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# WHEY 2 GO - Production of biogas from whey

**The canton of Valais is an important cheese producer, with more than 2000 tons produced every year. The whey formed during cheese production is a waste product with great potential, including for using it as a substrate for anaerobic digestion.**

- **Objectives of this work:** ⇒ **Characterize and optimize the use of whey by anaerobic digestion**
  ⇒ **Conceive a scale-up in the context of dairies in the canton of Valais**

## Anaerobic digestion metabolism and reactor types

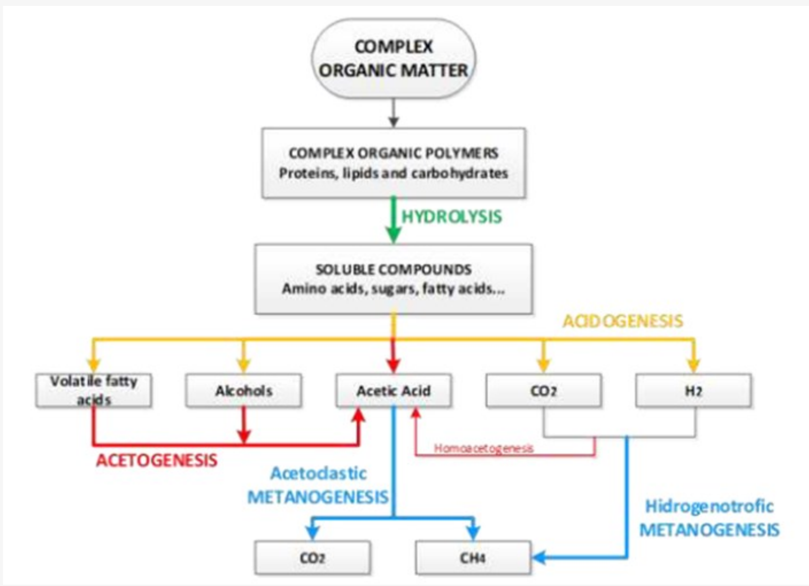


*Figure 1: Diagram of the different metabolic reactions in anaerobic digestion [1]*

The **4 phases** of anaerobic digestion :

- **Hydrolysis**: transforming proteins, lipids, and carbohydrates into soluble compounds such as sugars, amino acids, and fatty acids.
- **Acidogenesis**: transforming previous compounds into volatile fatty acids, alcohols, $CO_2$, and methane.
- **Acetogenesis**: transforming volatile fatty acids into acetic acid and $CO_2$ into acetic acid.
- **Methanogenesis**: transforming acetic acid into methane and $CO_2$ into methane

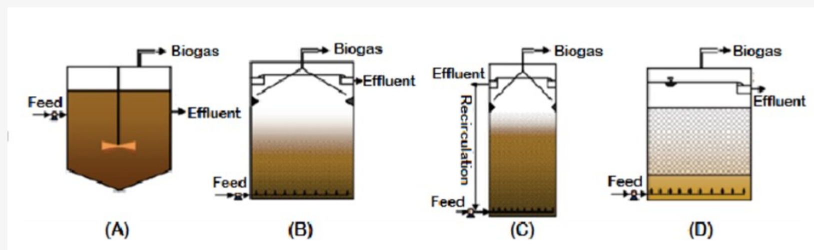


*Figure 2: Most commonly used anaerobic reactor types: (A) Completely mixed anaerobic digester, (B) UASB reactor, (C) AFB reactor, (D) Upflow AF reactor [2]*

The two culture modes studied in this work are the **Continuous Stirred Tank Reactor** (CSTR) and the **Upflow Anaerobic Sludge Blanket** (UASB).

