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Hélène Caillet, Alain Bastide, Graziella Chuppa-Tostain, Thomas Petit, Laetitia Adelard. ANAEROBIC DIGESTION OF VINASSE AND CFD MODELLING APPROACH CONTEXT AND OBJECTIVES OF THE WORK. WasteEng 2018, Jul 2018, Prague, Czech Republic. hal-01857314

HAL Id: hal-01857314

<https://hal.science/hal-01857314>

Submitted on 15 Aug 2018

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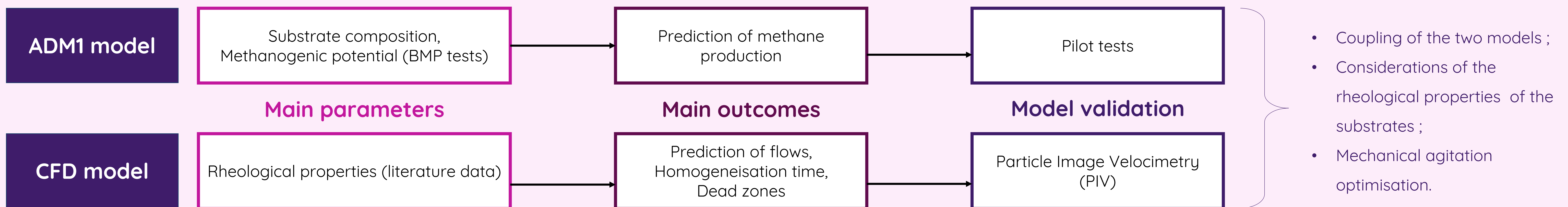
ANAEROBIC DIGESTION OF VINASSE AND CFD MODELLING APPROACH

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CONTEXT AND OBJECTIVES OF THE WORK

- CHARACTERISATION of the substrates with the PHYSICO-CHEMICAL and RHEOLOGICAL properties ;
- MODELLING and OPTIMISATION of WET and DRY anaerobic digestion ;
- CFD MODELLING of the fluids flow with the LARGE-EDDY SIMULATIONS (LES) approach with Boussinesq approximation ;
- Development of 3D SINGLE-PHASE model considering MECHANICAL AGITATION ;



MATERIALS AND METHODS

EXPERIMENTATIONS:



Figure 1: Pilot (10L)

Physico-chemical tests:

- Hack Lange tests are used for the chemical oxygen demand (COD), the total carbon organic (TOC), the ammonium, the alkalinity and the Kjeldahl azote ;
- BMP tests in triplicate with blanks and positives ;
- I/S ratio of BMP: 2 ;
- Mesophilic digestion (37°C) ;

Pilot test:

- Mesophilic digestion ;
- Working volume: 7 L ;
- Volume added during digestion due to medium analysis: 1.6 L ;
- Initial pH: 7.29.

LITERATURE REVIEW OF PHYSICAL PROPERTIES:

- The vinasse is Newtonian ;
- The sludge is non-Newtonian and modelled with the Power-Law;
- The physical properties of liquid manure are used for the physical characterisation of sludge ;
- Studies have shown that the viscosity and shear stress increase exponentially as total solid (TS) increases.

Table 1: Physical parameters of Newtonian fluids

Fluid	Density kg.m ⁻³	Dynamic viscosity Pa.s
Vinasse	1044.69	0.001 009 7
Sludge	999.66	0.065

Table 2: Physical parameters of sewage sludges in pseudo-plastic model

TS %	T °C	k Pa.s ⁿ	n	Density kg.m ⁻³	η _{min} Pa.s	η _{max} Pa.s	γ̇ s ⁻¹	C _p J.kg ⁻¹ .°C ⁻¹	λ W.m ⁻¹ .°C ⁻¹
2.5	35	0.042	0.710	1000.36	0.006	0.008	4186.78	4186.78	0.6171
5.4	35	0.103	0.639	1000.72	0.009	0.025	50-702	4185.94	0.6169
7.5	35	0.525	0.533	1001.00	0.03	0.17	11-399	4185.33	0.6168
9.1	35	1.052	0.467	1001.31	0.07	0.29	11-156	4184.87	0.6167
12.1	35	5.885	0.367	1001.73	0.25	2.93	3-149	4184.00	0.6165
15	17-24	31.3	0.30	973.0	3.35	44.24	0.61-24.37	4183.17	0.6163
20	17-24	35.4	0.29	1091.8	3.69	48.6	0.64-24.14	4181.72	0.6159

Temperature (T), consistency coefficient (k), power-law index (n), viscosity (η), shear rate (γ̇), specific heat (C_p), thermal conductivity (λ).

