# A new approach to energy-efficient treatment of wastewater produced by the fish industry in Vietnam

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## ABSTRACT

Economic growth in Vietnam in the last few years has brought about an increasing demand for energy and has had a severe environmental impact. Fish processing is one of the fastest-growing industries that discharge organically-polluted wastewater. To counter these environmental problems, new technologies for energy-efficient treatment are needed. By coupling innovative nitrogen removal systems with anaerobic treatment processes, it is possible to realise such technologies. In the present project, a combined deammonification and anaerobic carbon removal system is presented. Special requirements to enable reliable treatment are discussed, taking industrial wastewater characteristics into consideration. To evaluate energetic efficiency, energy balance calculations based on data from a fish-processing factory are made. The determined specific energy consumption and production rates show that energy recovery is possible, even when COD and nitrogen removal efficiencies of over 90% are achieved. Depending on the pre-treatment employed, energy recovery rates ranging from 0.6 to 2.5 kWh/mt raw fish can be reached.

**Key words** | deammonification, energy recovery, fish industry, nitrogen removal

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## INTRODUCTION

In the last few years, South-East Asia has experienced strong economic growth leading to an increasing number of industrial zones (IZs) and higher demand for energy. This trend is supported by the policies opted for, as the announcement of the implementation of 90 new IZs by 2015 shows (Vietnam News 2010).

The growth rate of energy consumption is more than 11% p.a. in Vietnam alone (APC 2008). Along with this higher energy consumption, increasing industrial production has a severe environmental impact (pollution of water bodies, greenhouse gas emissions). Furthermore, the implementation of strict discharge limitations emphasizes the need for sustainable wastewater treatment. Regarding adequate treatment of the wastewater from IZs, there is a special lack of appropriate technologies for an efficient integrated system for treatment and energy recovery purposes. Recent development of industrial production in Vietnam have shown that high-level technologies can also be handled under local conditions. As the treatment of industrial waste water is under the industry's responsibility, it is feasible to apply advanced treatment concepts. In a joint Vietnamese-German research project funded by the Federal German Ministry of Education and Research (BMBF) called AKIZ, such a system for the treatment of wastewater from the fish- and seafood-processing industry is to be developed and evaluated.

The focus of one sub-project is the development of a sustainable method of treating wastewater from the fish-processing industry. This branch of industry is the third largest industry in Vietnam and it has experienced enormous growth in the last few years, as is shown in Figure 1. In 2008 the total quantity of raw fish processed was more than 4.5 mt (FAO 2010).

These enormous quantities show the high degree of potential pollution that untreated wastewater discharges from fish factories into water bodies can be expected to generate. Taking into consideration the growing demand for energy for the industrial sector in general and for wastewater treatment in particular, new energy-efficient treatment systems have to be developed. This can be done by coupling both approved and new technologies for carbon and nitrogen removal. Sander *et al.* (2010) have shown that, taking certain boundary conditions into account, the combination of various energy-efficient processes can lead to an integrated treatment system.

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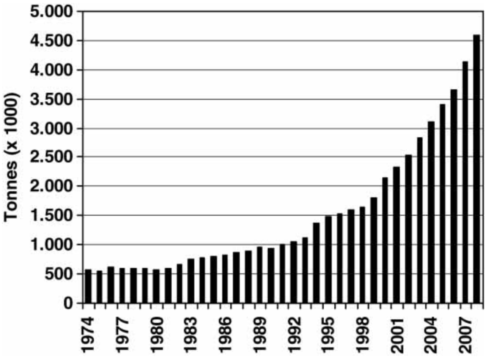


**Figure 1** | Fish production in Vietnam since 1974 (FAO 2010).

## State of the art

In the last few decades several investigations have been carried out on the treatment of wastewater from fish industries. Various biological systems have been implemented to provide major treatment facilities, e.g., activated sludge systems, UASB systems, rotating disk reactors, trickling filters and lagoons (Chowdhury *et al.* 2010). Due to high COD concentrations in raw wastewater, research and practical technology (e.g. Veiga *et al.* 1994; Palenzuela-Rollon *et al.* 2002) both focus on the use of anaerobic treatment steps. But as anaerobic systems don't remove nitrogen to a significant extent, there always has to be an aerobic treatment step in addition to comply with discharge limits. In Vietnam, limits of 50 mg/L (TN) and 400 mg/L (COD) have to be met by fish-processing wastewater discharges into sewer systems.