## Reactor and working parameters

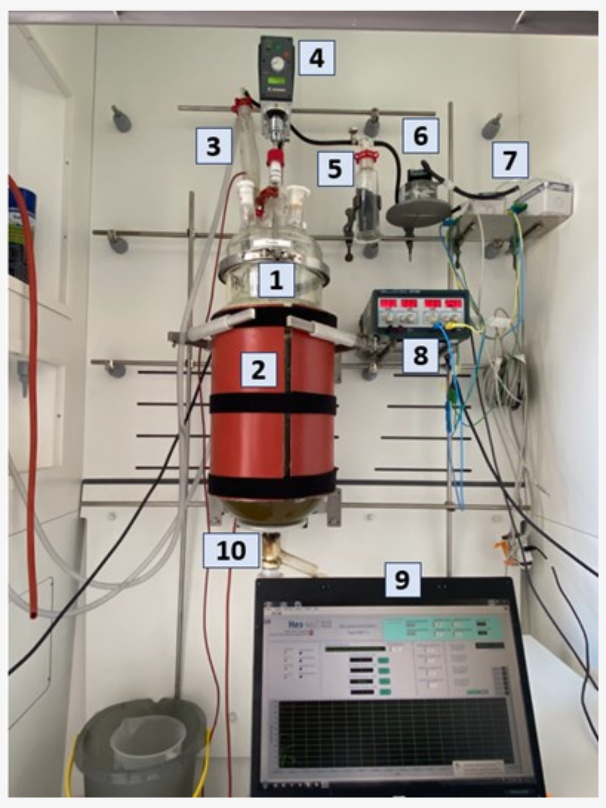


*Figure 3: Photo of the reactor used in the anaerobic digestion of whey with in 1 the 20 liters digester with a working volume of 18,5 liters, in 2 the heating cover, in 3 the condenser, in 4 the mechanism rotor with mixture speed of 55 rpm, in 5 the $H_2S$ absorbing beads, in 6 the Miligas counter Ritter, in 7 the $CH_4$ and $CO_2$ sensors, in 8 the power supply sensors, in 9 the laptop with LabView software, in 10 the digestate outlet.*

Two whey digestion trials were carried out, one in **CSTR** mode with the reactor shown in **Figure 3** and a second with the same reactor modified to correspond to a **UASB** culture system. The culture parameters are described in the table below.

*Table 1: Initial parameters for the CSTR and UASB trials*

| Reactor type | Temperature [°C] | HRT [day] | OLR [kg VS/m³/d] |
|---|---|---|---|
| CSTR | 23 — 30 | 100 — 50 | 0,61—1,22 |
| UASB | - | 39 — 29 | 4,31—5,75 |

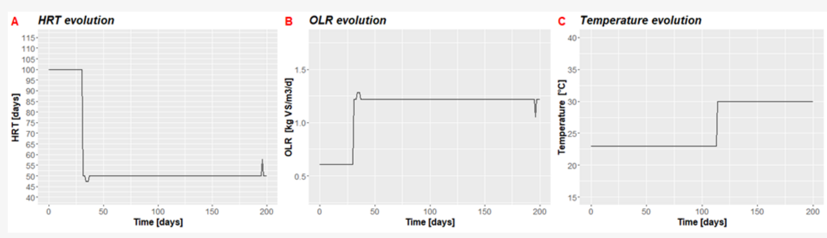


*Figure 4: Culture parameters evolution during the CSTR trial with whey*

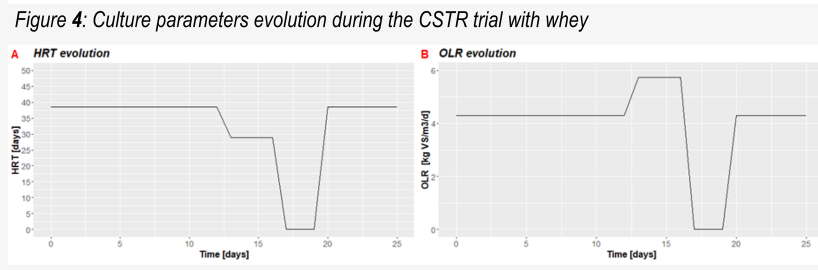


*Figure 5: Culture parameters evolution during the UASB trial with whey*

## Main results of CSTR trial

The first step is to characterize the whey with essential information for an anaerobic digestion process: **COD** (Chemical Oxygen Demand), **Carbon/Nitrogen** (C/N) ratio, **pH**, and the amount of **volatile solids** (VS). The data obtained from our experiments and the literature data are described in the table below.

*Table 2: Chemical and physical properties of sweet whey [3]*

| Characteristics | Sweet whey | Sweet whey (literature) [3] |
|---|---|---|
| Total solids [mg/g] | 65,7 ± 0,5 | 63,0 – 70,0 |
| Volatile solids [mg/g] | 61,0 ± 0,4 | 55,0 – 68,0 |
| pH [-] | 6,30 | 6,02 – 6,58 |
| TC [g/l] | 26,9 ± 1,8 | - |
| TN [g/l] | 1,44 ± 0,09 | 0,9 – 1,76 |
| IC [mg/l] | 30,4 ± 0,4 | - |
| C/N ratio [-] | 18,7 | - |
| BOD [g/l] | - | 30 - 50 |
| COD [g/l] | 69,0 ± 5,7 | 60 – 80 |
| Lactose [g/l] | 47,0 ± 0,4 | 44,0 – 52,0 |
| Total fats [mg/g] | 0,57 ± 0,11 | 0,6 – 8,0 |
| Total proteins [g/l] | 9,18 | 5,0 – 11,0 |
| Acetic acid [mg/l] | 144,1 ± 0,5 | - |

