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Full-scale experiences of nitrogen removal of fish-processing wastewater with flotation and anoxic-aerobic activated sludge system

M. Steinke and M. Barjenbruch

ABSTRACT

This article presents full scale experience of one of the largest fish-processing factories in Europe with a production capacity of about 50,000 tons herring per year and a maximum daily wastewater discharge of 1,500 m^3. The wastewater treatment plant is the only direct discharger in the fish-processing industry in Germany. Thus, very low effluent values have to be keep in, especially the nitrogen reduction has to be operated during the whole year even when the temperature is low. The central point of the multi-stage WWTP (about 90,000 PE) is the biological nutrient removal (BNR) with pre-denitrification. The wastewater pre-treatment with sieves (0.8 mm) and a two staged flotation reduces the nitrogen load – mainly the particle bounded fraction – but the optimal nutrient ratios for biological treatment need to be observed. The activated sludge system has maximum OLR of 0.12 g COD/(g MLSS d) and NLR of 0.015 g TN/(g MLSS d) but a "Stand-By"-Operation with periods without wastewater influent is unavoidable. Discontinuous operating is one problem. The dependence on temperature as one of the main influences of nitrification-activity is the second point. The article gives an overview about the start-up and the optimisation of the process.

Key words | activated sludge process, discontinuous production, fish-processing industry, flotation, nitrification, temperature

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INTRODUCTION

In Germany 86 fish-processing factories are currently operating. The total amount of fish products is about 470,000 tons annually. Just one plant is a direct discharger with regulations for advanced effluent treatment. This fish-processing centre is one of the largest factories in Europe. Herring is landed directly at the pier and is graded, filleted, marinated and frozen. The plant has a capacity to fillet about 50,000 tons of fish annually. The final products are semi-finished marinated herrings. The generated waste is treated in an integrated fishmeal factory. The wastewaters of the fish process and the fish meal production are treated with several purification steps while the anoxic-aerobic biological treatment with the activated sludge system is the significant stage. However, the pre-treatment with sieves and a two staged flotation is fundamental. This article presents the results of the first three operations years with the focus to nitrogen removal because it was the limiting point of operation. Stringent effluent requirements for nitrogen ($N_{inorg.}$ 18 mg/l, NH_4-N 10 mg/l) are demanded at all times regardless of the temperature in the biological reactor. This regulation is an exception. Generally the effluent requirements to ammonium nitrogen and total nitrogen ($N_{inorg.}$) apply at a wastewater temperature ≥12°C in the effluent from the biological reactor of the WWTP. This requirement takes into consideration that biological nitrogen removal depends on temperature.

The wastewater quantity and quality of fish-processing plants are the consequence of raw materials,

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the fish-processing technique and the final product. The specific wastewater generation of fish and seafood industries is in a wide range of 3–32 m^3/t raw materials (BREF 2006). The reported concentrations of suspended solids, organic matter and nutrients are in a wide range as well. Generally the concentration of total-nitrogen of fish-processing wastewater is about 120–700 mg/l (Prasertsan *et al.* 1994; Pallenzuela-Rollon 1999). For partial flows the concentrations are much higher, for example the tuna cooking process generates high concentrated streams with 5,000–6,000 mg TKN/L (Mosquera-Corral *et al.* 2003).

