Chapter 7
Reuse of Biologically Treated Process Water: Industrial Water Management in the Paper and Sugar Industry

Otto Nowak and Peter Enderle

Abstract Internal process water cycles have been installed in many industries throughout the last decades. Closing the water cycle is advantageous from the ecological as well as from the economic point of view, mainly because of savings of water and energy. However, closed water cycles may lead to serious operational problems in the production process, such as biofouling and encrustations of limescale. These problems can be avoided by implementing biological wastewater treatment in the internal water cycles. Moreover, energy can be recovered by biological wastewater treatment, particularly if the first treatment step is anaerobic. Examples of heat recovery in the paper industry are presented as well as an example of reuse of biologically treated wastewater in a beet sugar factory. Trends in the application of biological process water treatment for reuse are discussed.

Keywords Paper industry • Closing the water cycle • Biofouling and encrustations of limescale • Biological wastewater treatment • Heat recovery in the paper industry • Beet sugar factory

7.1 Introduction

Stricter environmental regulations, increasing wastewater treatment and discharge costs, and greater environmental awareness are some of the forces leading to development of innovative technologies and strategies to optimize industrial water management. To improve ecological and economic performance, internal process water cycles are installed in many industries. The implementation of process water

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reuse measures are nowadays widely considered the primary step for efficient water use within industrial branches that consume high amounts of water.

One of the first internationally known examples of reuse of biologically treated process water was the sugar mill *Leopoldsdorf* near Vienna [2]. In this mill, the process water has been treated in a single-stage activated sludge plant and reused as flushing and washing water since the 1980s.

More recently, two examples of reuse of biologically treated process water within the paper industry have become known. One of these was operated as a "zero emissions" plant prior to inclusion of biological treatment but increasing difficulties forced integration of a biological treatment plant in order to maintain a closed water cycle [3]. The second company decided to close the water cycle with an integrated process water treatment plant, as increasing wastewater disposal costs were resulting in a steady increase of environmental costs [1]. Meanwhile, additional examples, particularly within the paper industry, become known which at least partially reuse biologically treated process water.

This chapter gives an overview on the state of the art of reuse of biologically treated process water. Advantages and further possible applications are discussed.

7.2 Advantages and Problems in the Case of Process Water Reuse

Reuse of process water has been considered desirable for a long time as part of the general goal of "Cleaner Production". Even in central Europe there are many good reasons for companies to minimize their freshwater demand although in this region water saving measures are only of limited use from the economic point of view and from the perspective of water quantity management. Nevertheless, for many industries there are other good reasons to minimize fresh water consumption, as far-reaching ecological and economic advantages can be achieved. The ecological advantages can be summarized as followed:

- Less organic matter (COD) in the effluent
- Conservation of thermal energy

COD (Chemical Oxygen Demand) characterizes the amount of organic matter in the wastewater. The effluent of low-loaded biological wastewater treatment plants (WWTPs) consists of non-degradable ("inert") organic matter which is not degraded during the biological wastewater treatment process and of very slowly biodegradable COD ("recalcitrant COD"). In regard to the very slowly biodegradable COD, increased concentrations often lead to a higher removal rate and therefore to a reduced COD load in the effluent. Although not fully validated whether this enhanced removal is due to improved degradation or enhanced adsorption, there is evidence that it is due to improved biological degradation.

Conservation of thermal energy derives from the lower heating demand. Generally – e.g. in the paper industry – a higher water temperature is desired for production processes than temperatures characteristic of raw water entering the plant.

In addition to reductions in energy costs, economic advantages result from water supply and wastewater disposal fee structures. Significant cost savings may result from:

- Lower water supply costs
- Reduced wastewater charges for both indirect and direct dischargers (e.g. in Germany)

However, the reuse of organically polluted process water normally leads to significant production problems in both the paper industry and sugar industries. Within the paper and cardboard industry some companies known to the authors have abandoned their zero-emissions approach and reopened their closed water cycle to solve accrued production problems. All production problems that occur when reusing high organically-polluted process water result from the formation of organic layers, i.e. on biofouling.

Biofouling leads to significant production problems and necessitates the application of biocides. An immediate consequence of biofouling is the formation of organic acids out of glucose and starch, i.e. the formation of organic layers leads to an acidification of the process water. Due to this reaction, dissolution of calcium carbonate may occur if lime enters the production process, e.g. via raw materials such as waste paper. A subsequent increase of the pH in the process water cycle leads to the formation of limescales ("encrustations"). Lime hydrate ($Ca(OH)_2$) is often applied to increase the pH and reduce acidification. However, in doing so, the lime content in the process water will be increased accompanied by a higher risk of lime precipitation.

