

# **Wastewater treatment in the dairy processing industry - recovering energy using anaerobic technology**

## Introduction

The composition of wastewater from dairy processing plants makes it highly suitable for biological wastewater treatment processing. As well anaerobic biological treatment of the wastewater there is also the option of applying anaerobic biological processes. By applying anaerobic technology a large part of the organic load in the wastewater can be removed and converted into energy-rich biogas. In addition, the anaerobic technology can be used in dairies to produce biogas from waste whey. The biogas which is generated can be used to produce electrical and/or thermal energy.

## Quantity and composition of wastewater

In 2007 around 27.6 million tonnes of milk was delivered to milk-processing plants in Germany. [1] In the dairy industry around 1 - 2 m<sup>3</sup> of wastewater is created each day for each tonne of milk during its processing and in the production of a variety of milk products. [1] Table 1 shows examples of the volumes of wastewater for some production processes in the dairy industry.

*Table 1: Wastewater volumes for some dairy production processes [2]*

Volume of wastewater	
Production of saleable milk from 1 litre of milk as supplied	0.8 – 1.7 l/h
Production of milk powder from 1 litre of milk as supplied	0.8 – 1.5 l/h
Production of 1 kg of ice cream	2.7 – 4.0 l/kg

The wastewater created in a dairy comes mainly from the cleaning of the company's means of transport and of production. High organic loads are created on a changeover of production (especially from clearing out pipes and tubes), more than 90% of the organic contents consist of milk and production residues [3]. Table 2 shows the typical daily range of fluctuations of different parameters in dairy wastewater (sometimes the load is up to 7 times higher than in normal public wastewater), with peak values perhaps being even higher on occasion.

*Table 2: Specific concentrations in dairy wastewater [1]*

Parameter	Unit	Range of fluctuations (within a day)
BOD <sub>5</sub>	[mg/l]	600 – 2000
COD	[mg/l]	800 – 4500
NO <sub>3</sub> -N	[mg/l]	10 – 100
Total N-N	[mg/l]	20 – 230
Total P-P	[mg/l]	20 – 100
Sediments	[ml/l]	1 – 2
pH	[ $\text{-}$ ]	6 – 11
Lipophilic substances	[mg/l]	80 – 250

### **Wastewater purification in the milk processing industry for indirect and direct discharge**

Given the quantities of wastewater generated, as well as the fluctuations in load, (especially in relation to the pH value) treatment of the wastewater is necessary prior to either direct or indirect discharge. With direct discharge, a biological cleaning stage is normally used, as well as both grease separator systems (e.g. flotation systems), and mixing and equalising tanks. As dairy wastewater is easy to break down biologically, the COD can be reduced in the discharge to COD<sub>discharge</sub> < 40 mg/l by using a full biological breakdown.

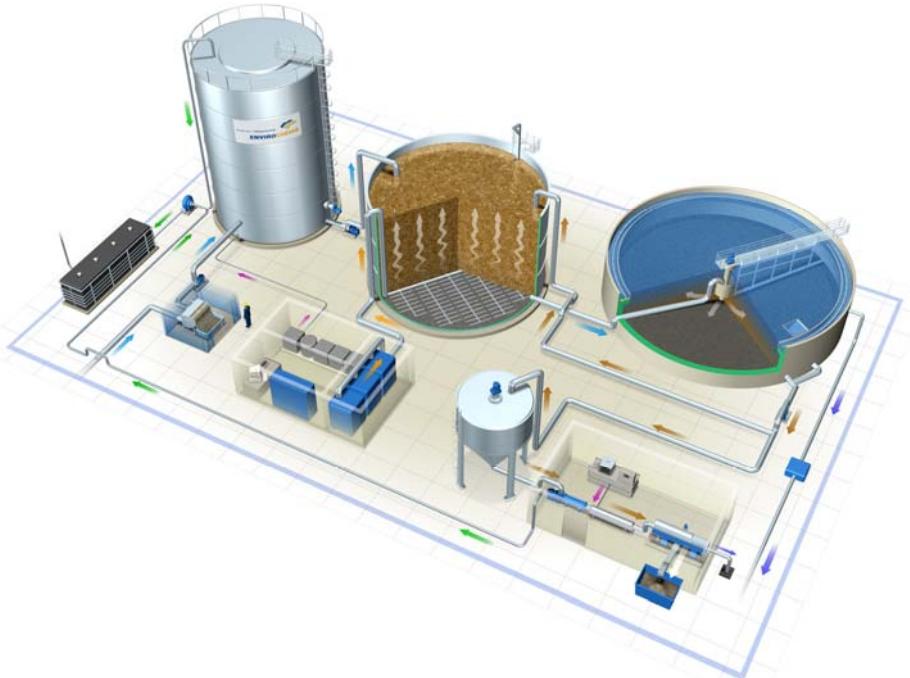
For indirect discharge, the wastewater treatment technology required will depend on the official regulations that apply, (for example local authority by-laws). In rural areas the public sewage plants are often not designed to handle high loads, so that it is necessary to pre-clean the wastewater generated from milk processing in the company's own sewage plant.