Nitrogen removal of fish-processing wastewaters

Most frequently the biological treatment of fish-processing wastewaters is focused to anaerobic operations (Balslev-Olesen *et al.* 1990; Palenzuela-Rollon 1999; Punal & Lema 1999). The removal of organic matter in conjunction with biogas production is a benefit. But anaerobic systems react more sensitive to discontinuous feeding which is one the main problem in fish industry. Before designing and starting up the process of the reported factory biological nitrogen removal in full-scale was not applied in fish factories so the state of the art has to be developed by predominantly laboratory or pilot scale investigations. Experiments with a lab-scale membrane assisted hybrid reactor for the treatment for wastewaters of a fish canning factory have been reported (Oyanedel *et al.* 2003). The system worked with suspended and attached biomass. The aerobic reactor attained at OLR of 4.5 kg COD/(m^3 d) and NLR of 1.8 kg NH_4-N/(m^3 d) elimination rates of 98% for COD and NH_4-N. The nitrifying activity was 0.25 g NH_4-N/(g VSS d). With the nitrification-denitrification stage 76% of nitrogen was eliminated while NLR was 0.8 kg NH_4-N/(m^3 d). Battistoni & Fava (1995) reported full-scale investigations on internal carbon source for denitrification. The input nitrogen content (20–30 mg/l) was very low in comparison to other reported values of fish-processing wastewaters. The achieved denitrifying rates are 0.5–6 g N/(kg VSS h). Investigations on nitrogen removal for the effluent of anaerobic reactors were accomplished by Mosquera-Corral *et al.* (2001, 2003, 2005). The system of UASB and anaerobic filter with loads of 1–1.25 kg COD/(m^3 d) and 0.22 kg NO_3-N/(m^3 d) effects an elimination of 80% COD and NO_3-N of nearly 100% (Mosquera-Corral *et al.* 2001). An anoxic filter with NLR of 0.08–3 kg NO_3-N/(m^3 d) effected a reduction of 60–72% NO_3-N (Mosquera-Corral *et al.* 2003). A SHARON reactor based on the nitritation reaction had influent concentrations of 1,000 mg NH_4-N/l and 10–250 mg TOC/l. The elimination of ammonia varied between 30–50% (Mosquera-Corral *et al.* 2005). The Anammox process was used for the effluent treatment of an anaerobic reactor which treated wastewaters from a fish cannery. The influent concentrations were 260–800 mg NH_4-N/l and 150–700 mg NO_2-N/l and elimination of N was 68% (Dapena- Mora *et al.* 2006). A literature review shows that considerable knowledge of anaerobic treatment in fish-processing, but full-scale experiences with activated sludge systems focused on nitrification and denitrification have not been reported before now.

State of the art with activated sludge system (pre-denitrification) in municipal sewage works

Full-scale experiences of nitrogen removal by pre-denitrification for fish-processing wastewaters are not investigated in detail so far. But, especially for municipal wastewater, nutrient removal by pre-denitrification is a common process. The organic matter in the wastewater is used as a carbon source. The optimum C/N ratio is 3–3.5 kg BOD_5/kg N or 4–5 kg COD/kg N (Henze *et al.* 2002). The nitrogen removal rates differ on account of various operation conditions such as loading rates and characteristics of the influent (e.g. C:N, C:P). For activated sludge systems nitrification rates of 1.5–4.5 g N/(kg MLSS h) and denitrification rates of 2–8 g N/(kg MLSS h) at 20°C were ascertained (Duine 2002).

MATERIALS AND METHODS

The flow scheme of the WWTP of the fish-processing factory is shown in Figure 1. This multi-stage technology for fish-processing wastewater is unique in Germany and may be so world-wide. Stringent effluent quality guidelines need to be complied with because of the direct discharge to the Baltic Sea. The raw wastewater passes two rotary sieves