*Table 3: Micronutrient and iron concentration in sweet whey compared to recommended standard values [4]*

| Micronutrients | Sweet whey | Recommended range [4] |
|---|---|---|
| Cobalt [mg/kg TS] | 3,0 ± 0,0 | 0,4 to 10 |
| Copper [mg/kg TS] | 9,0 ± 0,0 | 10 to 80 |
| Iron [mg/kg TS] | 0 | 750 to 5000 |
| Magnesium [mg/kg TS] | 1089 ± 2 | 100 to 1500 |
| Molybdate [mg/kg TS] | 1,0 ± 0,0 | 0,05 to 16 |
| Nickel [mg/kg TS] | 0 | 4 to 30 |
| Selenium [mg/kg TS] | 0,3 ± 0,0 | 0,05 to 4 |

Whey has interesting characteristics for anaerobic digestion with a **high COD** (between 60 and 80 g/l), a **relatively high pH** (between 6.0 and 6.6), and an **attractive C/N ratio** of 18.7. However, whey is **deficient in most mineral salts** essential for methanogenic bacteria.

A **200-day CSTR** test gave biogas flow rates and methane and carbon dioxide concentrations as shown in Figure **6**. The whole trial was divided in 4 stages: **stage 1:** stabilization; **phase 2:** biogas production at 23°C; **phase 3:** biogas production at 30 °C; **phase 4:** destabilization and production decline.

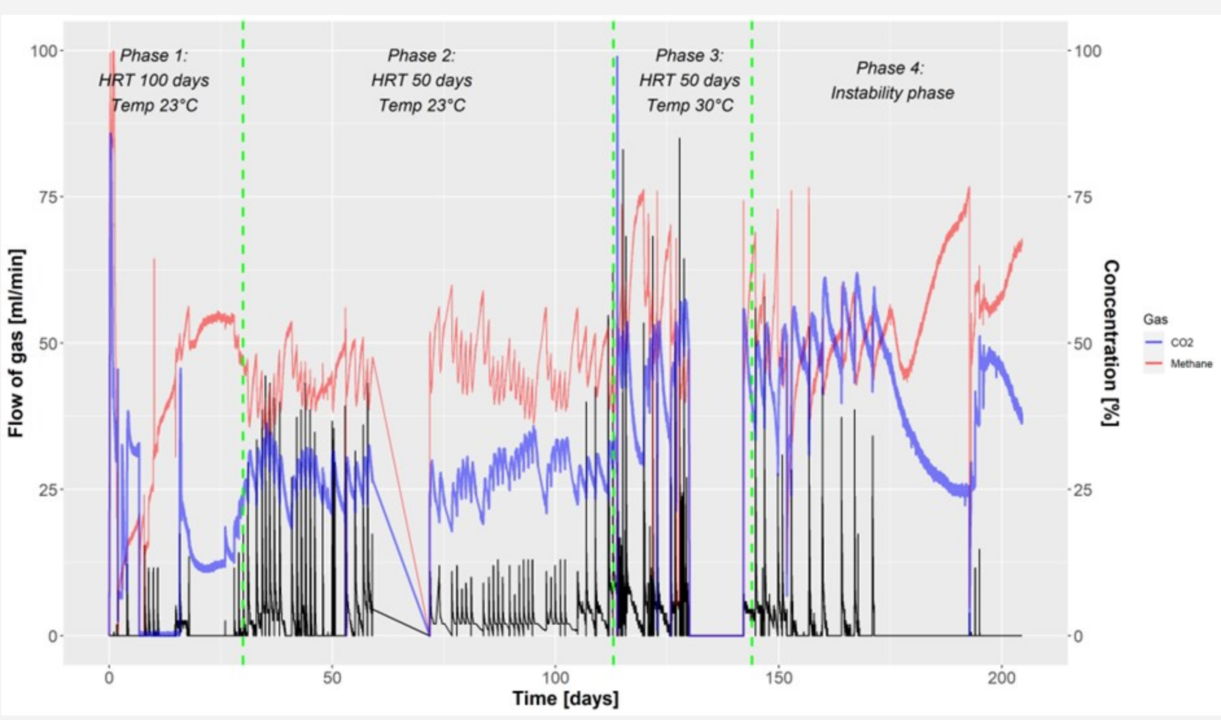


*Figure 6: Graph showing the gas flow rate produced (in black) in comparison with the evolution of CO2 (in blue) and CH4 (in red) concentrations during 144 days of anaerobic digestion of food waste in CSTR and thermophilic mode*

