AERATED BIOFILTERS FOR NITRIFICATION AND EFFLUENT POLISHING

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Abstract

To comply with new effluent discharge standards of 10 mg TKN/l, different upgrading methods for a highly loaded activated sludge plant were explored. As a conclusion, demonstration units were tested to assess process feasibility and performance data of an innovative technology. The Achères Treatment plant of the city of Paris is currently being extended to purify a flow of about 2 700 000 m³/d, corresponding to 8 Million population equivalents. Conventional activated sludge, loaded at about 0.6 kg BOD/kg SS d, delivers an effluent of 30 mg/l for both BOD and SS.

To achieve nitrification, a considerable multiplication of basin volume and clarifier area would be required. In the densely urbanised Paris area, insufficient space is available for such an extension. Therefore, new technology for plant upgrading was tested on industrial scale. Biological aerated filters combine aerobic degradation of pollutants with physical retention of suspended solids in one reactor. A high concentration of active biomass can be retained in the packed bed, and nitrifying bacteria can be attached to the filter media. Removal efficiency becomes thus independent of clarification and sludge settling, and ammonia oxidation can be achieved without sludge age requirements.

Four parallel units were installed on the Colombes research platform, handling a total flow of 3000 m³/d. An extensive demonstration test program was carried out over a period of five years to assess the feasibility and performances of the process in line with a conventional activated sludge plant. The limits of loading to achieve different residual ammonia concentrations were studied, and the influence of temperature on biological and hydraulic parameters was verified. Backwash requirements and residual values of carbonaceous and suspended matter were explored in dependence on influent values and filtration velocity.

At 13 °C, an ammonia load of 0.5 kg N/m³ d was completely oxidized. A concentration of 20 mg/l N-NH₄ can thus be totally converted with an empty bed contact time of 1 hour. The Arrhenius temperature coefficient for nitrification was measured as 1.05. Biodegradable carbonaceous and suspended matter was completely removed at filtration velocities higher than 4 m/h, yielding an effluent of less than 5 mg/l for both SS and BOD. Backwash frequency was less than once per day, and a maximum of 5 % of the filter flowrate was used for backwashing.

Keywords
Effluent Upgrading; Fixed Biomass; Wastewater Filtration; Biofilm Reactor; Nitrification

Introduction

Increasingly, nutrient removal from wastewaters is required to protect receiving waters. Simultaneous nitrification-denitrification and carbonaceous pollution removal can be achieved with the activated sludge process at BOD-loads of up to 0.8 kg/m³ d with the alternate aerobic/anoxic zone activated sludge system (1, 2). Many plants achieving conventional discharge standards of 20 to 30 mg/l for both BOD and SS have loading ranges twice as high. These units were often built several decades ago and are now in highly urbanised areas. Limited availability of space for extensions make it necessary to explore innovative methods for upgrading.
To allow the autotroph nitrifiers to remain in suspended biomass reactors, despite their slow growth rates, fixed submerged biomass carriers have been tested (3,4). Even though submerged carriers enhance nitrification by increasing sludge age (5), autotroph bacteria are only retained when carbon concentration is considerably lowered (6). Adding floating foam pads to increase biomass in activated sludge systems brought lower mass loadings and partial nitrogen removal (7). Settleability of sludge is improved, allowing higher bacteria concentrations (8). Low residuals in total nitrogen and phosphorus is obtained by regulating the redox potential in activated sludge (9).

To upgrade existing facilities for ammonia oxidation, several conventional systems have been adapted as tertiary units. Tertiary activated sludge may produce a diffuse floc difficult to settle (10). Tertiary trickling filters can retain nitrifiers without the need of a further separation stage, but downstream filtration is needed for low suspended solids effluent (11). Nevertheless, biomass grazing through filter flies can cause loss in efficiency and clogging can occur through floc carryover from activated sludge. Regular flooding of the filters can eliminate this problem and provide more stable performance (12). Tertiary RBC’s can also provide fixed film nitrification, but intermediate phase separation has to be added to stabilise reaction rates and avoid particle breakthrough (13).

Innovative technologies have been tried to provide tertiary nitrification with fixed biomass. Once carbon pollution is eliminated, biofilm reactors are particularly efficient in ammonia removal. No competition for oxygen or space is then occurring, and the slow growth rate of nitrifiers is counterbalanced by their attachment on media. Mobile biomass carriers (14,15) or fixed submerged elements (6,16) have been tried, but questions remain on hydraulic control and suspended solids balance.