### Pre-treatment

The elimination of suspended solids, oil and grease from fish factories' wastewater can be achieved through dissolved air flotation (DAF), as Genovese *et al.* (1995) and Steinke & Barjenbruch (2010) have shown. This results in the removal of organic nitrogen and COD at efficiencies of up to 36 and 56%, respectively (Steinke & Barjenbruch 2010). The volume-specific energy input required for DAF ranges from 0.08 to 0.125 $kWh/m^3$ according to Stark *et al.* (2008) and Bennoit & Schuster (2001).

### Anaerobic treatment

Anaerobic treatment is a suitable process for COD removal from fish-processing wastewater, as various examples in Chowdhury *et al.* (2010) show. Although high sodium concentrations can be inhibiting to anaerobic processes (Lefebvre & Moletta 2006), the latter list various examples showing that adaptation to high salinity is possible (e.g. Boardman *et al.* 1994; Omil *et al.* 1996). The energy input required is much less than for aerobic treatment as no aeration is necessary. Furthermore energy is recovered through biogas usage. According to Palenzuela-Rollon *et al.* (2002) it is necessary to eliminate most of the lipid load to permit a stable anaerobic treatment process with high-rate reactors (e.g. UASB). The energy consumption for pumping and for stirring can be assumed to be 0.005 $kWh/(m^3 * m_{height})$ and 0.12 $kWh/(m^3_{reactorvolume} * day)$, respectively (Urban 2009). Heating can be neglected, because the wastewater temperature is sufficient owing to the climatic conditions in tropical regions. Methane ($CH_4$) production is 0.35 $m^3/kg$ of $COD_{degraded}$ with a net calorific value of 10 $kWh/m^3$ $CH_4$ under standard conditions. The final energy output depends on the chosen technology for energy usage.

### Activated sludge systems

Conventional aerobic carbon and nitrogen removal systems are an appropriate technology for the complete treatment of wastewater produced by the fish-processing industry. Examples of its application can be found in Chowdhury *et al.* (2010) and Steinke & Barjenbruch (2010). The energy consumption of nitrogen removal by nitrification/denitrification is 3.7 kWh/kg N (Beier *et al.* 2008). This value refers to systems to which no external carbon source has to be added, to compensate a lack of COD in the wastewater stream. For denitrification reactors (stirring only) the energy demand is approx. 0.5 $kWh/m^3$ (Beier *et al.* 2008).

## POTENTIAL FOR ENERGY EFFICIENT TREATMENT SYSTEMS

The development of energy-efficient integrated treatment systems for the combined removal of carbon and nitrogen from wastewater streams of industrial origin allows more sustainable protection of water bodies. Wastewater that is polluted with large quantities of both components mainly derives from the agricultural product industry.

In the fish-processing industry a lot of process steps are executed depending on the end-product. Fish production for human use includes mainly skinning, washing and filleting, besides transportation, weighing and other operations. Most of the wastewater is produced in washing processes. As the material is of organic origin, the wastewater is mainly polluted with lipids and proteins (Gonzalez 1996).

Depending on the raw material and the end-product, the organic pollution can vary significantly between factories, as a list of different wastewater outputs from the fish-processing industry in Chowdhury *et al.* (2010) shows. According to Carawan (1991), for overall fish processing the COD concentrations vary over a range from 300 to 10,000 mg/L with regard to salmon, catfish, tuna and herring. The variety in pollutant concentration mainly is due to variations in water usage efficiency and raw material inputs and as well.

