# BIOGAS PRODUCTION FROM CHEESE WHEY IN TWO PHASE ANAEROBIC DIGESTION

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**Abstract.** Biogas production from cheese whey as an energetically rich product that can contain more than 50 $g \cdot l^{-1}$ lactose was investigated. A laboratory scale two phase anaerobic digester was used to investigate suitability of cheese whey for biogas production. Technological parameters for anaerobic digestion process were elaborated. The methane yield of local cheese whey has been determined and fluctuated 136.6-216.3 $l_m \cdot kg_{vs}^{-1}$. Conclusion – anaerobic digestion of local cheese whey in a two phase digester is acceptable, but some improvements of the equipment are necessary.

**Key words:** anaerobic fermentation, cheese whey, biogas, biomethane.

## Introduction

Cheese production is an important part of the dairy industry in the European Union as more than 40 % of the European Union (EU) milk is processed into cheese [1]. In the milk quota year 2008/2009 milk delivered to the dairies reached 133 621 102 tons [2]. There are a lot of varieties of cheese resulting in different cheese making technologies, but in average the final volume of whey is about 85-90 % of the volume of the processed milk. It can be estimated that more than 45 million tons of cheese whey each year are produced in the EU.

Whey has already been utilized directly as animal feed, processed for human consumption or used as field fertilizer, but usage of whey for energy production is not widespread. Although whey has sufficient biogas potential it is complicated substrate for biomethane production due to the process instability. The main components of cheese whey are: lactose (44-52 $g \cdot l^{-1}$), protein (6.1-6.6 $g \cdot l^{-1}$), fat (0.2-0.3 $g \cdot l^{-1}$) and minerals (5-7.9 $g \cdot l^{-1}$) [3]. Under anaerobic conditions lactose (main component of whey solids) is rapidly broken down into short chain fatty acids – acetic, propionic, butyric and other acids. As whey has little or no buffering capacity, pH drops dramatically inhibiting activity of methanogens what results in low gas yields with a low methane content [4; 5].

To control the optimal pH level for methanogenic bacteria several techniques have been described. Scientists often propose to co-ferment whey together with substrates with sufficient buffering capacities [5; 6; 7]. Ghaly and Ramkumar used a pH measurement and control system which consisted of a computer controlled pH electrode and peristaltic pump. At prescribed time intervals (30 min.) pH was automatically measured and compared with the setpoint of pH 7. If pH was lower than 6.9 the peristaltic pump added basic solution – 2.5 N NaOH [5].

Ghaly and Ramkumar reported biomethane production of 0.51 $v_m \cdot v_r^{-1} \cdot d^{-1}$ ($v_m$ – volume of methane, $v_r$ – volume of reactor, d – day) in the two stage continuous anaerobic digester with the loading rate 10 $l \cdot d^{-1}$ (hydraulic retention time (HRT) 15 days) [5]. According to Kavacik et al. co-digestion of cheese whey and dairy manure in continuous fermentation with HRT of 5 days and 8 % of total solids resulted in 0.906 $v_m \cdot v_r^{-1} \cdot d^{-1}$ [6]. In the continuously stirred pilot reactor the methane yield of 2.2 $v_m \cdot v_r^{-1} \cdot d^{-1}$ of diluted poultry manure and whey mixture was reported by Gelegenis et al. [4].

Cominio et al. investigated biogas potential of cow manure and whey biomass mix and achieved 211.4 $l_m \cdot kg_{vs}^{-1}$ ($l_m$ – liters of methane, $kg_{vs}$ – kg of volatile solids) [7].

## Materials and methods

### *Construction of bioreactor*

A modified two phase anaerobic bioreactor (W8, Armfield) was used in the current study. The schematic diagram of the system is presented in Fig. 1. The bioreactor consisted of two separate reactors – Reactor 1 and Reactor 2 made of PMMA with the total volume 5 l and working volume 4.6 l. Both reactors were equipped with peristaltic pumps. The temperature of each reactor was controlled by an electric heating mat wrapped around the external wall of the reactors. pH was

controlled in Reactor 2. Plastic gas-tight bags with capacity of two liters were used for gas collection and measurement of the amount produced.