Furthermore, acidification itself can lead to corrosion problems. This problem is exacerbated by the anaerobic processes under the organic layer. In these anaerobic zones, sulfate reducing bacteria (SRB) reduce sulfate (SO_4^{-2}) to hydrogen sulfide (H_2S), causing odor problems and leading to an enhancement of the corrosion affects when H_2S gets into the condensate and is oxidized to sulfuric acids. Finally, the accumulation of organic matter in combination with biofouling can lead to a decline of the product quality, e.g. within the paper and cardboard industry.

To avoid biofouling effects and the accompanying undesirable consequences, biological treatment of organically polluted process water before reuse has turned out to be advantageous. Industries in which biological treatment in the process water cycle can be usefully applied include: paper and pulp; sugar and starch; textile (usually only after filtration); and food industry (only after membrane filtration). Four examples from the paper and sugar industries are presented in detail in the following chapters.

7.3 Process Water Reuse After Biological Treatment Within the Paper Industry

Within the paper industry, producers of high quality papers are confronted with biofouling and its side effects, especially if the production process includes almost closed process water cycles designed to achieve close to zero-emissions and if waste

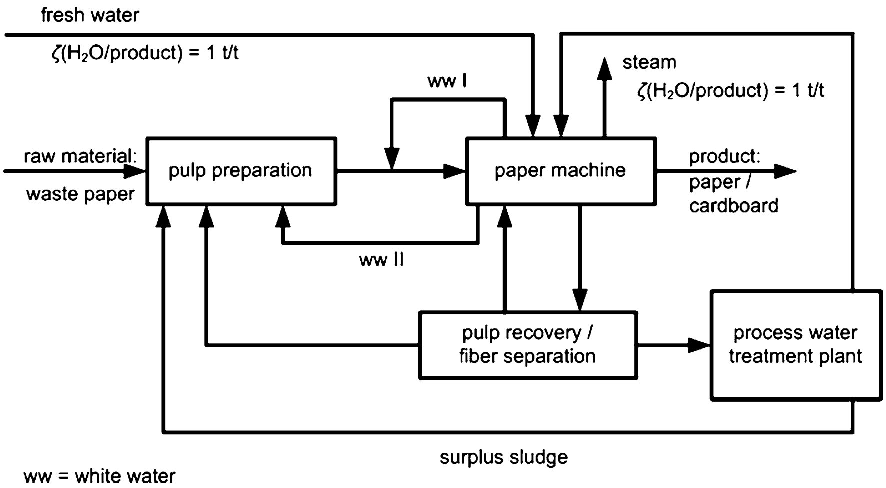

Fig. 7.1 Process water cycle of paper mill 1 and 2 closed over a process water treatment plant

paper is used as a raw material for the production process. To avoid negative effects on the production process and product quality, the input of biocides is required to inhibit biological conversion processes in the process water cycle. As mentioned in the previous chapter, acidification in the process water cycle is accompanied by the release of calcium ions out of the lime introduced with the waste paper and, as a consequence, by the formation of limescales ("encrustations").

Due to these operational problems and a planned expansion in production, the first paper mill discussed ("paper mill 1") decided to integrate a process water treatment plant into the closed process-water cycle [3].

The second paper mill discussed ("paper mill 2") had not originally operated under a completely closed process-water cycle. Due to high wastewater charges, the operators decided to integrate a process-water treatment plant accompanied by closure of the process water cycle [1].

Figure 7.1 shows the more or less identical process-water cycles of paper mills 1 and 2 after the integration of a process water treatment plant ("paper mill 1") and after closure of the process-water cycle and introduction of a process-water treatment plant ("paper mill 2"). In the paper industry, water is inevitable consumed due to the necessary drying processes, whereby approximately one cubic meter of fresh water is needed per produced ton of paper.

At both of these paper mills the excess sludge from the process-water treatment is returned to the production process and inserted into the product. However, this is not possible at all paper and cardboard mills.