An example of the characteristics of fish-processing wastewater in Vietnam is shown in Table 1. These figures arise from investigations at a fish-processing factory in an IZ in the Mekong Delta. In the same IZ, the specific water consumption per tonne of raw fish is 3.5–5 $m^3$/t. The specific loads in Table 1 relate to water consumption of 5 $m^3$/mt of raw fish. For the end-product the specific load is three times as high.

During the last two decades new processes have been developed to improve nitrogen removal from highly-polluted wastewater streams. On the basis of the conventional nitrification/denitrification process a more energy-efficient approach (energy savings: 25%) has been arrived at by shortening the nitrogen oxidation chain. This so-called nitritation/denitritation process has also been implemented for the treatment of industrial effluent and sub-streams from municipal treatment plants (Abeling & Seyfried 1992). Further energy and carbon savings can be attained by combining partial nitritation and anaerobic ammonia oxidation (Anamox). This coupled deammonification process (Figure 2) has been the topic of various publications (e.g. Hippen *et al.* 1997; Wett 2007). Nowadays deammonification systems are implemented in a couple of treatment plants for highly nitrogen-polluted sub-streams from sludge stabilization units and for leachate treatment.

Due to the absolutely autotrophic nitrogen conversion process, deammonification doesn't require any carbon source and is therefore most suitable for wastewater with low C/N ratios as you find in the effluent of anaerobic treatment systems. The lower yield compared to heterotrophic bacteria reduces sludge growth and disposal costs. As only 50% of the ammonia has to be oxidized, the energy savings compared to conventional nitrification/denitrification are about 60%. Besides elemental nitrogen ($N_2$) an ~10% nitrate output is produced during the Anamox step.

For full-scale applications, 1 and 2 step systems based on biofilm or suspended sludge have been developed. The nitritation and Anamox processes are implemented in one reactor or two separate ones. The energy input required for the full-scale deammonification process is ~1.5 kWh/kg N, when using energy-efficient units (Beier *et al.* 2008).

## INNOVATIVE TREATMENT CONCEPT

Based on the waste water characteristic from a fish processing factory (Table 1) a concept for energy efficient carbon and nitrogen removal is described.

**Table 1** | Characteristics of wastewater from a fish-processing factory in the Mekong Delta, Vietnam

| | COD (mg/L) | BOD (mg/L) | TN (mg/L) | SS (mg/L) | pH (–) | *T* (°C) |
|---|---|---|---|---|---|---|
| Conc. | 833 (kg/mt) | 615 (kg/mt) | 540 (kg/mt) | 110 (kg/mt) | 6.7 | 28–33.5 |
| Spec. load (5 $m^3$/mt) | 4.1 | 3.1 | 2.7 | 0.6 | | |

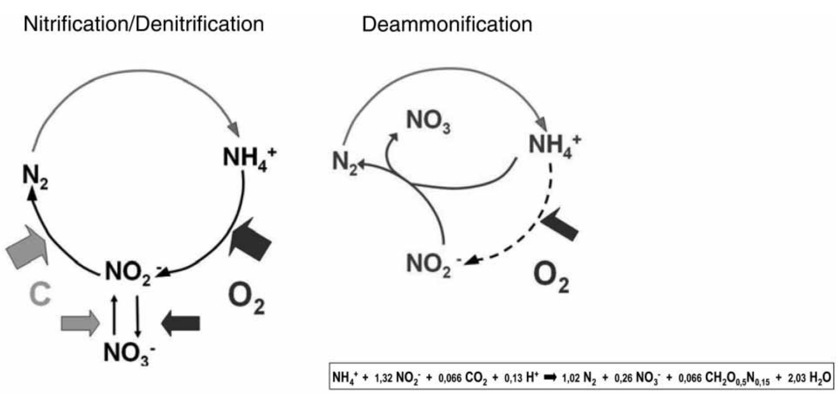


**Figure 2** | Nitrogen elimination process scheme and equation for Anamox process (Strouss *et al.* 1999).

The production of the fish-processing factory investigated is approx 40 mt/day of Pangasius. That represents 120 mt/day relative to raw fish-processing, this being responsible for 492 kg/day of COD and 324 kg/day of the TN load in the wastewater stream of 600 $m^3$/day.