Taking an international view, milk-processing plants are often not connected to public sewage treatment plants at all. They therefore, as direct dischargers, have to clean their wastewater within the plant to meet the limits imposed for discharge into a body of water.

## Aerobic biological treatment of wastewater in the dairy processing industry

In Germany, the biological cleaning stage normally used for wastewater treatment in the dairy processing industry is normally aerobic biological cleaning.

[1]. This will be described briefly below.



*Figure 1: Schematic representation of a commercial sewage treatment plant for aerobic biological cleaning of wastewater from milk processing*

In Figure 1 a commercial sewage treatment plant is shown for the aerobic biological cleaning of wastewater from milk processing. The water arrives via a grease and sludge trap in a mixing and equalising tank, where daily peaks are smoothed out and the pH-value can be adjusted as required. From there the wastewater is fed into an aerobic activation stage with the options of nitrification and denitrification. The activated sludge is then separated in a secondary sedimentation basin and the cleaned water is led off into the public sewer. In the case of direct discharge into a body of water, the sludge sedimentation should ideally be followed by a final filtration. The activated sludge separated in the secondary sedimentation basin is then partially recycled into the activation stage. The excess sludge (ES) is either transported without dewatering to be processed externally, or is dewatered using a sludge dewatering stage, such as, for example, pressure filters or decanters (centrifuge), and then disposed of. Pro kg reduction inBOD<sub>5</sub>, the dry matter recovered as excess sludge has  $ES_{C,BOD_5} = 0.6 - 1 \text{ kg DM/kg BOD}_5$ .

To reduce the phosphate load, chemical P-precipitation can be used as well as biological precipitation (pre-, concurrent and/or post-precipitation). Generally

precipitation using iron salts is used to effect precipitation of the phosphates in the separated sludge. The cleaning of the wastewater using the procedure described delivers the best results given the current state of technology, but demands considerable consumption of energy, especially to create the compressed air used during the activation stage. The energy consumption in an aerobic activation plant typically amounts to approx. 0.5 – 1 kWh/kg BOD<sub>5</sub> per kg reduction in BOD<sub>5</sub> [4].

### Comparison of aerobic and anaerobic biological cleaning of wastewater

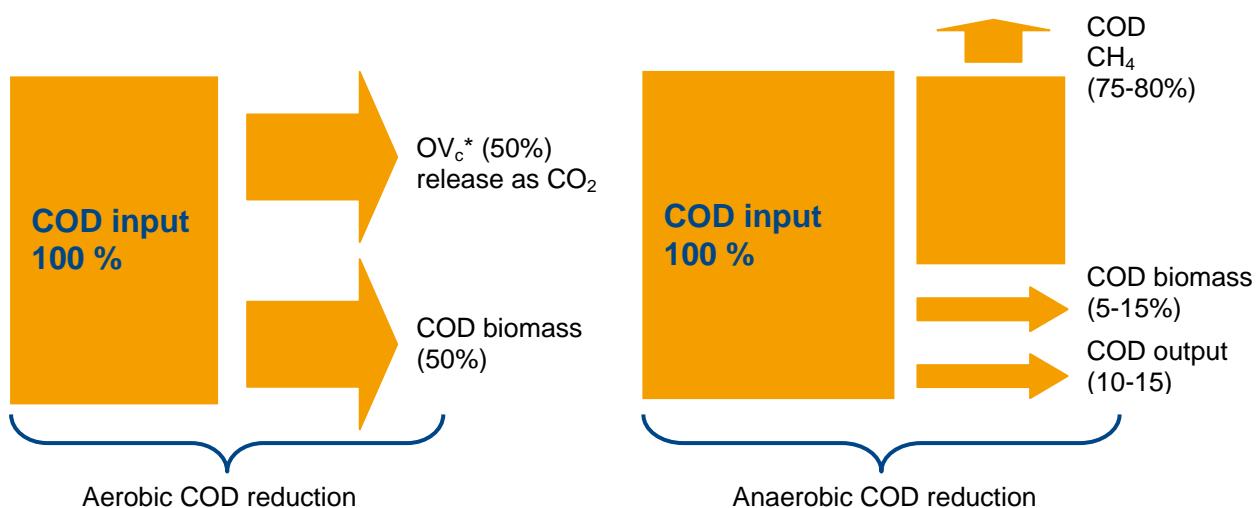
Depending on the level of purification being targeted, wastewater sub-streams with high loads can also be pre-treated upstream of the aerobic cleaning using anaerobic technology. The benefits of applying anaerobic technology arise primarily from

