# Kinetics of primary sludge digestion at various temperatures

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**Abstract**
Anaerobic digestion is now commonly used for sludge treatment. Most industrial digesters operate under mesophilic (37°C) or thermophilic (55°C) conditions. These two regimes are considered as optimal for methane production. In this work, continuous sludge digestion has been operated at lab-scale at 5 different temperatures comprised between 28° and 55°C. The reactors were first inoculated with anaerobic mesophilic sludge and were acclimatized to their new temperature during 4 weeks at a low loading rate. Then, they were fed with the same (primary) sludge during 9 weeks. The 1st results revealed that the methane production rate is increasing with temperature. In our experiments, the maximal methane production rate is obtained at 49°C. At 55°C, the methane production was slightly lower, probably due to the fact that volatile fatty acids (especially propionate) were formed at relatively large amounts (> 1500 mg/L).
**Keywords**
Anaerobic digestion; primary sludge; temperature; kinetics; methane production rate

## INTRODUCTION

The common temperatures used for sludge digestion are 37° (mesophilic regime) and 55° (thermophilic regime). These 2 temperatures are recognized for being optimal for anaerobic digestion in general. Many authors have investigated these 2 temperatures and it is now well established that thermophilic digestion is faster than mesophilic (Cecchi *et al.*, 1993; Kabouris *et al.*, 2009 among others). There have been only few authors that have investigated the kinetics of methane production as a function of temperature below, above and between the mesophilic and thermophilic regime. Van Lier *et al.* (1996) showed that VFA degradation rate increased according to Arrhenius law from 37° up to 65°C. It has also been shown that hydrolysis rate is higher at high temperature (Veeken and Hamelers, 1999; Yu and Fang, 2003; Mahmoud *et al.*, 2004). On the other hand, there are many reported data on loss of efficiency / lack of stability / lower uptake rate when the reactor is moved from 37° to higher (or lower) temperatures (Kasali and Senior, 1989; Donoso-Bravo *et al.*, 2009).

There are many questions, especially in hot climates, about the necessity of warming sludge digesters (or not). Temperature has become a design parameter for sludge digestion, and there is a need for data below 37°C and between 37° and 55°C. In order to better understand the influence of temperature under different regime, we have decided to investigate on a wide temperature range (from 28° to 55°C) the anaerobic digestion of primary sludge.

## MATERIALS AND METHODS

### Experimental setup

The experimental setup is composed of 5 PDMA reactors (total volume 6.9 L, working volume 5.6 L). In each reactor the temperature is controlled by water circulation in a water jacket. They are fed with peristaltic pumps on a daily basis. The inoculum is a mesophilic sludge from an industrial sludge digester located in Villeurbanne - La Feyssine near Lyon (France) WWTP.

After inoculation, the reactors were acclimatized during 2 weeks at their new temperature (28, 37, 42, 49 and 55°C) and then fed at half-capacity during two more weeks. After this acclimatization period, they were fed at their nominal capacity during 9 weeks. The operating conditions are listed in Table 1. The feed is primary sludge coming from the same WWTP. Since primary sludge cannot be stored even at low temperature, fresh sludge where used once or twice a week. The drawback is that sludge quality was not constant (TS content ranged from 30 to 40 g/L) due to abundant rainy events in the region of Lyon during the period (April – August 2012), leading thus to lower concentrations at the end of the experiments. The nominal conditions were obtained from the industrial practice for the mesophilic and thermophilic regimes (20 days HRT at 37°C and 10 days HRT at 55°C). At other temperatures, a linear model was fitted to determine the appropriate HRT.

### Follow-up and measurements

Biogas production was monitored continuously with an AMPTS (Bioprocess Control) device. The biogas composition ($CH_4$, $CO_2$, $H_2S$) was determined daily with a GA2000 (Geotech). Total Chemical Oxygen Demand (COD), soluble COD, Total and Volatile Solids were measured 3 times per week in the inlet and outlet of the reactors. Volatile Fatty Acids (VFA) were analysed 3 times per week at the outlet of each reactor by gas chromatography.