## Coupling of anaerobic and aerobic systems

### Requirements for the coupled process

Most experience with the deammonification process for wastewater with a high nitrogen content has been obtained from municipal sludge liquor treatment. In contrast to this experience, the requirements for the biological treatment of wastewater of industrial origin are much more complex. Sludge liquor production mainly depends on the quantity of stabilized sludge and the nitrogen content exhibits only small changes, whereas in the field of industrial wastewater there may be changes in the quantity and the degree of pollution due to changes in the production process (e.g. raw material, campaign-based production, shifts).

### Description of the coupled process

Anaerobic treatment technology for carbon removal and deammonification for nitrogen removal are two established processes that allow energy-efficient treatment. By combining these technologies, an optimum in energy savings and energy recovery can be obtained. A DAF might by necessary to separate lipids, before anaerobic treatment. As the COD concentration in waste water varies in a wide range between factories, different anaerobic reactor types can be applied. In this work an anaerobic CSTR with sludge recycling is applied.

In the anaerobic treatment step, the energy potential of the wastewater stream can be used for biogas production, without considering the carbon demand of a downstream nitrogen elimination step. The deammonification process enables the anaerobic reactor to be operated in a fashion that is optimized for biogas generation. If there are any anaerobically non-degradable wastewater constituents – and also in the event of the anaerobic reactor being affected by failures in operation – it may be necessary to implement another carbon elimination step. The latter can be operated under anoxic (denitrification) or aerobic conditions. To establish denitrification it is necessary to recycle the nitrate in the Anamox process effluent. With this measure the nitrogen removal efficiency of the whole system can be improved as well. Through the oxidation of substances possibly inhibiting the nitrifying and Anamox bacteria, the aerobic or anoxic carbon removal system also works as a barrier. The flowchart of the system described is presented in Figure 3.

## Energy recovery and utilization

In the overall process of production and wastewater treatment, many possible sinks and sources of energy (heat and electricity) can be identified. When applying a coupled carbon-nitrogen removal process, the energy system gets more complex, because with the production of biogas, another flexible energy source is included.