- The comparatively low energy consumption of anaerobic biological cleaning (because no aeration is needed)
- The energy provision from the biogas which is created (this can make a significant contribution to the overall net energy consumption of wastewater treatment).
- The low level of excess sludge in comparison to aerobic biological wastewater cleaning (significantly lower sludge handling costs)

The main disadvantage of using anaerobic technology is the worse discharge quality compared to aerobic technology.

This relationship is presented in Figure 2 showing the net COD levels for aerobic and anaerobic wastewater processing.

*Figure 2: Comparison of net COD levels for aerobic and anaerobic wastewater treatment*



\*OV<sub>C</sub> = Oxygen consumption for C-elimination

Figure 2 compares the net COD levels for aerobic and anaerobic wastewater processing. During aerobic COD-reduction, around 50% of the COD in the input is converted into biomass (excess sludge), and about 50% is released as carbon dioxide. The COD in the output is <1% and can be ignored in this context. In comparison to this, in anaerobic COD reduction only 5 to 15% of the COD of the input is converted to biomass, while 75 to 80% is converted to methane in the form of biogas. This shows clearly that the volume of excess sludge created by anaerobic wastewater cleaning is up to 10 times less than for aerobic treatment. At the same time anaerobic wastewater cleaning produces useful energy in the form of biogas.

The COD is reduced by about 75 – 80% in dairy wastewater when anaerobic cleaning is used (in comparison to aerobic wastewater cleaning with a COD-elimination performance of > 99%) [1]. This means that the discharge quality from anaerobic wastewater cleaning is worse in terms of COD than if using aerobic wastewater cleaning. In addition, anaerobic wastewater treatment eliminates almost no nitrogen or phosphorus. Generally, the anaerobic technology is therefore used as a pre-treatment stage.

### **Combining anaerobic and aerobic biological cleaning of wastewater – exploiting synergies**

If the use of anaerobic technology can deliver a level of cleaning of > 75% COD reduction, then an anaerobic wastewater treatment can be inserted prior to the aerobic wastewater cleaning. By this means, the benefits of the anaerobic process (75 - 80% COD reduction, reduced excess sludge, usable energy from biogas) can be combined with the benefits of the aerobic process (COD elimination performance > 99%). By using this combination of processes only the biomass not separated out by the retention system, plus the uneliminated COD (approx. 10 – 15% of the input COD level) transition from the anaerobic cleaning stage into the downstream aerobic cleaning stage.

Before the anaerobic cleaning stage, the wastewater needs to be treated to remove grease and possibly also solids (there is especially a risk of the biomass floating because of grease adhering to it).

Larger companies generally tend to use flotation for grease separation (normally dissolved air flotation). COD elimination rates of 40 – 60% can be achieved using a flotation plant [1]. Without using flocculation chemicals the elimination rate may range between 10 – 30%, depending on the composition of the wastewater.

Figure 3 shows an example of the net COD levels which result from an anaerobic cleaning stage being inserted before the aerobic wastewater cleaning stage, as well as initially using flotation for grease separation. As a comparison, it also shows what net COD levels would result from the use of an aerobic cleaning stage with initial grease separation.