The process-water treatment plants of both paper mills consist of an anaerobic and a downstream aerobic stage. In both cases the process water is cooled down from 55°C to a temperature of 37°C before entering the anaerobic stage. This is necessary to adjust mesophilic conditions in the anaerobic stage (Fig. 7.2). However, there is also experience with an anaerobic-thermophilic treatment of

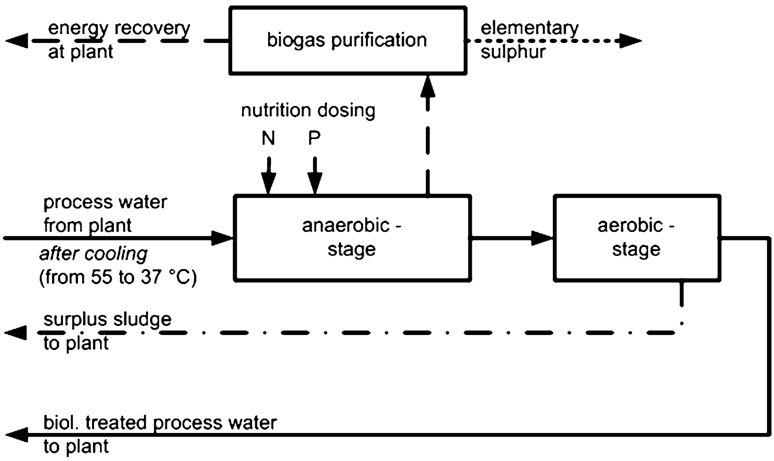

Fig. 7.2 Block diagram of the process water treatment plant of paper mill 1 and 2

process water from paper production followed by the reuse of the biologically treated process water [4, 5].

The aerobic treatment stages are an activated sludge plant at paper mill 1 and an aeration reactor without sludge retention at paper mill 2. Besides the aerobic treatment and the further degradation of the organic matter, the purpose of the aerobic stage is to achieve systematic precipitation of calcium carbonate in a fine crystalline form. This enables the calcium carbonate to be removed from the water cycle together with the excess sludge. This systematic precipitation was reached at paper mill 1 due to use of a shallow aeration tank aerated by surface aeration. This solution achieves a much better stripping of CO_2 compared to the high aerobic reactor with air diffuser used in paper mill 2 where a high amount of CO_2 and therefore calcium remains in solution.

Both paper mills combine purification of the biogas resulting from anaerobic digestion with sulfur recovery (Fig. 7.2). Consequently, the anaerobic process significantly reduces the sulfate concentration in the process water as a significant amount of sulfur is removed as sulfide from the digester gas.

Integration of an anaerobic-aerobic process water treatment plant enhanced the product quality at paper mill 1. The concentration of organic acids in the product was reduced significantly and the product output could be slightly increased. Furthermore, the concentration of calcium ions was considerably decreased by the significant increase of the pH-value in the process water. In contrast, the chloride concentration remained unchanged as expected.

Summarizing the results of the adapted production process, in comparison to the closed operation without an integrated process-water treatment plant at paper mill:

- the COD, calcium and sulfate concentration in the process water was decreased by 80%,
- the odor problem was reduced and
- the product quality improved [3].

In summarizing the advantages achieved by the integration of a process-water treatment plant in comparison to the operation without integrated process-water treatment with a wastewater flow of 3.2 $m^3 t^{-1}$ paper at paper mill 2:

- the COD concentration, especially the content of organic acids, was reduced,
- the calcium and sulfate concentrations in the process water remained approximately at the same levels,
- the chloride concentration in the process water and in the product increased and
- the integration of the process water treatment has been worth the investment [1].

In general, there is no cost-effective way to remove chloride in the course of wastewater treatment. The same applies for sulfate, if no anaerobic stage is integrated into the wastewater treatment process. Consequently, managers need to first clarify acceptable process water salt concentrations. Based on these decisions, the extent to which the process-water cycle can be closed by integrating a biological treatment plant [8] can be assessed.

Concerning the tendency of biofouling (organic layers) after the integration of an aerobic biological treatment within the water cycle, studies of Malmqvist et al. [7] have shown that this could be a critical issue. Although the investigations have revealed that the problem can be handled, an overdose of the nutrients nitrogen and phosphor can lead to increased growth of biofilms in the process water system.

It should be noted that, a partial recycle of biological treated process water to the production process is carried out even at paper mills where a closed process-water cycle seems not to be suitable because of the required product quality.