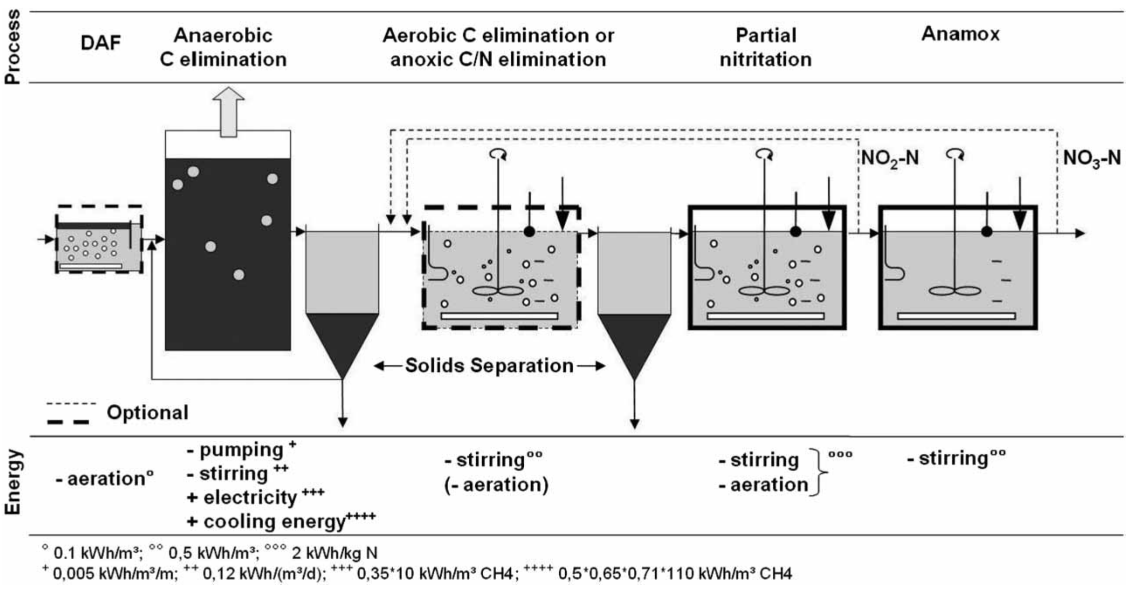


**Figure 3** | Coupled nitrogen/carbon removal and energy recovery system.

The energy carrier biogas can be used for heat and electricity generation, with technologies that have been state-of-the-art for years. The efficiency of conventional co-generation units is ~50% as regards heat and 35% as regards electricity. Waste heat can be used for heating in production processes and for cooling as well. When applying an adsorption refrigerator 60–70% of the introduced heat can be gained as cooling energy. One kWh of cooling energy represents an electricity consumption of 0.63–0.76 kWh only, because evaporation chill in coldness production has to be considered. With the growth of agricultural production of biogas, more efficient technologies for methane enrichment have been developed. They allow methane to be utilized as a substitute for natural gas or liquid fuels (Pölz & Salchenegger 2005).

### Energy balancing

The energy-related evaluation of the proposed coupled treatment system will be carried out by balancing energy streams. These include electricity consumption with the specific values mentioned above and energy production based on anaerobic carbon elimination. For the production of electricity a co-generation unit is assumed, as it is the most favoured technology. As heat isn't used in the production and treatment process, the generation of cooling energy through absorption refrigeration is calculated. As pre-treatment with DAF is recommended for anaerobic systems, two variants with and without DAF have been calculated. For nitrogen removal a 2-step system with upstream denitritation as shown in Figure 3 is considered. The recycling stream from the Anamox reactor's effluent into the anoxic zone is calculated on the basis of the carbon available in the anaerobic reactor's effluent and the nitrate concentration in the recycling stream. Heating for the anaerobic and Anamox processes is neglected due to the climatic conditions in southern Vietnam. In the variant with DAF, the disposal of the solids separated off is not included in the energy calculations.

## RESULTS

The energy consumption and production values calculated for the proposed combined treatment system are shown in Table 2. All energy values are based on the assumed removal rates.

The calculation shows that with the coupled anaerobic/aerobic system the energy content of the generated biogas is higher than the energy consumption of the overall system. This can be observed in the variants with and without DAF. Taking the efficiency of the co-generation unit into consideration, electricity consumption is higher than electricity production. As the off-heat isn't needed in the wastewater treatment system, it can be used in production processes for cooling as well.

The utilization of a DAF unit leads to a smaller C/N ratio in the wastewater stream. This reduces energy recovery through biogas, while energy consumption for nitrogen removal doesn't decrease by the same amount. A high degree of energy recovery through biogas utilization is only possible in combination with the deammonification

**Table 2** | Energy balance based on removal rates of the coupled system and on the following loads: COD = 492 and TN = 324 kg/d; $Q$ = 600 $m^3$/day (variant based on DAF in brackets)

| | Unit | DAF | Anaerobic C elimination | Anoxic zone | Partial nitritation | Anamox | Overall performance | |
|---|---|---|---|---|---|---|---|---|
| COD removal[a] | [%] | (30) | 80 (56) | 18 (12) | – | | 98 (98) | |
| N removal | [%] | (15) | – | 5 (3.5) | – | 86 (75) | 91 (93.5) | |
| Biogas generation | kWh/day | – | 1,394 (976) | – | – | – | – | |
| Heat production[b] | kWh/day | – | 697 (488) | – | – | – | 697 (488) | |
| Cooling energy production[c] | kWh/day | – | 324 (226) | – | – | – | 324 (226) | |
| Electricity production[b] | kWh/day | – | 488 (342) | – | – | – | 488 (342) | 300 (68) |
| Energy consumption | kWh/day | (−60) | −72 (−72) | −20 (−20) | −400 (−337) | −20 (−20) | −512 (−500) | |

[a]2% non-biodegradable.
[b]Efficiency of co-generation unit: 35% electricity, 50% heat.
[c]Electricity equivalent, efficiency of adsorption refrigerator: 65% of heat, efficiency of compression refrigerator: 140% of electricity.

