Biological Anaerobic–Aerobic Treatment Of Dairy Wastewater In Poland

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Abstract In 2014, farms across the EU-28 produced approximately 164.8 million tones of milk, of which 159.6 million tones (or 96.8 %) were cows' milk. Cows' milk production on farms was the highest in Bretagne (France), Southern and Eastern Ireland and Lombardia (Italy) and Masovia (Poland) (8,3%). Milk processing produces wastewater. In Poland 1 m^3 of processed milk accounts for 3.2 m^3 of wastewater. In 2013 the production of dairy products in Poland generated 26.5 hm^3 of sewage: 14.7 hm^3 of which was treated (9.3 hm^3 biologically and 5.4 hm^3 with increased nutrient removal). The dairy wastewater is primarily generated from the cleaning and washing operations. Its main contaminants are: high BOD and COD concentrations, and it contains fats, nutrients, lactose, as well as detergents and sanitizing agents. Biological treatment is the basic method used for wastewater from food processing. Dairy wastewater in Poland is treated using aerobic biological methods: circulated pond, activated sludge process, sequencing batch reactor, Moving Bed Biofilm Reactor and anaerobic reactors. The two steps anaerobic-aerobic reactors are used in two cases in Poland.

Keywords: wastewater, dairy, biological treatment, anaerobic reactor, aerobic reactor

1. Introduction

Production and processing of milk in Poland is very important for the agriculture and food industry. Poland is the third world's producer of milk. Milk production in 2014 was 12607 million liters and it was higher than 12348 million liters obtained in 2013 of almost 260 million liters (increased 2%) (Environment, 2014).

Cow's milk plays the dominant role in the Polish production and processing. The most common products include: drinking milk, cottage cheese, cheese, milk powder, butter, cream, and milk drinks. The dairy industry is considered among the food industries as one of the most polluting sectors (Andrade et al., 2013 and Mendes et al., 2014). Dairy wastewater is characterized by a high content of BOD, COD, dissolved and suspended solids, fats and oils, and nutrients (Praneeth et al., 2014, Farizoglu and Uzuner, 2011, Fraga et al., 2016).

The unit operation used in the dairy wastewater treatment includes: screening, sedimentation, flotation, flow equalization and biological aerobic and anaerobic processes. They are often used as combinations of biological reactors depending on content of nutrients in dairy wastewater.

The quality of treated dairy wastewater discharged into the river according to the Polish Regulation (PR, 2014) should be: BOD below 25 mg O_2/L, COD below 125 mg O_2/L, TSS below 30 mg/L, TN below 30 mg N/L, TP below 2 mg P/L.

The aim of this paper is to compare the work of two dairy wastewater treatment plants where biological treatment takes place in anaerobic and aerobic reactors. It is based on the wastewater quality parameters measured twice a week during the year 2014.

2. Biological anaerobic and aerobic treatment application for the dairy industry

2.1 Anaerobic and aerobic process used for industrial wastewater treatment

The methane fermentation is the most popular method, used by Wastewater Treatment Plant (WWTP) for anaerobic decomposition of organic matter in the sludge. Also industrial wastewater with high organic contents can be treated anaerobically. In general, aerobic systems are suitable for the treatment of low strength wastewater (biodegradable COD concentrations less than 1000 mg/L) while anaerobic systems are suitable for the treatment of high strength wastewater (biodegradable COD concentrations over 4000 mg/L) (Chan et al., 2009). Biological methods, like activated sludge process, are employed for the treatment of a large number of dairy wastewater because of the ability to remove nutrients (phosphorus and nitrogen). The disadvantages of aerobic biological technologies are the high costs of the electricity for the air supply to aeration tanks.

2.2.Anaerobic-aerobic dairy treatment application in Poland

In Poland, two dairies use a combination of anaerobic and aerobic reactors for wastewater treatment. In the dairy one (I) there are produced: cheese, cottage cheese and butter and in the dairy two (II): milk, sour cream, yoghurt, milk powder, cheese whey powder, cheese, butter.

Both dairy wastewater treatment plants were designed for the same parameters. The average flow 1500 m^3/d , concentration and load of parameters are shown in table 1.