7.4 Process Water Reuse After Biological Treatment Within the Sugar Industry

As mentioned in the introduction, the first internationally known example of reusing biologically treated process water was at the sugar mill *Leopoldsdorf* near Vienna [2],

The production processes of this sugar mill ("sugar mill 1") and the second discussed Austrian sugar mill ("sugar mill 2") although not identical are quite similar. However, the water and wastewater process flows (Figs. 7.3 and 7.4) differ significantly as these sugar mills have been built taking specific local situations into consideration [6].

Most beet sugar mills nowadays, have two main wastewater flows within the production process:

- Vapor condensate from the cooling water circuit (ca. 4 $m^3 t^{-1}$ beet) with a temperature of 25–40°C: $\gamma_{COD} < 30$ mg L^{-1}, $\gamma_{NH4\text{-}N} < 200$ mg L^{-1}
- Flume and washing water (ca. 4 $m^3 t^{-1}$ beet) including 70–90% of the organic matter (mainly sugar, parts of beets) and adherent soil (50–100 kg dry matter per t beet) which gets eliminated in the sedimentation tank [6].

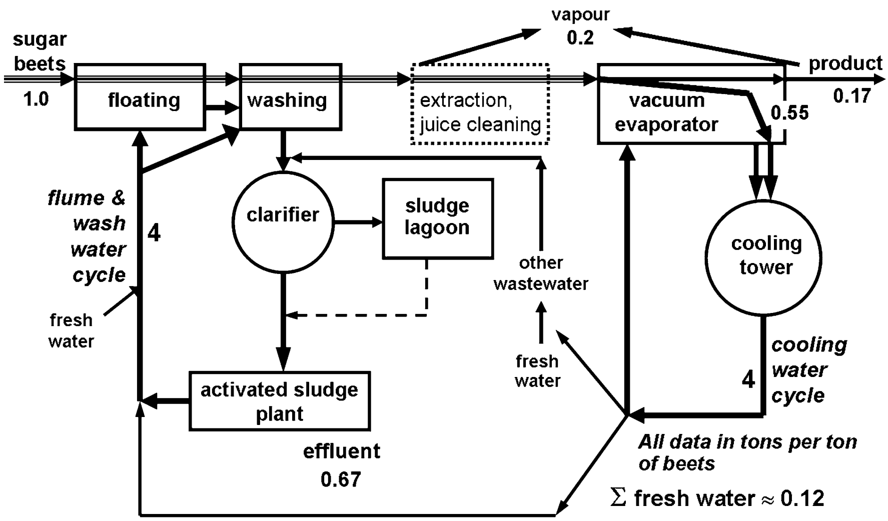

Fig. 7.3 Process flow diagram of sugar mill 1 (= sugar mill *Leopoldsdorf*)

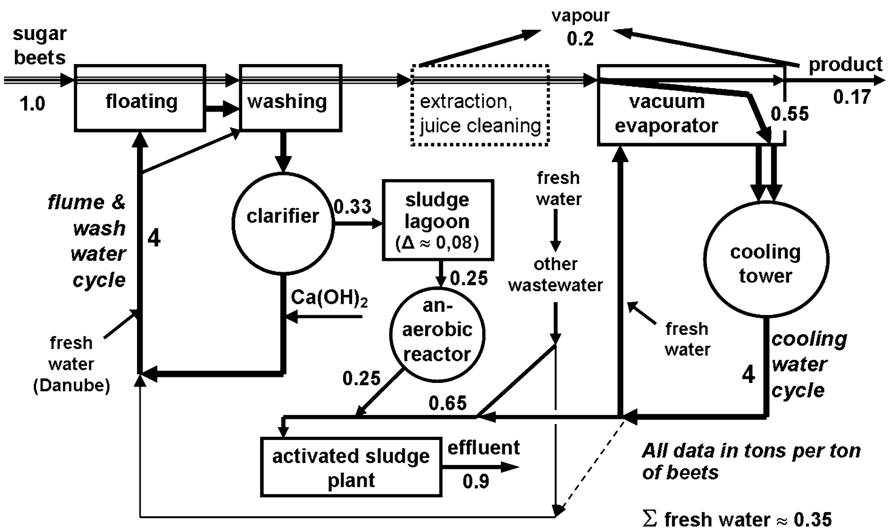

Fig. 7.4 Process flow diagram of sugar mill 2

Accordingly, at both Austrian sugar mills the internal water management is designed with two water cycles: cooling water circuit, where the vapor condensate accrues; and the organically highly polluted washing- and flume-water cycle (compare Figs. 7.3 and 7.4).