**Table 3** | Specific electricity consumption, production and recovery of electricity and cooling energy (based on raw fish)

| Energy in kWh/mt | Without DAF | With DAF |
|---|---|---|
| Consumption | 4.3 | 4.1 |
| Production | 6.8 | 4.7 |
| Recovery | 2.5 | 0.6 |

process. But even without anaerobic COD elimination, conventional nitrification/denitrification systems are not suitable as the C/N ratio is not sufficient to achieve complete nitrogen removal – in that case a C-dosage has to be taken into account with the negative impact on the overall energy-balance.

### Rough estimate of the potential involved

The raw fish-specific energy consumption of the wastewater treatment system is presented in Table 3. Considering the quantity of 4.5 million tonnes of fish processed in Vietnam in 2008, it shows that there is a huge potential for recovery of energy out of fish-processing wastewater, as long as electricity and cooling energy from biogas is used. By optimizing biogas utilization and solving the nitrogen removal problem this energy can be used as a direct substitute for conventional energy sources.

## CONCLUSIONS

The present paper shows that suitable processes exist for accomplishing energy-efficient treatment of organically-polluted wastewater from the fish industry. For the shown example the combination of anaerobic treatment (CSTR) with an innovative nitrogen removal system, such as deammonification, allows a positive energy balance to be attained for the overall treatment system. Without pre-treatment by DAF, the energy recovery potential is even higher. Due to the low efficiency of the current technology for electricity generation it is presently not possible to cover the total demand of the treatment system. The whole potential can only be utilised, when co-generation's off heat it used for cooling. Taking the expected growth of the Vietnamese economy and fish production industry into consideration, the energy input required, along with its greenhouse emissions, for the treatment of fish-processing wastewater can be minimized with the technology presented. For emerging economies that are highly dependent on marine and agricultural production, the presented technology offers a solution to satisfy the growing demand for energy and at the same time fulfil the need for industrial wastewater treatment.

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## REFERENCES

Abeling, U. & Seyfried, C.-F. 1992 Anaerobic-aerobic treatment of high-strength ammonium wastewater – nitrogen removal via nitrite. *Water Science and Technology* **26** (5–6), 1007–1015.

Asia-Pacific Committee (APC) 2008 *Chancen der vietnamesisch deutschen Wirtschaftskooperation, (Prospects of Vietnamese-German economical cooperation)*. APC, Berlin, Germany. http://www.asien-pazifik-ausschuss.de (accessed 15 March 2008).

Beier, M., Sander, M., Schneider, Y. & Rosenwinkel, K.-H. 2008 Energieeffiziente Stickstoff-behandlung (Energy-efficient nitrogen removal). *Korrespondenz Abwasser u. Abfall* **55** (6), 1–13.

Bennoit, H. & Schuster, C. 2001 Fortschritte des Flotationsverfahrens in der Abwasser-technik und Schlammbehandlung (Progress of flotation processes in wastewater and sludge treatment). In *Proceedings of the GVC-Fachausschuß meeting (technical committee) on "Mechanische Flüssigkeitsabtrennung" (mechanical separation of liquids), March 2001*. GVC, Berlin, Germany.

Boardman, G. D., Tisinger, J. L. & Gallagher, D. L. 1994 Treatment of clam processing wastewaters by means of upflow anaerobic sludge blanket technology. *Water Research* **29** (6), 1483–1490.

Carawan, R. E. 1991 *Processing Plant Waste Management Guidelines for Aquaticfishery Products*. Available from: http://www.p2pays.org/ref/02/01796.pdf (accessed 25 August 2010).