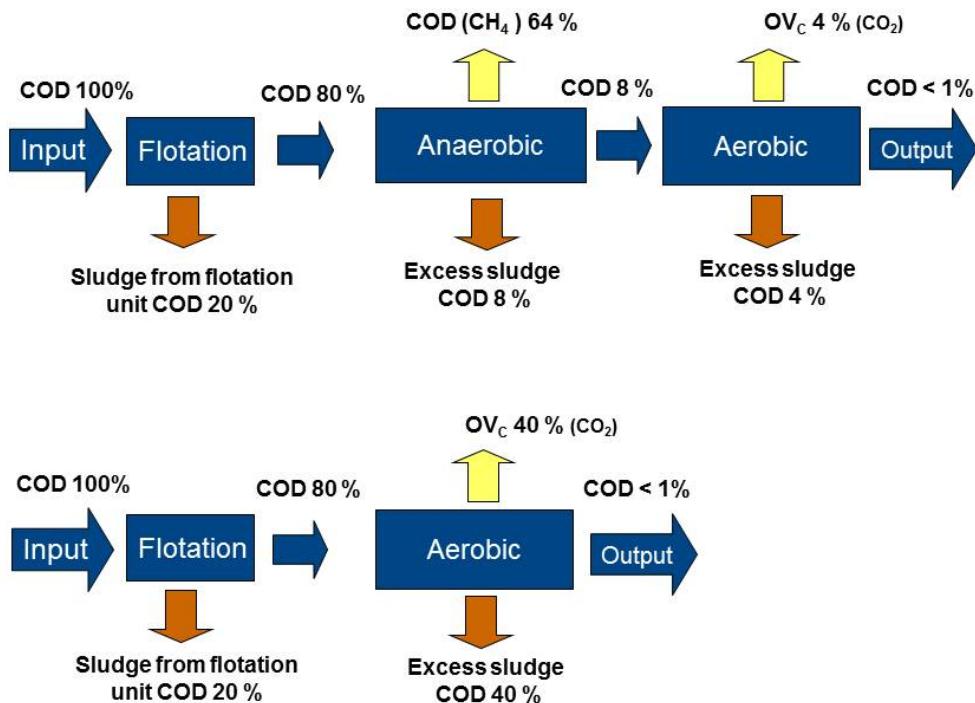


Figure 3: COD levels from a combination of anaerobic and aerobic wastewater cleaning: for comparison COD levels from aerobic wastewater cleaning (both times with initial flotation)

Figure 3 shows clearly that the combination of anaerobic and aerobic wastewater cleaning compared with just aerobic wastewater cleaning (in each case with initial flotation) results in:

- 70% less excess sludge being created (12% ES instead of 40% ES)
- 80% of the COD still in the wastewater following flotation being converted into methane ( $\text{CH}_4$ ) and can be used as energy.
- The net energy consumption being improved, since less energy is required for aeration in the aerobic stage.

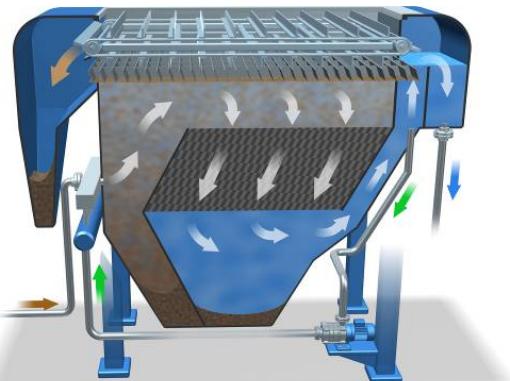
A wastewater cleaning plant is shown below which consists of an anaerobic and aerobic biological cleaning stage with grease separation in a milk processing plant (Illustration 4).



*Figure 4: Wastewater cleaning plant with aerobic and anaerobic cleaning stages*

The wastewater generated by production is fed into the mixing and equalising tank via a drum sieve to remove solid particles. The mixing and equalising tank is of sufficient size to allow hydrolysis and pre-acidification processes to take place. To remove the grease, the wastewater is then fed through a flotation system (Illustration 5) where the free fats can be separated out either with or without the addition of flocculants and flocculation aids. In the actual anaerobic reactor (shown here as being a fixed-bed reactor) the greatest possible conversion of organic wastewater contents via intermediate substances to biogas ( $\text{CH}_4$ ,  $\text{CO}_2$ ) takes place. One kilogram of eliminated COD creates approx.  $0.35 \text{ Sm}^3 \text{ CH}_4/\text{kg COD}_{\text{el}}$ <sup>1)</sup>. As a rule, the proportion of methane in the biogas is approx. 60 – 80%. The generated biogas can be burned directly in the company's steam boiler after it has been dried and, if necessary, desulphurised (Illustration 6). Excess gas can be burned off in a gas flare.

<sup>1)</sup>  $\text{Sm}^3$  = Standard cubic meter



*Figure 5: Flotation plant for grease separation*



*Figure 6: Steam boiler burning biogas*

### **Energy efficiency and sustainability from applying anaerobic technology provide economic benefits**

By using anaerobic technology for wastewater cleaning, around 2 m<sup>3</sup> of biogas can be generated per m<sup>3</sup> of average milk wastewater which replaces about 1.2 l of fuel oil.

The excess sludge volumes are reduced by about 80% which in turn reduces their disposal costs. The excess sludge which is created in the anaerobic plant contains high concentrations of calcium and phosphates. As well as an agricultural dressing, given the high phosphate content other uses can be envisaged in future (e.g. in the fertiliser industry).

The excess sludge which occurs in the aerobic cleaning stage can generally be used for agricultural purposes (normally it meets the requirements of the Fertilisers Regulation and Sewage Sludge Directive [1]).