At both sugar mills the water cycles are predominantly closed. The difference between the water cycle systems at the two mills is that sugar mill 1 has integrated an aerobic wastewater treatment plant within the highly polluted wash- and flume-water cycle.

In contrast to sugar mill 1, in sugar mill 2 the organically highly polluted wash and flume water only passes through a sedimentation tank with the consequence that organic matter accumulates in the water cycle. To avoid excessive biofouling, lime hydrate is dosed into the wash- and flume-water cycle (Fig. 7.4).

The sludge from the sedimentation tank, basically soil, gets extracted into so called sludge lagoons. The supernatant of these lagoons is fed into an anaerobic biological treatment stage (anaerobic reactor). The effluent of this anaerobic stage is treated at an activated sludge plant together with the excess vapor condensate and other wastewater streams. While at sugar mill 1, nitrogen has to be added to the aerobic treatment to avoid nitrogen deficiency, at sugar mill 2, nitrogen is present in excess in the influent to the aerobic stage due to the removal of COD, but not of nitrogen in the anaerobic reactor. Accordingly, at sugar mill 2 the aerobic treatment has to be operated with nitrification and denitrification.

Sugar beets contain approximately 75% water and 17% sugar. During the production process about 0.2 m^3 water evaporates and 0.55 m^3 of wastewater are produced per ton of sugar beets processed, even without freshwater input.

Within sugar mill 1 only a small amount of fresh water is used for supplying the wash- and flume-water cycle, the water primarily being supplied by the cooling water cycle, i.e. by the surplus water from the sugar beets resulting from processing. Altogether, sugar mill 1 has had a water demand of 0.12 $m^3\ t^{-1}$ sugar beets over the recent years.

At sugar mill 2, a small amount of fresh water is used within the production process as well as to supply the wash- and flume-water cycle. In addition, some fresh water is used for the cooling water cycle. The water consumption at sugar mill 2 is around 0.35 $m^3\ t^{-1}$ sugar beet.

Regarding these two sugar mills, it turns out that the process water treatment at sugar mill 1 shows advantages compared to the process performance of sugar mill 2. At sugar mill 1 there is:

- almost no biofouling; therefore less organic layers and hardly any organic acids in the process water (wash and flume water) and therefore no corrosion problems in the piping system,
- no need to add calcium hydroxide to the wash and flume cycle to avoid biofouling; therefore no limescales,
- significantly lower investment costs for the process water treatment compared to sugar mill 2 and
- much easier operation of the process water treatment plant than at sugar mill 2.

The disadvantage of the process-water treatment at sugar mill 1 compared to sugar mill 2 is that as a result of the aerobic degradation more nutrients (nitrogen and phosphor) have to be added and more energy is needed. However, the electricity demand is covered by means of cogeneration.

7.5 Conclusion

The integration of a biological treatment stage in a process water cycle can lead to significant operational and energetic advantages. Within this paper, examples of the paper and the sugar industry have been presented and discussed.

Currently the focus of efforts to integrate biological treatment into industrial operations seems the paper and cardboard industry, industries with relatively low water demand and high COD concentrations in the process water, which makes anaerobic treatment together with biogas production feasible.

However, energy can also be gained from the biogenic heat produced in aerobic systems, where the amount of energy is in the same range as the amount of calorific energy in the methane formed during anaerobic degradation. In this case, energy is needed for the aeration system in the aerobic wastewater treatment plant. However, the gain of thermal energy is larger than the energy demand for suitable aeration systems, even when calculated as primary energy. Consequently, in cases where process water needs to be warmed up, it may be advantageous to integrate an aerobic treatment stage into the process water cycle, especially as the energy demand for the drying process (paper and cardboard) declines with the reduction of the COD concentration in the process water. This is particularly applicable for small companies, where an anaerobic stage including gas purification and utilization would lead to high investment and operating costs.

Finally it should be mentioned that combinations of biological and chemo-physical treatment systems are gradually becoming more important in both wastewater treatment and in process-water treatment. An important step in the reuse of biologically treated process water in industry is the application of membrane activated sludge systems, so-called "membrane bio-reactors" (MBR).

On the one hand, these systems are sensible for economic reasons in particular for wastewaters with high organic concentrations. On the other hand the main advantage of these systems is the bacteria-free effluent that can be expected. Moreover, as the effluent of an MBR is free of particles, it can be directly fed into reverse osmosis (RO) systems and the filtrate from RO can be used instead of desalinated or softened fresh water.

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