Over the first 75 days propionic acid gradually accumulated above 1 g/l ; this concentration had an **inhibitory effect** on the methanogenic bacteria which caused instability and the **final inhibition** of digestion. The optimum yields obtained in phase 3 are **4.30 * $10^{-3}$** m³ of methane per day and **2.38 * $10^{-3}$** m³ of methane per kg of volatile solids added, with an average methane concentration of **55.1%** and a DOC removal efficiency of **79.4%**.

## Main results of UASB trial

The second test conducted in **UASB** mode over **30 days** gave an average yield of **5.69 * $10^{-1}$** m³ of methane per day and **7.63 * $10^{-2}$** m³ of methane per kg of volatile solids. The average methane concentration was lower at **41.5%**, but a better COD removal efficiency of **98.2%** was observed. The pH of the **effluent** decreased from **6.7** to **5.0** at the end of the test, and an **increase** in the concentration of **VFAs** and **lactose** could be observed throughout the process. Figure 7 shows the biogas flow rate and the daily biogas production obtained.

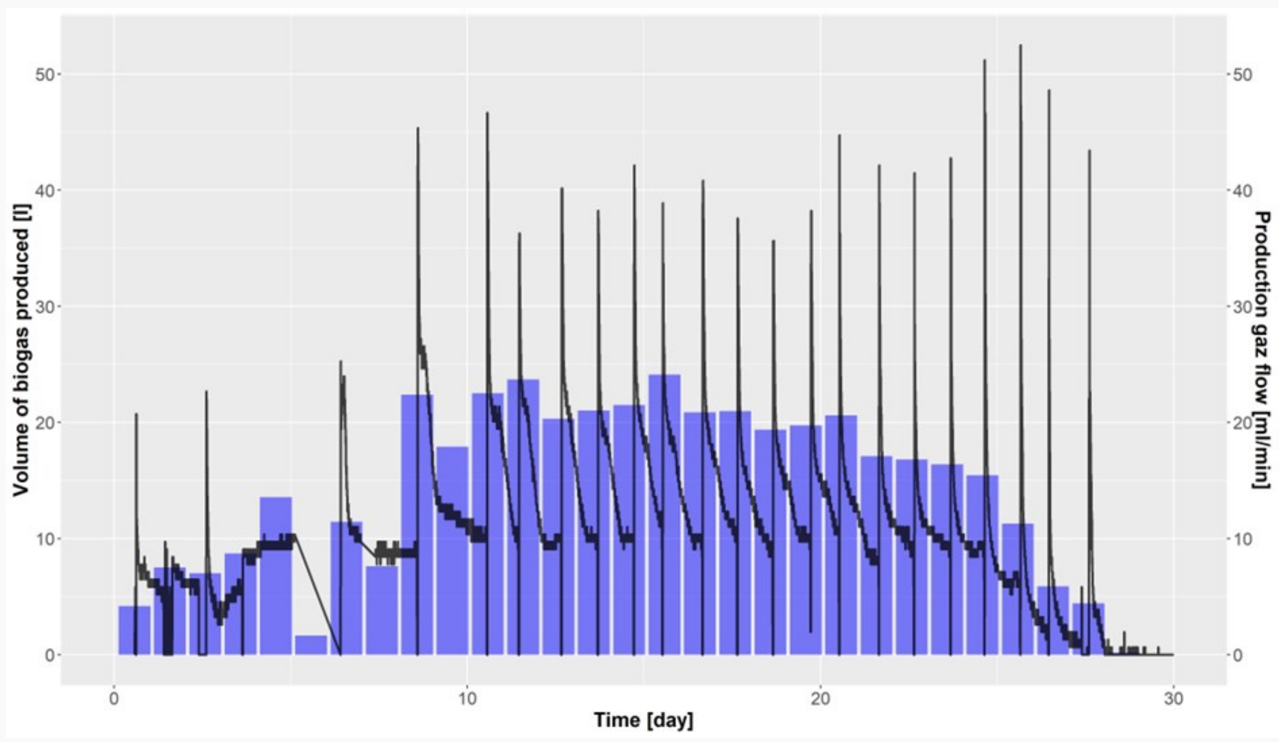


*Figure 7: Graph showing the gas flow rate produced (in black) in comparison to the total production per day (in blue) during 30 days of anaerobic digestion of whey in UASB and continuous mode*