**Biofilters**

Biological aerated filters (Biocarbone), combining aeration and retention of suspended solids in one unit, have gained acceptance as compact and simple wastewater treatment plants (17) in the last decade. They allow simultaneous removal of BOD, SS and Ammonia either for complete treatment or tertiary upgrading (18). Applications include a variety of different effluents (19) and different treatment standards (20, 21). Large-scale testing has confirmed the similarity between pilot and full-scale results (21, 22). The mechanisms of oxygen transfer and the biological characteristics of the reactors have been investigated in detail (23, 24, 25) and first attempts of modelling are made (26).

In addition to the large-scale applications of fixed beds (17), wastewater nitrification on upflow and downflow biological filters has been modelled (27). To remove nitrates from drinking water, fixed biomass denitrification has been introduced in a large plant in France (28). Total nitrogen removal from wastewater is possible by recycling the nitrified effluent into an anoxic filter, similar to single sludge nitrification and denitrification (2). Design considerations of two fixed-bed biofilters in series have been described (29), and applied on full scale (30). New solutions allow complete degradation of nitrogen in a single granular aerated filter (31).

Tertiary filters are used for phosphorus polishing (32) and elimination of micro-organisms (33). Aerated biofilters were chosen for nitrifier attachment and to achieve suspended solids removal without additional clarifiers. Considerable reduction of all pollutants including bacteria count was obtained, favouring disinfection through low suspended solids (20,34). The objective of this research was to explore the limits of an advanced aeration system following secondary clarification of a high-rate activated sludge treatment. For large-scale applications, design recommendations and technology evaluation, as well as long term reliability and temperature influences, had to be established.

**Demonstration System**

Industrial pilot reactors were used in this study, carried out at the Research Center of the Paris Metropolitan Area Sewage Service (SIAAP - Syndicat Interdepartemental pour l’Assainissement de l’Agglomération Parisienne) situated in the Parisian suburbs. Four parallel cells of each 7 m² surface area and a media height varying between 2 and 3 m were used, allowing for a total flow of up to 3000 m³/h. The total study over a five year period covered different wastewater characteristics and operational parameters. Various loading configurations with changes in both concentrations and detention times were tested. Technological details such as filter bed heights, aeration intensities, as well as media types and sizes were verified (Standard sizes 2 - 4 and 3 - 6 mm).

The BAF is similar to conventional rapid sandfilters, except that air is sparged into the lower portion of the filter bed, and a coarser filter medium is used. A schematic drawing of the the pilot filters is given in Fig 1. The filter grain retains the suspended solids and provides surface for biofilm development. Fixed bacteria in the filter bed allow the combination of aerobic degradation of pollution and physical clarification in one reactor. The granular bed consists of expanded schist with a grain size that can be varied according to the desired treatment objective.

The downflow immersed granular bed was designed for high oxygen transfer by countercurrent aeration (13,22). Sewage is fed into a mixing zone at the top of the filter bed. Any distribution device sensitive to clogging by influent solids is therefore unnecessary. Also, countercurrent backwashing first rinses the top of the filter bed, where the solids retention is greatest and the most intensive rinsing is required (29). Backwashing is performed automatically according to headloss buildup and the washing sequences are controlled by microcomputer. Fluid flow during backwash is shown in Fig. 2.
Fig. 1. HOCA ONE Flowscheme

Influent  clogging probes  Process air  Process air  medium  water being treated  Effluent  sluice open

Fig. 2 Backwash Fluid Flow

wastewater extraction siphon  probes  Sludge extraction  medium  Backwash air and water  backwash water  backwash air  sluice closed

Treatment Results

Carbon Removal
Average effluent quality before and after biofiltration for BOD, COD and SS are given in Table 1. Throughout the test period, carbon pollution was never limiting, since loading rates remained below the critical values of 3 kg BOD/m³ d (22). As shown in Figure 4, average effluent BOD was below 5 mg/l even at lower temperatures for the entire range of loadings tested. Similar results were obtained for residual SS (Fig. 5). At filtration velocities up to 4 m/h, average final SS remained stable around 5 mg/l and independent of influent SS. Almost total removal of biodegradable pollution was achieved regardless of influent quality, yielding a residual COD below 30 mg/l.

Nitrification
Ammonia removal depended on temperature, filter media size and applied load as shown in Fig. 3. Following higher nitrification rates on smaller filter grains, a schist between 2 and 4 mm was chosen. The loading rates that can be tolerated at different temperatures to achieve a 75% elimination efficiency are given in Table 2. The minimum average elimination rate at the design temperature of 13°C is 0.5 kg/m³ h. Fig. 6 shows the relationship between influent and effluent ammonia concentration for two filtration velocities. A flux of 0.5 kg N/m³ d can be removed, corresponding to a total oxidation of 20 mg N/l at an apparent detention time of 1 hour.