Characteristic of WWTP for dairy I

Raw sewage from the milk factory is directed to the grit removal and to the fine 1mm screen. Screenings are transported to the waste container. There is a possibility to averaging wastewater flow and parameters in equalization tank (MAB), volume 594 m^3. The next step is the flotation (DAF). Before the DAF, the correction of the pH with sodium hydroxide is possible. Before anaerobic reactor (ANR) wastewater free of fat and TSS is heated. The volume of anaerobic reactor (ANR) is 1698 m^3. Operational parameters designed for the project: OLR = 4 $kgCOD/m^3 \bullet d$, HRT = 21.6 h. The process is conducted at the mesophilic temperature in the range of 30-35°C. After the anaerobic process the wastewater is additionally cleaned in activated sludge reactor (ASR) (anoxic tank V=270 m^3, aeration tank V=730 m^3). The separation of the sludge from the treated wastewater is held in the secondary clarifier. Purified wastewater is discharged to the river Sierpienica.

Characteristic of WWTP for dairy II

Raw sewage from the milk factory is directed to the fine 2 mm screen. Next, wastewater goes to averaging tank V=742 m^3 where there is a possibility to add 50% NaOH or 35% HCl to correct the pH. From the averaging tank, the effluent flows to DAF. Before DAF, the polymer flocculant and PAX18 coagulant are added. Wastewater is heated before flowing to the anaerobic reactor IC (ANR-IC) of 300 m^3 capacity. Operational parameters assumed for the project: OLR = 11-30 $kgCOD/m^3 \bullet d$, temperature of the process 32°C. Wastewater from the anaerobic reactor is directed to the activated sludge reactor (ASR) (anoxic tank V=500 m^3, aeration tank V=1500 m^3). The last step is the secondary clarifier. Purified wastewater is discharged to the river Rypienica.

In table 2 there are actual parameters in raw wastewater flow into dairy I and II.

Table 1. The concentration and the load of contamination designed for the project

Parameter	Concentration mg/L	Load kg/d
BOD	2200	5250
COD	3500	3300
Total N	100	150
Total P	40	40

Table 2 Characteristic actual parameters in raw wastewater

Parameters	Max		Min		Average	
	Dairy I	Dairy II	Dairy I	Dairy II	Dairy I	Dairy II
Q m^3/d	1787	1770	989	1052	1369	1433
COD mg/L	5056	8639	1513	1329	2310	4001
LCOD kg/d	7640	12166	1708	1984	3173	5676
N total mgN/L	39,8	148	25,7	26,0	35,7	99,0
P Total mg/l	18,4	60,0	14,3	11,4	17,4	26,9

The volumes of the wastewater flowing to both treatment plants are similar - respectively 91 and 95% of supply designed for the project. In the dairy I, the average load of organic compounds expressed as COD is 96% of the value estimated for project. In the case of dairy II both COD concentration and the load are significantly higher than assumed. Wastewater from dairy II is characterized by a nitrogen concentration such as the assumed level, and a lower concentration of phosphorus. The actual sewage pollution concentrations discharged to both WWTP are identical to the values given by Demirel (Demirel, 2003) for effluent from a mixed dairy processing. According to (Demirel, 2003), the parameters in mixed dairy processing wastewater are: COD=1150-9200 mg/L, TKN=14-272 mg/L, total P = 8-68 mg/L.

Primary unit of both WWTP is screening and DAF, for this reason in table 3 there are parameters in influent and effluent to anaerobic reactors (ANR).

Figures 1 and 3 show the actual OLR for anaerobic and aerobic reactor in the dairy I and II and figures 2 and 4 show the actual COD reduction.