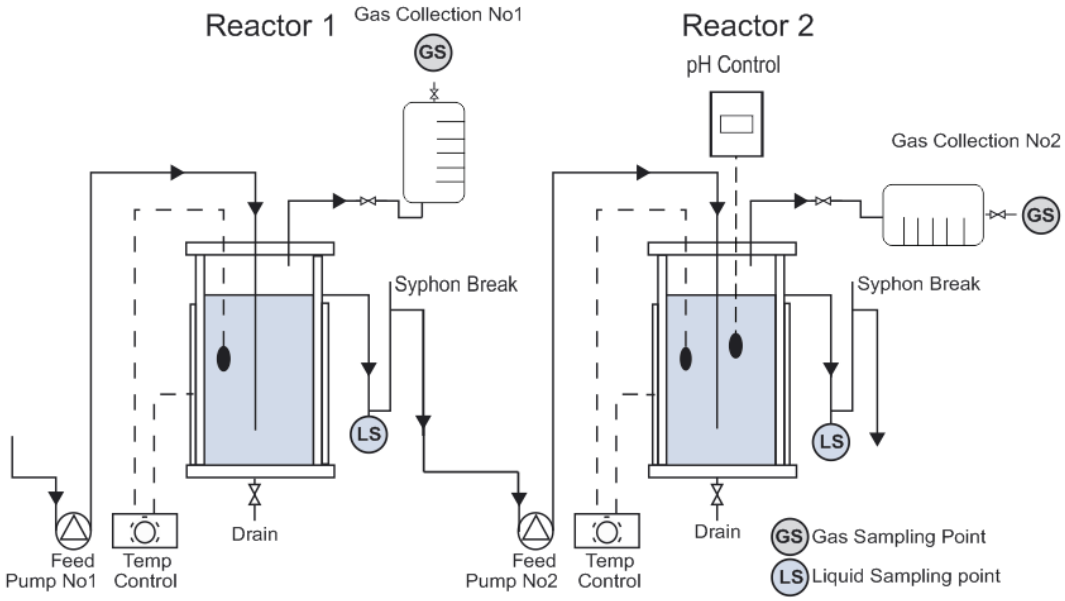


Fig. 1. **Schematic diagram of two phase anaerobic bioreactor used in study**

***Description of cheese whey***

Raw cheese whey was obtained from a home made cheese maker in Riga. Cheese whey was collected in 5 l plastic containers and stored in the refrigerator at 4 ºC for no longer than two weeks. Fresh cheese whey was used when possible. Some characteristics of cheese whey used are summarized in Table 1.

Table 1

**Characteristics of cheese whey used in this study**

| Parameter | Value |
|---|---|
| Total solids, $mg \cdot l^{-1}$ (%) | 71 669±5 767 (7.03±0.56) |
| Volatile solids, $mg \cdot l^{-1}$ (%) | 65 881±6 020 (6.46±0.59) |
| COD, $mg \cdot l^{-1}$ | 79 500±8 290 |
| pH | 5.3±0.1 |

***Bioreactor startup***

The seed material was obtained from anaerobic batch reactors used for seed material cultivation in own laboratory. Diluted cow manure was used as the initial substrate. Fresh inoculum from the batch reactor, witch produced biogas with average methane content of 60 % was used for the startup procedure. In Reactor 1 1949 g of whey were mixed with 921 g of seed material and 692 g of tap water. Whey was gradually added in the reactor within a week till the full working capacity of Reactor 1 (4.6 l) was obtained. In Reactor 2 1500 g of seed material were mixed with 3000 g of liquid fraction of cow manure (with particle size ≤1 mm). Additionally 50 g of $NaHCO_3$ were added in both reactors to increase initial buffering capacity.

***Analytical methods***

The gas composition was determined by the gas analyzer (GA2000, Geotech).

Total solids were determined by the moisture balance (MOC-120H, Shimadzu). Volatile solids were determined by keeping dried samples in a laboratory furnace (L3/11/B170, Nabertherm) at constant temperature of 550±5 ºC during the period of 0.5 hours.

In Reactor 1 pH was periodically monitored by pH meter (PH-208, Lutron; electrode PE-05T Lutron). In Reactor 2 pH was continuously monitored by pH electrode (PE-06HD, Lutron) and controller (KE400, KURT).

**Results and discussion**

The experiment was carried out for 53 days during witch five separate periods can be distinguished. Daily biogas production is demonstrated in Fig. 1. Average daily biogas production of 3 days is used to normalize day-to-day fluctuations of biogas amounts due to the manual operations when emptying gas bags.

Five periods can be distinguished in Fig. 2, *a* – from start of the experiment till day 11, *b* – from day 11 till day 30, *c* – from day 30 till day 39, *d* – from day 39 till day 52, *e* – from day 52 till the end of experiment. The loading rate for the first 5 days was 100 ml·day$^{-1}$ (HRT – 46 days) and 200 ml·day$^{-1}$ (HRT – 23 days) for the rest of the experiment till period *e*.

During period *a,* as it can be seen in Fig. 2, daily biogas production gradually increased. In the same time pH level gradually decreased as microorganisms in Reactor 2 adapted to the acidic whey digestate from Reactor 1. On day 11 the pH meter electrode was changed in Reactor 2 (arrow 1 in Fig. 2) what lead to substantial contamination with air. As a result the amount of gas production lowered.

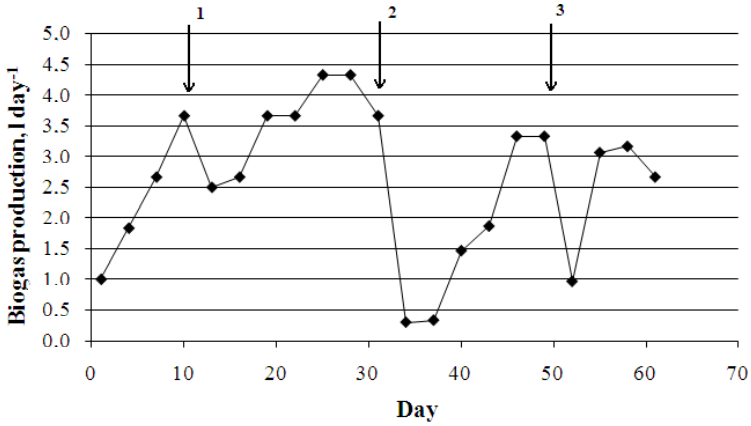


Fig. 2. **Normalized daily biogas production in second reactor:**
1 – Change of pH meter; 2 – appearance of ethanol odor in the first reactor; 3 – pH lowers below 7