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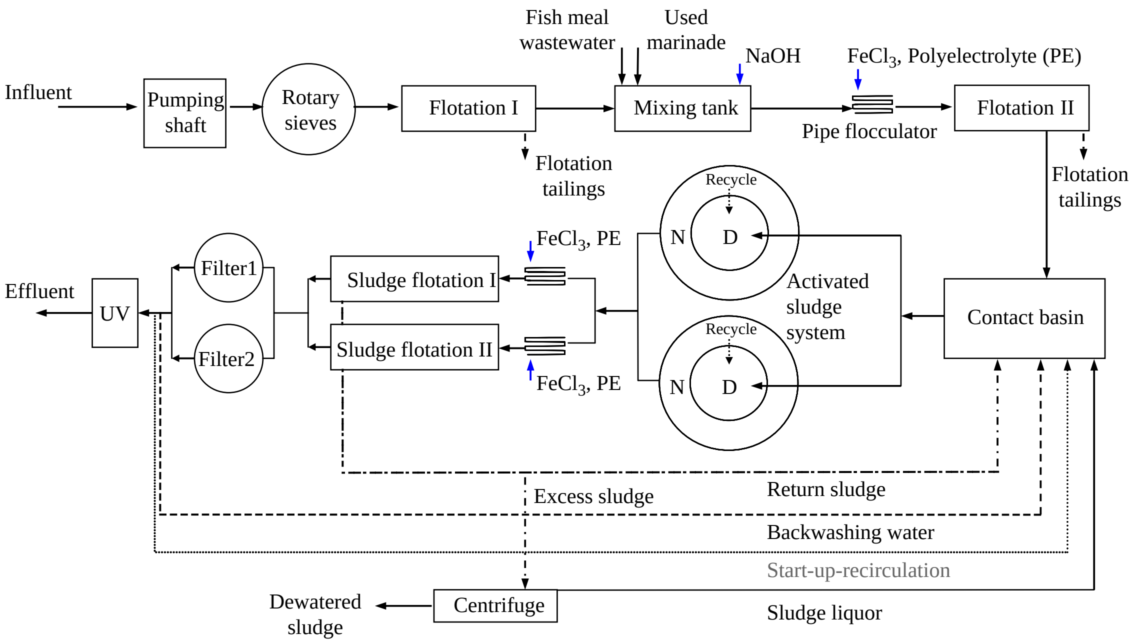

Figure 1 | Flow scheme of the wastewater treatment plant.

(0.8 mm) and DAF (Dissolved Air Flotation). In a mixing tank the wastewater of the fish meal production and used marinade (a mixture of vinegar, oil and salt) are added, if they accrue. The second flotation (DAF) is working with the dosage of precipitants and flocculants. The physical-chemical treated wastewater is collected in the contact basin and mixed with the return sludge. The activated sludge system is formed of two circular tanks and corresponds to conventional pre-denitrification. The separation of sludge and wastewater takes place with flotations and chemical dosage. The final steps are sand filtration and UV disinfection.

Operation of the flotation

The high concentrated partial flows such as wastewater from the fish meal process were added in the mixing tank in front of the flotation II (Figure 1). Flotation removes suspended solids, oils and grease. Air bubbles attach to the particles so the solids-bubble conglomeration floats to the water surface where it can be skimmed off. To form flocs and to optimize the removal precipitants and flocculants agents are added with a pipe flocculator. Ferric chloride ($FeCl_3$, 40% solution) is used on an average with 1.5 l/m^3 and the polymer dosage is about 25–50 g/m^3. The basis for flocculation is a convenient pH-value. While the pH-value of the raw wastewater is 4–5 there is a need to enhance the pH to 6–7 with sodium hydroxide. The flotation cell has a maximum discharge of 60 m^3/h. The maximum surface flow rate is 2.6 m/h and the minimum retention time is about 1 h.

Operation of the activated sludge system

The biological treatment is based on an activated sludge system with pre-denitrification. For the inoculation of the process the biomass was taken from a municipal WWTP. The wastewater and the return sludge which were collected in the contact basins are pumped to the internal anoxic zone. The external zone is aerated and the nitrate is recycled back into the center via pumps. The average discharge is 700 m^3/d but only the days with wastewater production are regarded. Attention should be paid to the fact that about 30% of the days in one year there is no wastewater at all (Figure 2).

