Application of semi-continuous pilot-scale AD tests to assess biochemical methane potential and hydrolysis rate constant of raw and pre-treated sludge

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http://www.wearwe.polito.it
Municipal and industrial wastewater
Capacity: 2,000,000 E.I.
Average flow rate: 7 m³/s
**Pre-treatments**

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**Polito-Smat**

**Low temperature thermo-alkali pre-treatment**

4kg NaOH /100kg TS, 90 °C, 1.5h

“Review of feedstock pretreatment strategies for improved anaerobic digestion: From lab-scale research to full-scale application”

Batch Reactor

\[ \frac{dS}{dt} = -kS_0 \quad S = S_0 e^{-k t} \]

\[ B = \left( 1 - e^{-k t} \right) B_0 \]

CST Reactor

\[ \frac{dS}{dt} = \frac{qS_0}{V} - \frac{qS}{V} - kS \]

\[ S = \frac{1}{1 + k \text{HRT}} S_0 \]

\[ B = \left( 1 - \frac{1}{1 + k \text{HRT}} \right) B_0 \]
\[ \frac{dV_S(t)}{dt} = \frac{q(t) \times V_S(t)}{V} \]

\[ B_{CH_4}(t) = V_S(t) \times k \times B_{th} \times V \]

\[ \frac{dV_{S_{nb}}(t)}{dt} = \frac{q(t) \times V_{S_{nb,in}}(t)}{V} - \frac{q(t) \times V_{S_{nb}}(t)}{V} \]

\[ \frac{dNVS(t)}{dt} = \frac{q(t) \times NVS_{in}(t)}{V} - \frac{q(t) \times NVS(t)}{V} \]
\[
\frac{dV S_b(t)}{dt} = \frac{q(t) \times V S_{b_{in}}(t)}{V} - \frac{q(t) \times V S_b(t)}{V} - k \times V S_b(t)
\]

\[
\frac{d aV S(t)}{dt} = \frac{q(t) \times V S_{in}(t)}{V} - \frac{q(t) \times aV S(t)}{V} - k \times aV S(t)
\]

\[
B_{CH_4}(t) = V S_b(t) \times k \times B_{th} \times V
\]

\[
B_d(t) = aV S_b(t) \times k \times B_o \times V
\]
Pilot Anaerobic digestion tests

Secondary Sludge

Primary Sludge

Mesophilic Anaerobic Digestion (38°C)
\[
\frac{daVS(t)}{dt} = \frac{q(t) \times VS_{in}(t)}{V} - \frac{q(t) \times aVS(t)}{V} - k \times aVS(t)
\]

\[B_d(t) = aVS(t) \times k \times B_o \times V\]

\[C_{CH_4} = \int_0^t B_d(t)dt\]

\[B_{exp\_CH_4} = [B_{exp\_t(1)}; B_{exp\_t(2)}; B_{exp\_t(3)}; \ldots \ldots B_{exp\_t\_end}]\]

\[C_{exp\_CH_4} = \sum_{t(1)}^{t(i)} B_{exp\_CH_4}\]

\[M_{S\_RSS}(i,j) = \sum_{t=1}^{t=\text{end}} \left( C_{exp\_CH_4}(t) - C_{CH_4}(t) \right)^2\]

\[J_{\text{min}} = \min_{M_{S\_RSS}(i,j)}\]
Secondary Sludge

Cumulative methane production

\[ \text{Secondary Sludge} = 0.147 \text{[Nm}^3/\text{kgVS]} \]

\[ k_{hyd} = 0.009 \text{[1/d]} \]

Daily methane production
**Pre-treatment:** 90 °C - 1.5 h - 4g NaOH/100gST

Cumulative methane production

\[ \dot{V}_{\text{CH}_4} = 0.250 \text{Nm}^3/\text{kgSV} \]

\[ k_{\text{hyd}} = 0.46 \text{ 1/d} \]

Daily methane production
Secondary Sludge

Pre-treatment: 90 °C - 1,5 h - 4g NaOH/100gST

Cumulative methane production

\[ \text{Model} \quad \text{Experimental} \]

\[ Nm^3/kgsV + 71\% \]

\[ k_{hyd} = 4.47 \% / 47\% \]

Daily methane production

Days

Calibration
Cumulative methane production

$E_0 \theta (\bar{b}N_m^3/kgSV$  

$N_m^3/kgSV$  

$k_{hyd} = 0.52 1/d$
90 °C - 1.5 h - 4g NaOH/100gST

Secondary sludge

Primary sludge

Cumulative methane production

Daily methane production

Sperimentale

Days

Nm³

0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70

Days

Nm³

0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07

Days
Secondary sludge

$B_0 = 0.250 \text{Nm}^3/\text{kgVS}$

$k_{hyd} = 0.46 \text{ 1/d}$

Primary sludge

$B_0 = 0.300 \text{Nm}^3/\text{kgVS}$

$k_{hyd} = 0.52 \text{ 1/d}$

Cumulative methane production

Error 1.1%

Daily methane production
Present conditions

WAS
Mesophilic AD 38 °C

\[ k = 0.09 \text{ \ 1/d} \]
\[ B_0 = 0.147 \text{ Nm}^3/\text{kg VS} \]

\[ B_{20d} = 0.09 \text{ Nm}^3/\text{kg VS} \]
WAS A.D. in WWTP Castiglione Torinese

Present conditions

WAS
Mesophilic AD 38°C

\[ k = 0.09 \text{ 1/d} \]
\[ B_o = 0.147 \text{ Nm}^3/\text{kg VS} \]
\[ B_{20d} = 0.09 \text{ Nm}^3/\text{kg VS} \]

Scenario 1

WAS Pretreatment + AD 38°C

NaOH 4g/100g TS
90 °C, 1,5h

\[ k = 0.46 \text{ 1/d} \]
\[ B_o = 0.250 \text{ Nm}^3/\text{kg VS} \]
\[ B_{20d} = 0.226 \text{ Nm}^3/\text{kg VS} \]

+ 144 %
Present conditions

WAS Mesophilic AD 38°C

\[ k = 0.09 \, \text{1/d} \]
\[ B_0 = 0.147 \, \text{Nm}^3/\text{kg VS} \]
\[ B_{20d} = 0.09 \, \text{Nm}^3/\text{kg VS} \]

Scenario 1

WAS Pre-treatment + AD 38°C

NaOH 4g/100g TS
90 °C, 1,5h

\[ k = 0.46 \, \text{1/d} \]
\[ B_0 = 0.250 \, \text{Nm}^3/\text{kg VS} \]
\[ B_{20d} = 0.226 \, \text{Nm}^3/\text{kg VS} \]

\[ +144 \% \]

Scenario 2

WAS Thermophilic AD 55°C

\[ k = 0.360 \, \text{1/d} \]
\[ B_0 = 0.778 \, \text{Nm}^3/\text{kg VS} \]
\[ B_{20d} = 0.193 \, \text{Nm}^3/\text{kg VS} \]

\[ +108 \% \]
Conclusions:

- The proposed first order kinetic model can be used as a tool in order to obtain a good estimation of the couple of parameters Bo and k.

- The thermo-alkali treatment improved the biomethane potential by 70.1%.

- The raw secondary sludge is slowly biodegradable (k =0.09 d⁻¹) but the thermo-alkali treatment increased the hydrolysis constant by 447%.
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Thank you for your attention!

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