Biogas production stabilized in period *b* and reached the biogas production rate of 4.3 l biogas per day (0.61 $v_m \cdot v_r^{-1} \cdot d^{-1}$; 216.3 $l_m \cdot kg_{vs}^{-1}$). pH in the first reactor during this period decreased from 4.96 to 4.06. At the same time pH in Reactor 2 was stabile around 7.3, as can be seen in Fig. 3.

On day 31 specific ethanol odor was detected (arrow 2 in Fig. 2) what indicates elevated activity of yeasts or other ethanol producing microorganisms. Biogas production decreased substantially till 0.3 l per day. During period *c* microbiota in Reactor 2 adapted to new composition of digestate from Reactor 1 and biogas production started to increase.

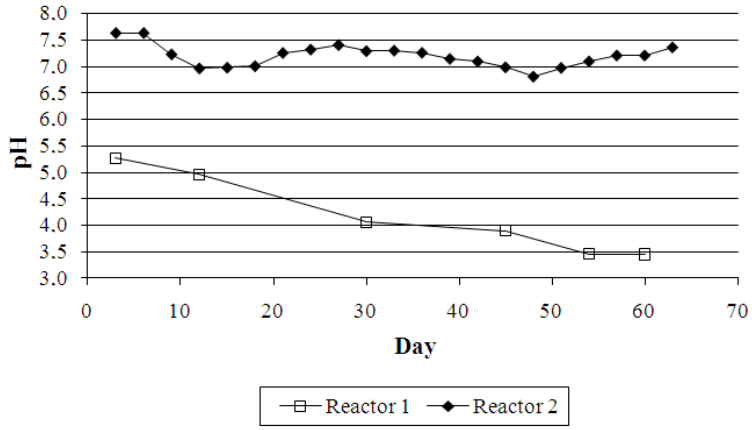


Fig. 3. **pH measurements in Reactor 1 and Reactor 2**

In period *d* biogas production in Reactor 2 increased till 3,3 l biogas per day (0.38 $v_m \cdot v_r^{-1} \cdot d^{-1}$; 135.6 $l_m \cdot kg_{vs}^{-1}$). During period *d* pH in Reactor 1 decreased to 3.46 and in Reactor 2 to 6.82.

As a result of pH drop in both reactors biogas production in Reactor 2 decreased sharply. To stabilize the process feeding was stopped in period *e*. Feeding of bioreactor was restored on day 55 adding 100 ml divided in two portions by 50 ml. Feeding in period *e* was adjusted regarding to pH in Reactor 2 and did not exceed 100 ml per day. The differences in the composition of biogas from Reactor 2 can be seen in Table 2. The amount of methane in biogas varied between the periods of the experiment reaching the maximum 65.0 % in the most steady *b* period.

Gas production in Reactor 1 was not detectable what complies with the findings of other scientists. Ghaly and Ramkumar reported gas production as low as 0.06 $v_g \cdot v_r^{-1} \cdot d^{-1}$ from the first phase reactor without pH control [5].

The pH level in the first phase plays an important role in the two phase anaerobic digestion. It can be concluded from the presented study, that pH below 4 in the first phase substantially lowers the pH level in second phase as the buffering capacity in the second phase is weak. Two possible solutions can be suggested: introduction of pH control system in the first section as reported by other authors [5] or reduction of the volume of Reactor 1. Reduction of the volume for Reactor 1 will shorten HRT for the first phase and reduce the amount of organic acids produced by acid forming bacteria.

Table 2

**Composition of biogas from Reactor 2 during different periods of experiment**

| Period | $CH_4$, % | $CO_2$, % | $O_2$, % | $H_2S$, ppm |
|---|---|---|---|---|
| *a* | 59.0 (±1.5) | 18.0 (±5. 8) | 4.8 (±1.2) | 83 (±60) |
| *b* | 65.0 (±2.7) | 24.2 (±3.3) | 2.9 (±0.5) | 186 (±54) |
| *c* | 54.0 (±7.9) | 28.0 (±5.8) | 4.0 (±2.0) | 184 (±65) |
| *d* | 53.1 (±9.6) | 36.2 (±14.0) | 3.0 (±1.3) | 247 (±148) |
| *e* | 64.7 (±1.9) | 19.4 (±4.2) | 3.9 (±0.9) | 65 (±38) |

*Standard deviations are calculated from at least 4 independent gas measurements in each case

## Conclusions

1. Anaerobic digestion of local cheese whey in a two phase bioreactor is acceptable;
2. Usage of pH control should be considered in two phase anaerobic digestion of local cheese whey for the first phase;
3. Smaller volume of Reactor 1 should be considered.

## Acknowledgements

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