## Perspectives and Scale-up design

The results obtained from the laboratory tests demonstrate the interest of anaerobic digestion for the treatment of whey, which is more suitable in **UASB mode**. The following improvements can be made to the system:

- **Addition of essential micronutrients** for methanogenic bacteria
- Dilution of whey with white water from dairies to **dilute COD to a maximum of 30 g/l**
- **Recirculation of the effluent** to improve digestion efficiency

Based on a whey production of **22,000 m³ per year** in Valais, a reactor design capable of processing **20 m³/day** of whey mixed with **40 m³/day** of white water has been designed for three locations in the canton. Figure 8 shows the 3D drawing of this reactor, while Figure 9 shows the internal functioning of the reactor.

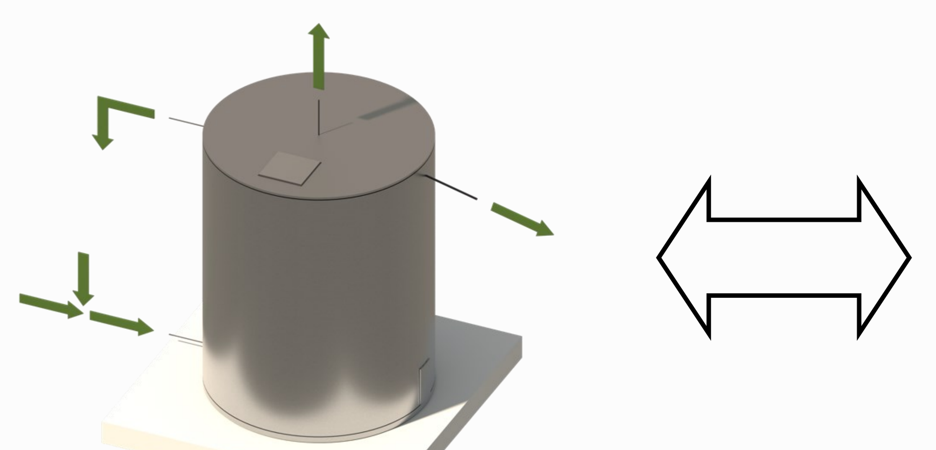

*Figure 8: 3D diagram of the 700 m³ UASB reactor with arrows indicating the different liquid and gas flows*

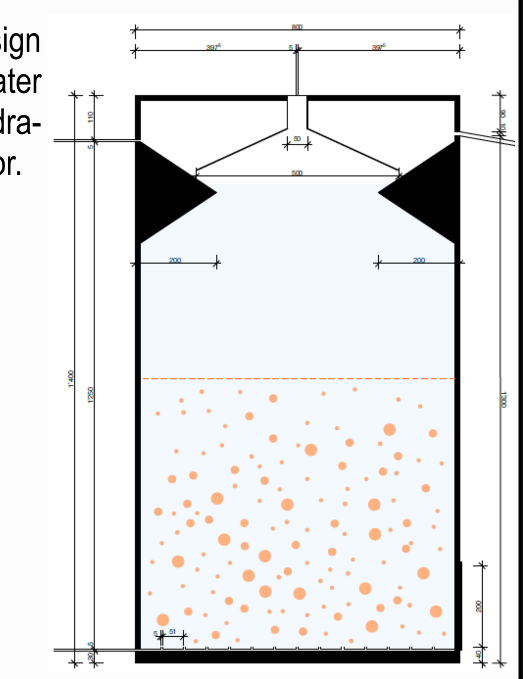

*Figure 9: Schematic diagram of the operation of the UASB reactor with a gas/liquid separator, a working volume of 600 m³, and effluent recirculation*

**References :**

[1] Morales-Polo, Carlos, María del Mar Cledera-Castro, et B. Yolanda Moratilla Soria. « Reviewing the Anaerobic Digestion of Food Waste: From Waste Generation and Anaerobic Process to Its Perspectives ». *Applied Sciences* 8, n° 10 (2 octobre 2018): 1804. https://doi.org/10.3390/app8101804.
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[3] Souci, Siegfried W., W. Fachmann, et Heinrich Kraut. Food Composition and Nutrition Tables, 7th Revised and Completed Edition. MedPharm, 2008.
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