Because of the discontinuous amount there is a fluctuation of the used volume in the activated

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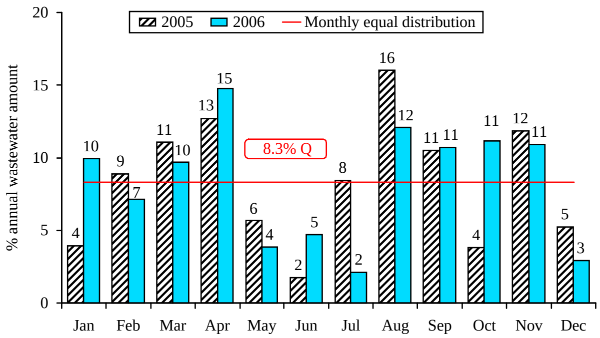

Figure 2 | Fluctuation of wastewater discharge.

sludge basins. The mean value of the total volume is 5,700 m^3 whereof 65% are aerated. The mixed liquor suspended solid content (MLSS) is 10 kg/m^3 (VS 70%); due to the batch operation it is much higher than in conventional systems; another reason was the centrifuge which was used for sludge removal and sludge amount rises. The sludge volume index (SVI) is 79 l/kg with a range of 30–184 l/kg. The sludge age is 21–26 d. The temperature varies depending on the wastewater inflow and the outside temperature. The pH-value is 7–7.5. The separation of activated sludge and the treated wastewater takes place with flotation with effluent suspended solid contents of 15–20 mg SS/l (see Table 1).

RESULTS AND DISSCUSSION

With respect to the wastewater treatment there is a problem in that fish-processing factories are mostly dedicated to fresh products. The described factory depends on the herring catch with peak seasons from February to May.

Table 1 | Basic parameters and measurements of the activated sludge system

		Mean	Minimum	Maximum
Wastewater discharge, Q	(m^3/d)	702	8	1,500
Volume activated sludge basin	(m^3)	5,700	3,040	6,800
MLSS	(kg/m^3)	10	4.4	19.7
SVI	(l/kg)	79	30	184
Temperature θ	(°C)	18	6.3	28

As a consequence the wastewater production is discontinuous; 30% of the days in one year there is no discharge. In June and December the minimum values occur. In August a peak of production starts after a longer period of 4–6 weeks without or marginal production. The discontinuous wastewater flow and loading is in general a problem for the operation of biological stages due to the fact that other parameters such as temperature depend on the input.

Flotation

If fish-processing is taking place in the factory the flotation cell operates with the maximum wastewater discharge of 60 m^3/h. The TN influent concentrations are predominantly in the range of 200–800 mg/l (Figure 3). The average effluent TN is 350 mg/L. At least it is possible to reduce total nitrogen for 10% with DAF. The maximum elimination rate is 77%. The efficiency of the flotation has been optimised by the use of a more effective flocculant. The pH-value control was also adjusted. But even if the load reduction is significant, a nitrogen concentration $<$130 mg TN/l could not be achieved. Nevertheless, the remaining nitrogen load for the biological process is still high. In the effluent of the flotation TN is about 91% organic nitrogen, just 8.5% is ammonia, so at least ammonifcation has not passed at that point. This process takes places in the contact basin where the return sludge is mixed with the pre-treated wastewater.

The flotation process influences the wastewater composition and need to be balanced to the following biological treatment. It is shown that the elimination of phosphorus can reach 98%, but too high efficiencies cause a lack of phosphorus on nitrification (Nowak *et al.* 1996). COD-removal effects a reduction of energy for the aeration in the activated sludge system, but an extreme removal causes a lack of organic matter for denitrification. The optimum COD/N ratio is 4–5 (Henze *et al.* 2002). Hence the mean COD/N ratio of 10 is sufficient and the minimum ratio of $<$2 is an exception. High nitrogen elimination in the pre-treatment causes a load relieving for denitrification and nitrification process and enhances the capacity for nitrogen removal (Table 2).