For a three month winter period, in which a low residual of N-NH₄ was sought, the relationship between applied loading and elimination rate is shown in Fig. 7. Complete removal of ammonia is obtained as long as the applied loading is below 0.6 kg N/m³ d. Maximum removal rates can exceed 0.8 kg/m³ d even at low temperature. The cumulative frequency of different residual values during this test period is shown in Figure 8. For a loading rate below 0.8 kg N/m³ d, more than 50% of the samples had an effluent concentration below 1 mg N-NH₄/l. For a residual below 5 mg N-NH₄/l as 95 percentile, loading rates up to 1 kg N-NH₄/m³ d can be tolerated.

Temperature Influence
For carbon removal only, no sensitive reduction of biological activity with temperature was observed (35), but the impact depends on loading rates and grain size (22). Nitrification rates on larger grain is more sensitive to temperature variations (36). On trickling filters, the Arrhenius correction factor for temperature on nitrification rates was measured as 1.045 (13), but the interrelationship of diffusion, reaction rates and kinetic order makes the application of a simple factor questionable (39). Temperature influence varies according to loading rates, BOD/N ratio and required residual (37). For this tertiary nitrification study, as shown in Fig. 9, the slope of the temperature curve corresponds to an Arrhenius coefficient of 1.05. In a similar study, the limit of nitrogen loading to obtain ammonia residuals smaller than 5 mg/l at temperatures below 10°C is 0.5 kgN/m³ (38).

Aeration and Backwashing
Air requirements were established around 130 Nm³/kg N eliminated, corresponding to an air transfer efficiency of about 11%. Air to water ratio is close to 5 for a secondary wastewater with 30 mg/l of BOD, SS and NTK. Backwash frequency approached 1 cycle per 24 h as water velocity exceeded 4 m/h on a bed height of 3 m. Sludge corresponding to about 1.1 kg TSS/m³ media was evacuated during backwash. The solids concentration of the backwash water is between 300 and 500 mg TSS/l. The water requirements for backwashing averaged less than 5%.
Table 1. Average BOD and SS influent and effluent data

<table>
<thead>
<tr>
<th></th>
<th>Influent (mg/l)</th>
<th>Effluent (mg/l)</th>
<th>Loading (kg/m³ d)</th>
<th>Efficiency (%)</th>
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</thead>
<tbody>
<tr>
<td>SS</td>
<td>36</td>
<td>5</td>
<td>1</td>
<td>86</td>
</tr>
<tr>
<td>COD</td>
<td>72</td>
<td>25</td>
<td>2</td>
<td>65</td>
</tr>
<tr>
<td>BOD</td>
<td>29</td>
<td>4</td>
<td>0.8</td>
<td>86</td>
</tr>
</tbody>
</table>

Fig 3. Influence of grain size on nitrification. Filter 2 from 19/8/82 to 30/3/85; T < 12.5 °C (min), 13.9 °C (max)

Fig 4. Residual BOD as a function of loading

Biodagene 2–4

10 < temperature < 15
Fig 5. Residual SS versus influent SS

Biodagene 2-4

V. water = 3.6 m/h

Table 2. Loading rates

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Applied load (kg/m³ d)</th>
<th>Elimination rate (kg/m³ d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-13.9</td>
<td>0.67</td>
<td>0.50</td>
</tr>
<tr>
<td>14-15.9</td>
<td>0.76</td>
<td>0.57</td>
</tr>
<tr>
<td>16-17.9</td>
<td>0.87</td>
<td>0.65</td>
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<tr>
<td>18-19.9</td>
<td>1.00</td>
<td>0.74</td>
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</tbody>
</table>

Fig 6. Effluent N-NH₄ versus influent N-NH₄

11 < temperature < 14
- V. water = 2.5 m/h
+ V. water = 4.0 m/h
Fig 7. Ammonia elimination rate and efficiency in relation to applied loading (filtration velocity between 1.5 and 5 m/h, temperature 12 - 14 °C, influent concentration 10 - 35 mg N-NH₄/l)

Fig 8. Frequency distribution of ammonia residuals over a three-month winter period (11 < T °C < 14); Velocity, 2.5 < V m/h < 4; Influent 15 < N mg/l < 30.

Fig 9. Temperature influence on nitrification: N-NH₄ load removed versus temperature
Conclusion

The feasibility of a compact tertiary treatment for effluent polishing and nitrification was confirmed. Biological aerated filters in series with conventional treatment plants allow to upgrade effluent quality and thus to extend the capacity of existing facilities. Starting from an effluent of a high-rate activated sludge plant with around 30 mg/L for BOD, SS and N-NH₄, a polished effluent of below 5 mg/L of BOD, SS and N-NH₄ can be obtained with an apparent hydraulic retention time below 1 hour. The industrial-scale tests established process data and confirmed technological solutions.

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Aerated biofilters