**Table 1**. Nominal operating conditions applied to the reactors during 9 weeks of continuous operation.

| | HRT | Inlet sludge | | |
|---|---|---|---|---|
| | (days) | ($g_{TS}$/L) | ($g_{VS}$/L) | Total COD (g/L) |
| 28°C | 40 | | Week 1-7 | |
| 37°C | 20 | 37.9±1.8 | 27.9±1.1 | 40.7±3.5 |
| 42°C | 15.7 | | Week 8-9 | |
| 49°C | 12 | 28.8±0.2 | 21.4±1.5 | 25.9±1.2 |
| 55°C | 10 | | | |

## RESULTS AND DISCUSSION

### Start-up and nominal operation

In the following, all results are presented on a weekly average and on a COD (chemical oxygen demand) basis. The time evolution of the 5 reactors is presented on Figure 1 (loading rate, methane production rate and VFA concentration). During the 2 first weeks, the reactors were fed at low loading rate and then at their nominal conditions. In all 5 reactors, the methane production followed well the incoming load, indicating that the anaerobic sludge is acclimatized to the new temperature. Despite the variations in the incoming sludge concentration, a stable biogas production is established (apart from the 2 last weeks for some reactors). It is interesting to note that the level of VFA accumulation increases with temperature. The amount of VFA remains quite insignificant at 28 and 37°C (below 150 $mg_{COD}$/L). At 42°C, the total VFA reaches 2500 $mg_{COD}$/L during the first days, and is reduced during the next weeks down to a low value (250 $mg_{COD}$/L). This behaviour is more pronounced at 49° (longer accumulation time, stabilized values around 500 $mg_{COD}$/L). At 55°C, the level of VFA remains elevated all through the experiment with a total value around 4000 $mg_{COD}$/L.

**Table 2**. Typical VFA concentrations during start-up and stabilized periods at 42, 49 and 55°C.

| | 42° | | 49°C | | 55°C |
|---|---|---|---|---|---|
| | Start-up | stabilized | Start-up | stabilized | avge |
| Acetate (mg/L) | 200 | 100 | 300 | 200 | 300 |
| Propionate (mg/L) | 900 | 50 | 1200 | 185 | 1800 |

During the VFA accumulation period at 42°C and 49°C, propionate was predominating over acetate (see values Table 2). When the reactors were stabilized, the level of propionate decreased. At 55°C, propionate was the most abundant acid present in the medium all through the experiment. This shows that the 55°C reactor is not stabilized at the end of the test. Much probably, the applied load was too elevated and / or the reactor was not yet adapted.