Table 3. Actual parameters in wastewater influent and effluent to anaerobic reactor

Parameters	Max		Min		Average	
	Dairy I	Dairy II	Dairy I	Dairy II	Dairy I	Dairy II
COD_{inf} mg/L	3417	4841	933	561	1886	2394
$LCOD_{inf}$ kg/d	5163	7234	1053	716	2592	3475
COD_{eff} mg/L	2017	3597	813	431	1279	1768
$LCOD_{eff}$ mg/L	3181	5344	973	587	1744	2528
VFA_{eff} $mgCH_3COOH/L$	811	892	200	143	437	427
OLR_{ANR} $kgCOD/m^3 \cdot d$	3,8	32,1	0,8	2,7	1,9	13,1
Temperature °C	34,3	-	27,0	-	31,2	-
HRT h	32,8	6,4	18,1	2,6	24,1	5,1
Biogas production m^3/d	897	5477	169	326	396	1412

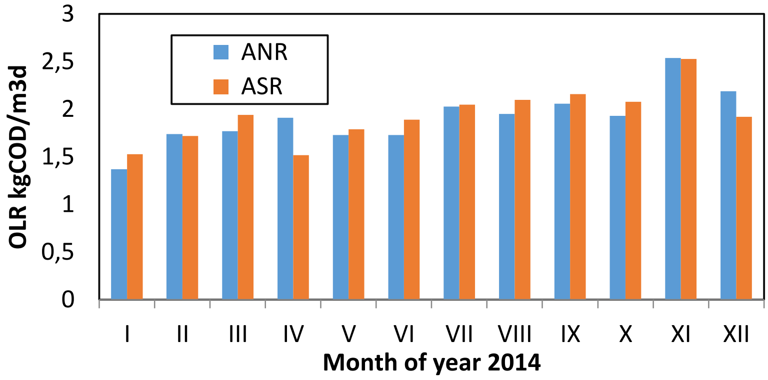

Figure 1. OLR in anaerobic (ANR) and aerobic (ASR) reactor –dairy I

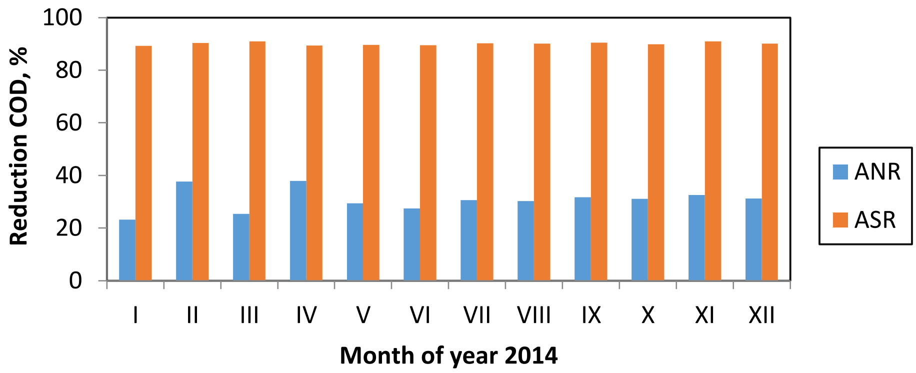

Figure 2. COD reduction in anaerobic (ANR) and aerobic (ASR) reactors-dairy I

Anaerobic reactor (ANR) in the dairy I works at a very low rate (0,8-3,8 $kgCOD/m^3$•d) never reaching OLR assumed for the project- 4 $kgCOD/m^3$•d Average HRT ANR is as long as 24,1h. The average reduction of COD is only 30.7% (Fig.2). Typical COD reduction in anaerobic process should be 70-80%. At such a low COD reduction affects actual low wastewater temperature (average 31,2°C- table 3).

So it is necessary to use the aerobic reactor for the further reduction of organic contamination and nutrient. The OLR in the reactor ASR is in the range of 1.52-to 2.53 4 $kgCOD/m^3$•d (average 1.94) - reactor is at moderate or high rate (it is characteristic for carbonaceous oxidation) (EN 12255-6, 2002). In the ASR reactor average reduction of COD is approximately 90% (Fig.2)