The grease sludge which is created during grease separation can be used to good effect in biogas systems. Depending on the legal situation, a precondition for their use is that any domestic wastewater, which generally is created only in small quantities in the company's offices, must be disposed of and treated separately.

The energy consumption of the existing aerobic treatment stage is reduced on average by up to 75% thanks to the ability to scale down the aeration system.

### **Producing energy from surplus whey using anaerobic technology**

As well as wastewater flows with high levels of organic contents, surplus whey or whey permeate can also be processed in milk-processing plants using anaerobic technology.

During cheese and casein manufacture significant volumes of whey are produced

(around 90% of the milk used in cheese production turns into the high energy whey by-product). A part of the whey can, for example, be marketed as whey drinks or as animal feed for farm animals. Companies who are unable to sell all or part of their surplus whey need to dispose of it, which involves high costs. The same is true of whey permeate, which has no commercial value, and cannot be sold. Fermenting and converting the whey into energy in a separate, dedicated fermentation reactor can prove substantially cheaper than disposal.

Depending on the volume of surplus whey which is produced, the biogas created from fermentation and its subsequent conversion to energy may be able to cover the entire primary energy needs in a milk processing company. This was demonstrated in a pilot project at the Norrmejerier dairy factory in Umeå in northern Sweden. The fermentation plant used there was based on a reactor system which has been submitted for patenting (called Anaerob Whey Reaktor by its manufacturer). Using the anaerobic contact sludge process, where anaerobic bio-sludge is retained by a centrifugal system, more than 90% of the organic load contained in the whey or whey permeate is converted into biogas. This allows around 40 cubic metres of biogas to be produced per tonne of whey/whey permeate, or if converted (using the thermal value of biogas of 6.5 kWh/Nm<sup>3</sup> biogas) approx. 260 kWh of thermal energy per tonne of whey/whey permeate.

The factory produces a daily volume of up to 10,000 m<sup>3</sup>/d of biogas from 250 m<sup>3</sup>/d whey (which represents approx. 20 t COD/d). This also includes a certain proportion of biogas from the company's wastewater (from production). Prior to the anaerobic treatment, dissolved air flotation is used to remove free grease. The floate which is created by flotation is processed in a separate, small grease fermentation and then disposed of. The biogas generated improves the profitability of the total plant. With the biogas, the company is producing around 50% of the energy needed for the steam boiler plant. A further extension is planned, so that soon it will completely replace all external energy sources.

Figure 7 shows the relation between the eliminated COD load, the biogas yield and the substituted fuel oil volumes (assumption: 0.5 m<sup>3</sup> Biogas/kg COD<sub>el</sub>; fuel oil equivalent 0.6 l/m<sup>3</sup> of biogas).

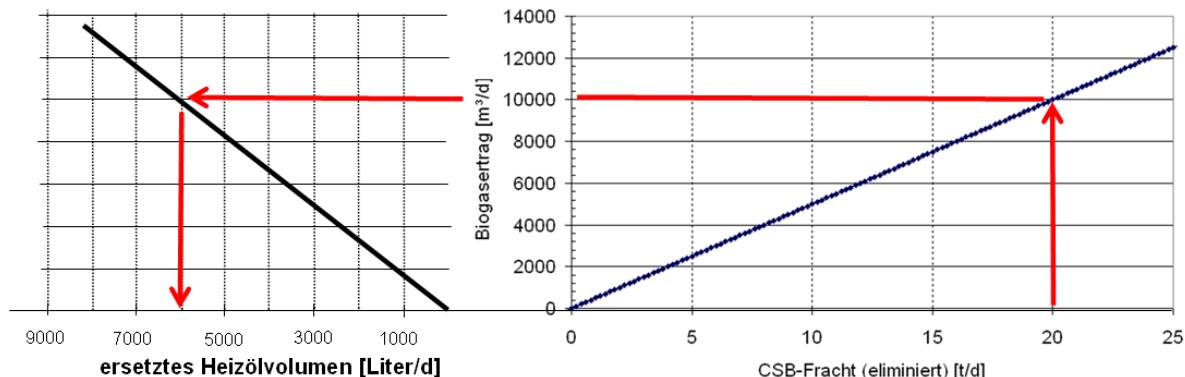


Figure 7: Combinations of COD load, biogas yield and substitution of fuel oil

For example, the COD load of 20 t COD/d eliminated daily in a pilot project at Norrmejerier yields, as shown in illustration 7, a biogas yield of approx. 10,000 m<sup>3</sup>/d. This means that a daily volume of approx. 6,000 l/d fuel oil can be saved.

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