Chowdhury, P., Viraraghavan, T. & Srinivasan, A. 2010 Biological treatment processes for fish processing wastewater – a review. *Bioresource Technology* **101**, 439–449.

Food and Agricultural Organization (FAO) 2010 National Aquaculture Sector Overview. Viet Nam. *National Aquaculture Sector Overview Fact Sheets*. FAO, Fisheries and Aquaculture Department [online], Rome. See: http://www.fao.org/fishery/countrysector/naso_vietnam/en.

Genovese, C. & González, F. 1995 Evaluation of dissolved air flotation applied to fish filleting wastewater. *Bioresource Technology* **50**, 175–179.

Gonzalez, J. F. 1996 Wastewater Treatment in the Fishery Industry. *Food and Agricultural Organisation (FAO) Fisheries Technical Paper, No. 355*. Rome, Italy. See: ftp://ftp.fao.org/FI/CDrom/TechPapV2/techpap.htm.

Hippen, A., Rosenwinkel, K.-H. & Baumgarten, G. 1997 Aerobic deammonification: A new experience in the treatment of wastewaters. *Water Science and Technology* **35** (10), 111–120.

Lefebvre, O. & Moletta, R. 2006 Treatment of organic pollution in industrial saline wastewater: a literature review. *Water Research* **40**, 3671–3682.

Omil, F., Méndez, R. & Lema, J. M. 1996 Anaerobic treatment of seafood processing waste water in an industrial anaerobic pilot plant. *Water SA* **22** (2), 173–181.

Palenzuela-Rollon, A., Zeeman, G., Lubberding, H. J., Lettinga, G. & Alaerts, G. J. 2002 Treatment of fish processing wastewater in a one- or two-step upflow anaerobic sludge blanket (UASB) reactor. *Water Science and Technology* **45** (10), 207–212.

Pölz, W. & Salchenegger, S. 2005 Biogas im Verkehrssektor – Technische Möglichkeiten, Potentiale und Klimarelevanz. (Biogas in the transportation sector – Technics, Potentials and Climate Impact). *Berichte 283*, Umweltbundesamt Wien (Federal Environmental Agency, Vienna).

Sander, M., Trautmann, N., Beier, M. & Rosenwinkel, K.-H. 2010 Potentiale der Deammonifikation – Innovationen im Bereich der Stickstoffelimination (Potential of the deammonification process – innovations for nitrogen removal). In *Proceedings of the 11. Hannover Industrieabwasser-Tagung (11th Hanover Industrial Waste Water Congress)*, March 2010, Hannover, Germany.

Stark, O. K., Damann, R. & Stein, A. 2008 Abtrennung von Biomasse mittels Mikroflotation (Seperation of biomass via micro flotation). *Korrespondenz Abwasser u. Abfall* **55** (5), 23–27.

Steinke, M. & Barjenbruch, M. 2010 Nitrogen removal in fish-processing wastewater. *Water Science and Technology* **61** (9), 2227–2233.

Strouss, M., Kuenen, J. G. & Jetten, M. S. M. 1999 Key Physiology of anaerobic Ammonium Oxidation. *Applied and Environmental Microbiology* **65** (7), 3248–3250.

Urban, I. 2009 *Anaerobe Kommunalabwasserbehandlung – Einsatz und Bemessung von UASB-Reaktoren (Anaerobic Municipal Wastewater Treatment – Utilization and Design of UASB-reactors)*. Dissertation, ISAH, Leibniz University of Hanover.

Veiga, M. C., Méndez, R. & Lema, J. M. 1994 Anaerobic Filter and DSFF reactors in anaerobic treatment of tuna processing wastewater. *Water Science and Technology* **30** (12), 423–432.

Vietnam News 2010 Industrial zones to be forced to think green. *Vietnam News (newspaper)*, 17 May 2010.

Wett, B. 2007 Development and implementation of a robust deammonification process. *Water Science and Technology* **56** (7), 81–88.

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