusions

- Ions could be beneficial at low concentration and inhibitory on hydrogen production whatever the ionic species :
  - Total inhibition of hydrogen production at 1.2 mol/L ionic strength

- Global decrease of the microbial activity suggesting stressful conditions caused by ions concentration

- Switch of microbial community probably due to the increase of osmotic pressure

- **In the objective to optimize the hydrogen production, the ions concentration should not exceed 0.7 mol/L of ionic strength**
  (online measure of conductivity)

Thank you for your kind attention

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