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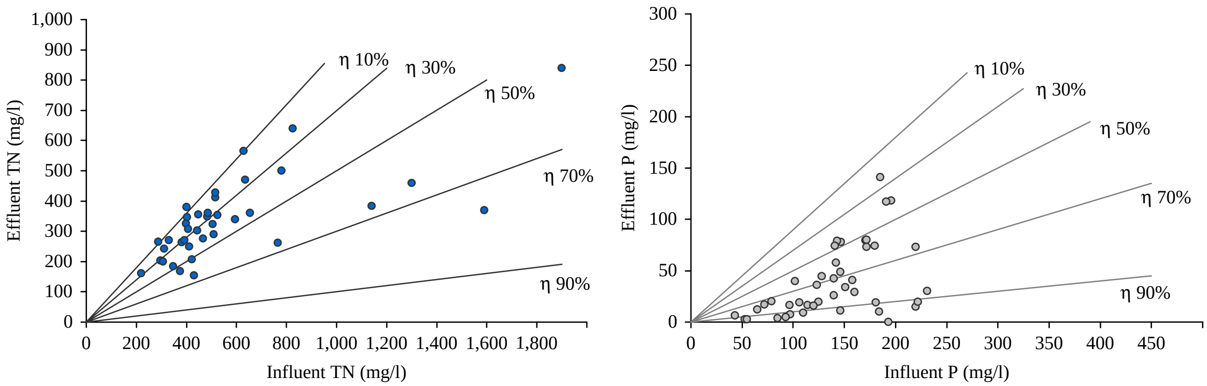

Figure 3 | Nitrogen and phosphorus removal with flotation.

Nitrogen removal by pre-denitrification

The OLR of the activated sludge system is 0.035 g COD/(g MLSS d) in average with a range of 0.003–0.12 g COD/(g MLSS d). Even in periods of fish season it is a “Stand-by”-Operation with daily fluctuations of flow and loading rates. The NLR is 0.004 g TN/(g MLSS d) and varies from 0.001–0.015 g TN/(g MLSS d) (Table 3). The nitrogen compounds in Table 3 present the wastewater influent to the contact basin, where organic nitrogen starts converting to ammonia. In the effluent of the WWTP N_{org} is 2–10 mg/l which indicates good ammonification rates.

To provide a proper nitrification performance a certain level of temperature has to be ensured, but because of the discontinuous wastewater flow and the unstable processing of fish meal, the temperatures were somewhat lower than was calculated in the design. In winter the temperatures in the activated sludge tank decrease as a consequence of low wastewater influent and cold climate. The minimum value was 6°C (Figure 4). In this case problems with nitrification appeared as the nitrifying activity is a function of temperature. Henceforward the temperature in the activated sludge basin was controlled and in some cases the wastewater influent was heated by steam, which is available in the factory. On the other hand the nitrification performance decreased in August with temperatures of 20–25°C but with a longer period of low feeding before and a fast increase of wastewater loads. In April 2006 a lower feeding period was foregoing also and due to the high loading peak the oxygen concentration decreased. Therefore liquid oxygen was installed to push oxygen fast and efficient into the system. Based on the problem of discontinuous feeding in times of long breaks a carbon source or marinate, as a waste product of the fish process, are dosed temporarily to increase the biomass activity. In the period under review 87% of all data are <10 mg NH_4-N/l. The maximum nitrite concentration

Table 2 | Wastewater characterisation influent and effluent of the flotation

		COD (mg/l)	TN (mg/l)	TP (mg/l)	SS (mg/l)	COD/TN (–)	COD/TP (–)
Influent	Mean	6,160	544	133	1,960	12	61
	Min	950	41	4	210	2.6	30
	Max	14,580	1,900	267	4,460	24	714
Effluent	Mean	2,638	350	35	375	10	166
	Min	300	130	0.5	26	1.8	16
	Max	7,340	840	236	1,470	16	664
Removal	%	56	36	69	79	–	–

Table 3 | Nitrogen influent concentrations and loads of the biological treatment system

	TN (mg/l)	$N_{Inorg.}$ (mg/l)	NH_4-N (mg/l)	TN (kg/d)	$N_{Inorg.}$ (kg/d)	NH_4-N (kg/d)	NLR (g TN/(g MLSS d))
Mean	350	19	18	175	13	12	0.004
Minimum	130	0.35	0.08	54	0.4	0.1	0.001
Maximum	840	131	131	588	83	82	0.015

Period under review: Feb. 2004 - Feb. 2007; Analysis in the influent of contact basin.