CFD MODELLING:

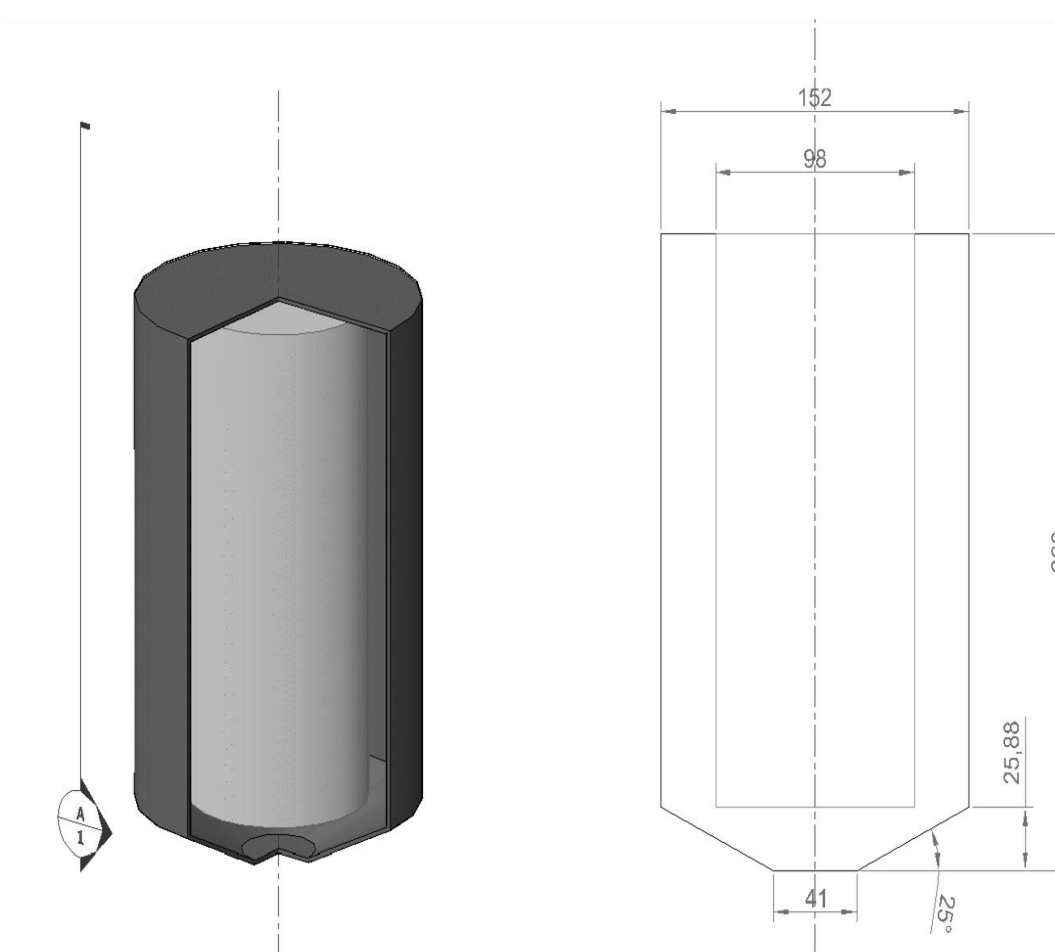


Figure 2: Digester geometry (mm)

We use the same geometry of Wu (2012). The internal cylinder is the sliding zone which contains the impeller.

- Mass and momentum conservation equations:

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0 \quad \frac{\partial (\rho \bar{u}_i)}{\partial t} + \frac{\partial (\rho \bar{u}_i \bar{u}_j)}{\partial x_j} = -\frac{\partial \bar{P}}{\partial x_i} + \frac{\partial (\sigma_{ij})}{\partial x_j} - \frac{\partial \tau_{ij}}{\partial x_j} + g \beta \bar{\theta} e_z$$

- Heat transfer equation:
- SGS stress tensor:

$$\frac{\partial \bar{\theta}}{\partial t} + \bar{u}_r \frac{\partial \bar{\theta}}{\partial x_i} = \frac{\partial^2 D_r \bar{\theta}}{\partial x_j \partial x_j}$$

$$\tau_{ij} = -2\mu_s \bar{S}_{ij}$$

- Dynamic Lagrangian turbulence model.
- Pseudo-plastic model:

$$\tau = k \dot{\gamma}^n \quad \eta = k \dot{\gamma}^{n-1}$$

Velocity (u), fluid density (ρ), pressure (P), gravity (g), thermal expansion coefficient (β), temperature (θ), thermal diffusion coefficient (D_r), turbulent viscosity (μ_s), strain rate (S_{ij}).