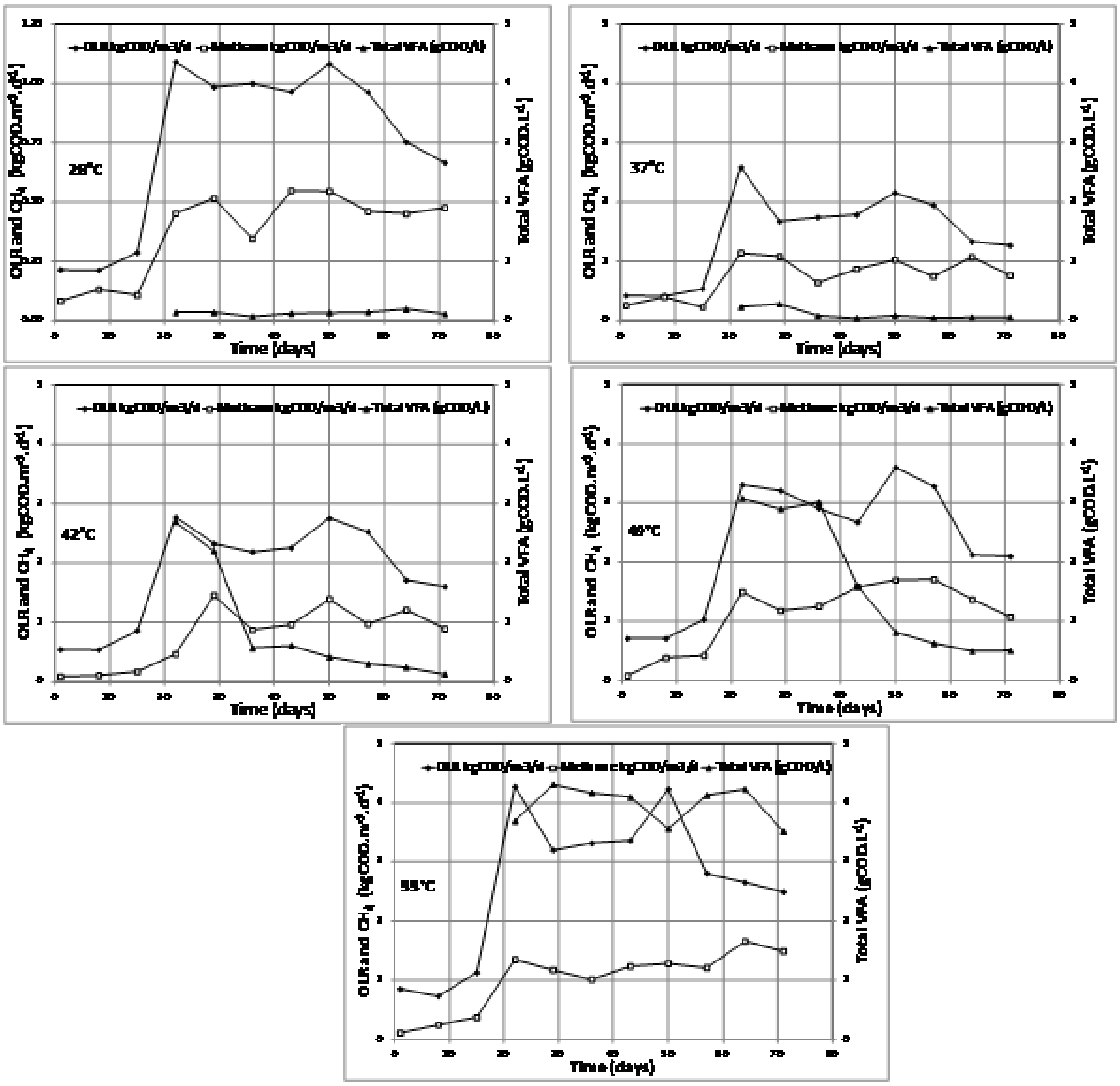


**Figure 1**. Evolution of organic loading rate, methane production rate, and total VFA concentration with time (all data are expressed on a COD basis: 1g $CH_4$-COD equivalent to 350 mL$CH_4$ STP).

## Overall performance and kinetics of methane production

The better removal efficiency is obtained at 37°C. The values are very similar from 28° to 49°C for all parameters (TS, VS or total COD, see Table 3) and are common for this kind of sludge. The methane production rate increases with temperature between 28° and 49°C. The average and the maximal methane production rate both follow a similar trend. A slight decrease of the methane production rate is observed at 55°C. This result is in line with the lower removal efficiencies observed at this temperature, and with the VFA accumulation as mentioned above. With our experiments, it is difficult to know if the measured methane production rate is relevant of the maximal rate at a given temperature. For instance, at 28 and 37°C, the reactors are obviously substrate limited and could probably reach higher methane production rates. On the opposite, the 55°C reactor is apparently overloaded and the observed methane rate could be hindered by some inhibition effects. Nevertheless, our results rather suggest that the methane production rate follows Arrhenius law, and that there are no local optimal regimes at 37°C and 55°C. Further investigations will be done at various loading rates.

It is known that a given microorganism has an optimal growth temperature. Nevertheless, anaerobic digestion is a mixed population medium with hundreds of different organisms. A rapid change of the temperature on a well adapted reactor may lead to transitory negative effects, as observed by many authors. But after some time, other microorganisms takeover and a novel adapted bacterial consortium can be established. Some problems may also occur at high temperature due to a shift in the methane production pathway: the acetoclastic pathway is no longer the dominant mode and methane is rather produced by hydrogenotrophy (Wilson *et al.*, 2008). This could lead to a longer adaptation time required to reach stable operations under thermophilic conditions, as observed in the present work.

**Table 3**. Summary of steady-state data: removal efficiencies and methane production rates.

| | Removal efficiency | | | $CH_4$ rate ($kg_{COD}.m^{-3}.d^{-1}$) | |
|---|---|---|---|---|---|
| | TS (%) | VS (%) | $COD_{tot}$ (%) | Average (SD) | max |
| 28°C | 35.4% | 40.5% | 39% | 0.48 (0.07) | 0.55 |
| 37°C | 37.0% | 42.6% | 36% | 0.92 (0.19) | 1.15 |
| 42°C | 31.6% | 37.5% | 33% | 1.11 (0.24) | 1.46 |
| 49°C | 30.9% | 37.9% | 31% | 1.42 (0.21) | 1.71 |
| 55°C | 26.6% | 32.4% | 25% | 1.30 (0.20) | 1.66 |

## CONCLUSION

- The effect of temperature on the anaerobic digestion of primary sludge was investigated at 5 different temperatures from 28° to 55°C.
- The removal efficiencies were similar at 28°, 37°, 42° and 49°C. Transitory formation of VFA was observed at 42 and 49°C. During these periods, propionate was the most abundant acid present.
- At 55°C, the removal efficiency was quite lower, and VFA concentrations remained high with important amounts of propionate (1800 mg/L).
- The methane production rate increased regularly with temperature between 28°C and 49°C; at 55°C however, it was quite lower than at 49°C, probably due to overloading conditions.

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