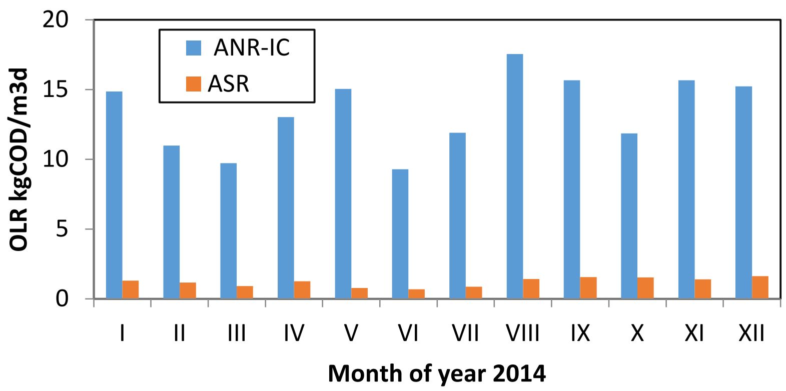

Figure 3. OLR in anaerobic (ANR-IC) and aerobic (ASR) reactor –dairy II

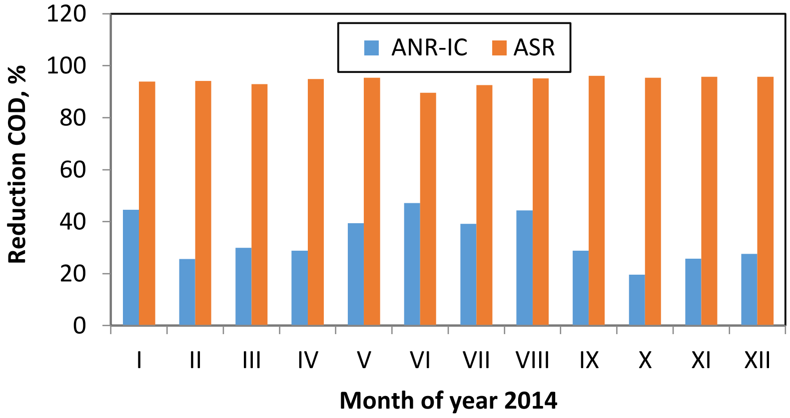

Figure 4. COD reduction in anaerobic (ANR -IC) and aerobic (ASR) reactors-dairy II

IC anaerobic reactor offers the highest possible organic loading rate (Mutombo, 2004). Recommended in the literature OLR for IC reactors is in the range of 15-30 kgCOD/m^3•d (Driessen, 1999). Actual average OLR in ANR-IC is 13.1 kgCOD/m^3 • d. The reduction of COD is in the range of 19,6%-47,1, average only 33.4% . The temperature in the reactor, which was lower than typical for mesophilic processes, may be the reason for such a low reduction. The project assumes that at a temperature of 38 ° C, it is possible to achieve 85% COD reduction. The temperature is not permanently measured, but it is known, however, that it is around 31 ° C. The average HRT ANR is 5,1h. In ASR reactor conventional medium rate process takes place, so only carbon compounds oxidation is realized. The actual reduction in the value of COD in the ASR is 89,6-96,1% (average 94.3%) (Fig.4).

As a positive result of the anaerobic processes, the biogas is generated in a theoretical amount of 0.35 m^3 / kg COD_{red} (Tchobanoglous, 2003). The actual amount of biogas produced on the WWTP for dairy II is significantly larger than on a WWTP for dairy I (respectively 396 and 1412 m^3/d). The reason for such a large biogas quantity in the WWTP for dairy II is the fact that the quantity of the biogas produced in the reactor and during the sludge stabilization are measured together.

3 Conclusion

On the both wastewater treatment plants for diary industry the anaerobic- aerobic system is used. For these dairies, the quality of treated wastewater discharged into the river meets the Polish law requirements. In the both anaerobic reactors a very low percentage reduction of organic compounds expressed in COD (ca. 30%) is achieved. One reason may be the sewage temperature, which is too low for the mesophilic bacteria - approximately 31°C. The other reason could be the presence of the Long-Chain Fatty Acids resulting from the hydrolysis of lipids. Even in millmolar concentrations can inhibit many microorganisms, particularly slowly multiplying bacteria acetogenic and methanogenic (Koster et al, 1987). Unsaturated LCFA are more toxic than saturated LCFA. Due to the low operational efficiency of anaerobic reactor, further polishing processes must be implemented in the aerobic reactors. The undoubted advantage of the system used is the production capacity of biogas, which can satisfy some of the demand for heat treatment.

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