RESULTS, DISCUSSIONS AND EXPECTED RESULTS

EXPERIMENTATION RESULTS:

Substrates	Total solid %	Volatile solid %	pH	COD g _{O2} .L ⁻¹	TOC mg.L ⁻¹	Ammonium mg.L ⁻¹	Alkalinity mg.L ⁻¹ .CaCO ₃	Kjeldahl nitrogen mg.L ⁻¹
Sewage sludge	2.2480	0.9700	4.84	9.93	-	517.67	-	-
Vinasse	6.6391	4.0378	7.57	79.67	27646.11	239.00	3651.25	1815.00

Table 3: Physico-chemical characteristics

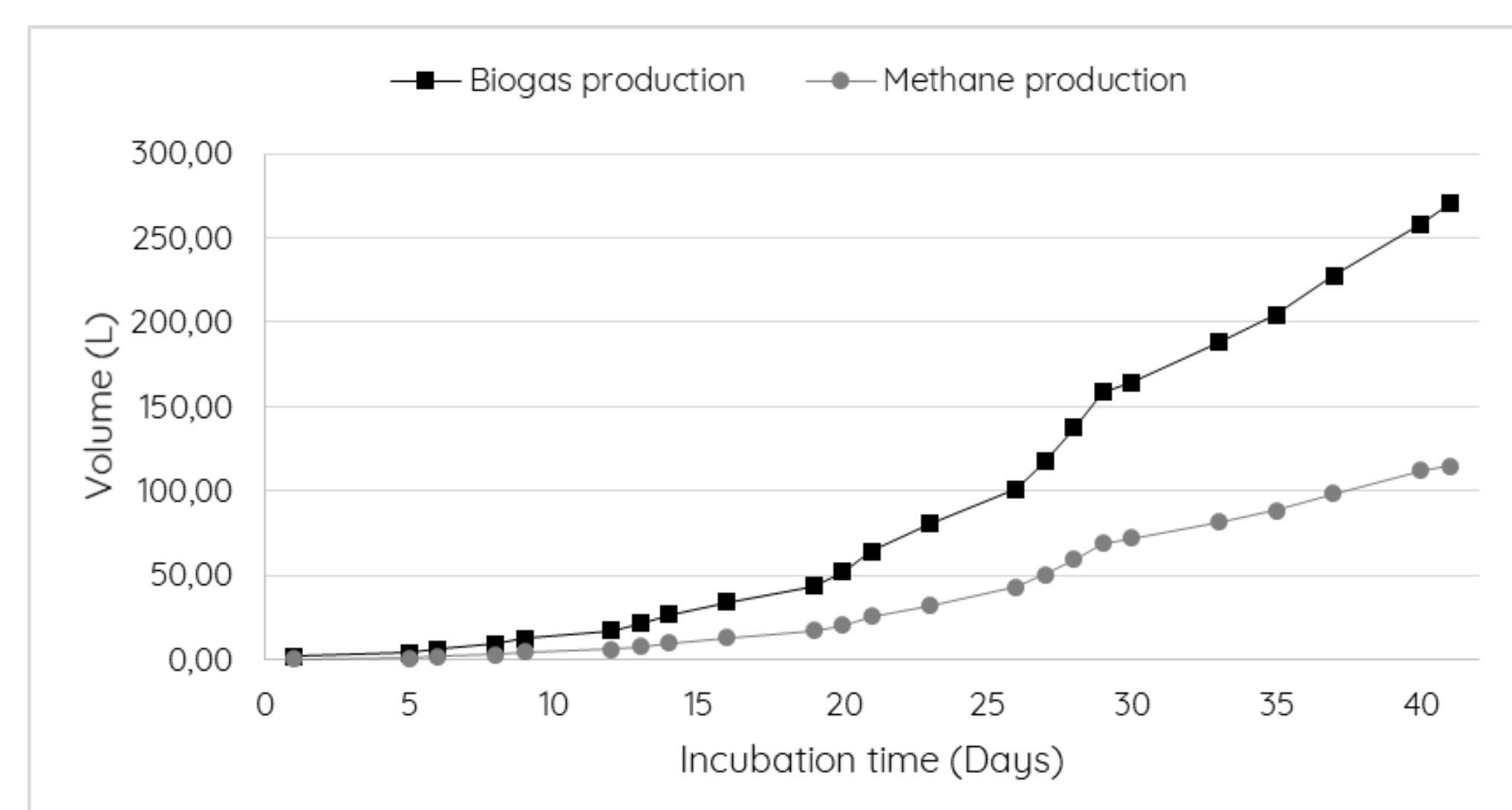
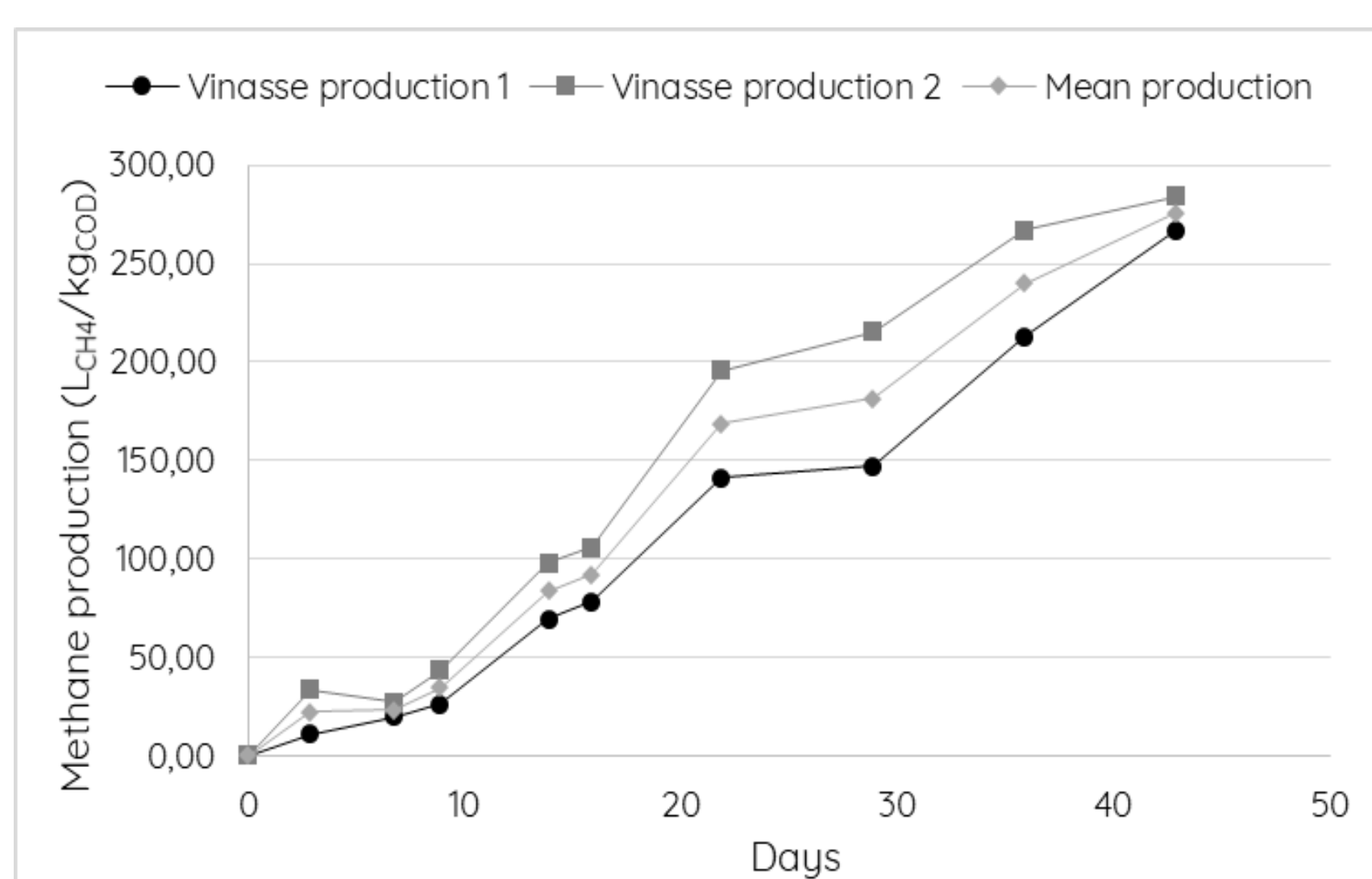


Figure 3: Cumulative methane production average as a function of time of vinasse in BMP (left) and pilot (right) tests

EXPERIMENTATION DISCUSSIONS:

- C/N ratio: 15.23
- Beyond 45 days to reach maximum methane production ;
- The vinasse is a complex substrate ;
- Vinasse methanogenic potential: 284.29 L_{CH4}.kg_{DCCO}⁻¹ ;
- Pilot biogas production: 270.22 L_{Biogas} ;
- Pilot methane production: 114.64 L_{CH4}.

EXPECTED MODEL RESULTS:

- Validation of the CFD model ;
- The 3D single-phase simulations provide:
 - The velocities profiles ;
 - The temperature field ;
 - The power and the flow numbers ;
- Study of the dead zones (volume and position) and the homogenisation of the digestion medium.

CONCLUSION AND PERSPECTIVES

- Carry out CO-DIGESTION experimentations ;
- Carry out PILOT tests at different TS rates ;
- Develop MULTIPHASE model to predict the SPREAD OF MICROORGANISMS ;
- COUPLING of the CFD model to the ADM1 model ;
- OPTIMISATION of the MECHANICAL STIRRING of the process depending on the PHYSICAL PROPERTIES of the digestion medium.

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