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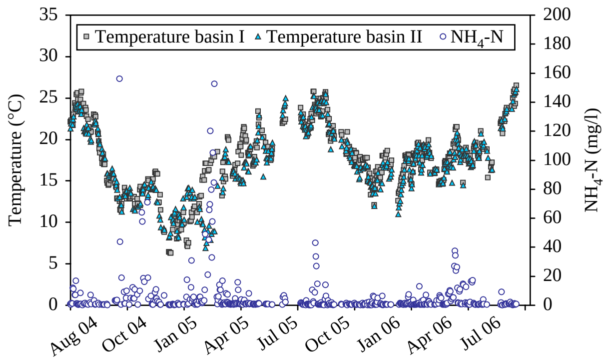

Figure 4 | Temperature in the activated sludge basins and ammonia nitrogen in the effluent.

amounts to 7 mg/l, but mostly the effluent concentration is <1 mg NO_2-N/l. The mean concentration of nitrate nitrogen is 2.9 mg/l and 96% of all values are <10 mg/l (Figure 5).

Related to total inorganic nitrogen in the effluent the elimination-rate is in general about 95–99%. The maximum nitrifying rates are 0.012 g N/(g MLSS d) and maximum denitrifying rates are 0.023 g N/(g MLSS d). But in general removal rates for nitrification are 0.003–0.004 g N/(g MLSS d) and for denitrification 0.006–0.008 g N/(g MLSS d) are occurred. Compared to common nitrifying rates of 0.04–0.11 g N/(g MLSS d) and denitrification rates of 0.05–0.2 g N/(g MLSS d) (Abeling 1994; Duine 2002) the achieved activities are lower. The main reasons of lower biomass activity are breaks with low feeding and low temperatures in cold season. Parallel laboratory tests verified the results of the full scale operation and indicated the decrease of biomass activity in times without or low feeding.

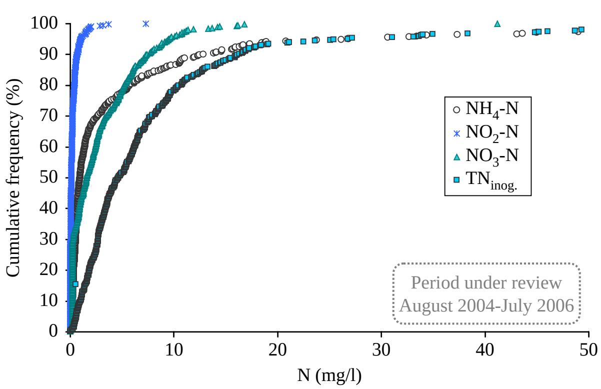

Figure 5 | Statistic analysis of nitrogen concentrations in the effluent. Subscribers to the online version of *Water Science and Technology* can access the colour version of this figure from http://www.iwaponline.com/wst

CONCLUSIONS

So far the nitrogen removal of fish-processing wastewaters is investigated predominantly in laboratory and pilot scale. Full-scale application of a flotation and activated sludge system at one of the largest fish-processing centres in Europe was presented. With flotation and the dosage of coagulants a significant nitrogen removal is achievable but the remaining nitrogen load for the activated sludge system is still high. The biological nutrient removal (especially nitrification) is affected by low feeding and decreasing temperature in cold seasons. Several processes have been applied successfully to improve the biological nitrogen removal. Liquid oxygen is used in times of impact load to increase oxygen content. The temperature in the activated sludge system is controlled and if necessary it is heated with warm streams, which are available in the factory. The decline of the biomass activity is reduced by dosing a carbon source or marinate in times of low wastewater amount.

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