Integration of high-rate DAF technology within a municipal biofiltration plant for the treatment and thickening of backwash wastewaters

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Abstract

Industrial full-scale application of high-rate dissolved air floatation (DAF) in the municipal wastewater treatment plant (WWTP) of Grenoble (France) has highlighted outstanding performance results leading to new design-to-cost perspectives. The integration of DAF technology to treat the returns from the backwash waters of submerged biological aerated filters (BAF) (nitrification stage) has demonstrated removal efficiencies that allow further room for global process optimization. The results obtained on nitrifying BAF backwash water showed a DAF outlet water concentration of less than 25 mgL⁻¹ of total suspended solids at 25 m³h⁻¹, with only polymer conditioning. Such high clarification performance allows leveraging of valuable cost optimization of global process design integration. Direct discharge from DAF’s outlet into the receiving body can be implemented. Hydraulic and solid return loads can therefore be significantly reduced at the inlet of the WWTP. Moreover, floated sludge extracted from the DAF units achieved 4.4% dryness on average. The high thickening operational performance of this DAF technology is able to produce sludge directly compatible with anaerobic digestion. These full-scale results demonstrate that Suez’s GreenDAF™-BWW technology in such application can leverage new rooms for design improvement for BAF treatment and total cost optimization of both the mainstream water treatment line and sludge line.

Key words: backwash water, biological aerated filter, dissolved air flotation, high rate flotation, wastewater

INTRODUCTION

Submerged biological aerated filtration (BAF) is one of the most compact technologies for wastewater treatment. One of the major interests in using BAF for wastewater treatment is its small footprint, which is of great interest for new projects in dense urban areas, as well as for the extension and upgrading of existing works (Rogalla et al. 1994), especially those in built-up areas where limited space is available for expansion (Pujol et al. 1994). When used as a secondary treatment step, BAF backwash water represents 12 to 35% of the total treated water volume (Mendoza-Espinosa & Stephenson 1999), which is usually returned at the head of the works, thus impacting the hydraulic design of the BAF units. Due to the need for several BAF units in series to achieve the increasingly stringent nitrogen discharge standards, hence: (a) pre-denitrification; (b) carbon-nitrification; and possibly (c) post-denitrification BAFs; this backwash volume ratio tends to shift to the upper part of this range with backwash volumes of each stage adding up (a + b + c). Plants operated by Suez reported backwash volume ratio ranges of 5–10%, 10–20% and 20–35% of raw water volumes respectively for one-, two- and three-stage BAF plants.

According to the size of the wastewater treatment plant (WWTP), this backwash water is either directly recirculated to a primary treatment stage, usually chemically-enhanced primary settlement,
or sent to a dedicated backwash water treatment unit in order to extract excess biological sludge produced and limit the total suspended solids (TSS) recirculation to the downstream BAF units. Considering the high proportion that backwash water represents in the global treated flow, there is a huge advantage in avoiding recycling it upstream of the BAF. In that view, specific treatment processes achieving high solid separation with low TSS discharge could enable the disposal of treated BAF backwash water directly into the environment, thus helping in optimizing the BAF sizing and operation.

DAF technology has been broadly used in wastewater treatment, or at least tested, for a wide range of applications, including: (1) primary treatment (Mels et al. 2001); (2) tertiary TSS polishing and phosphorus treatment; (3) sludge thickening; and (4) moving bed bioreactor clarification (Krofta et al. 1995; Odegaard 2001; Steichen et al. 2010).

Although use of high rate DAF has been reported for spent-filter backwash application in the field of potable water production (Bourgeois et al. 2004; Crossley & Valade 2006), as well as some pilot studies on wastewater tertiary filtration wash waters (Samuel et al. 2006), only a few results have been published on the use of DAF in the municipal wastewater secondary treatment of BAF backwash waters (Backer et al. 2007).

This paper proposes to restitute the full-scale results of the Aquapole WWTP in Grenoble (France), where Suez proposed for the first time the use of high-rate GreenDAF™ BWW units for the clarification of municipal wastewater BAF backwash waters, with the aim of directly discharging the treated water into the environment.

**METHODS**

**BAF plant and DAF unit’s presentation and operational conditions**

Aquipole is a 600,000 people equivalent WWTP located in Grenoble, France with a peak nominal flowrate of 305 MLD. The nitrogen treatment stage has been recently extended and commissioned at the end of 2015. The biological process is now composed of $14 + 8$ carbon stage BAFs (Biofor-C) in series with 12 nitrifying BAFs (Biofor-N), as presented in Figure 1, which describes the Aquapole WWTP process layout.

C-stage BAF backwash wastewater (BWW) is clarified with high-rate lamellar settlers (Actidyn® & DensaDeg®), whereas N-stage BAF backwash water is clarified with high rate DAF since the nitrogen treatment was latter built as an extension.

This study only concerns the performance of the DAF treatment of the BWW produced by the nitrifying BAF units (highlighted in grey in Figure 1). These BWW are sent towards a buffer tank from

![Figure 1](http://iwaponline.com/wpt/article-pdf/13/4/812/527511/wpt0130812.pdf)
which individual pumps feed two high-rate flotation units (GreenDAF™ BWW, a Degremont® product, trademark of Suez, ‘BWW’ standing for Backwash WasteWater).

The GreenDAF™ BWW, as highlighted in Figure 2, is constituted of: (1) a two-step mixing zone (reagent – raw water) for (1.1) coagulation with a static mixer and (1.2) piston flocculation; (2) one pressurization line per unit; (3) pressurized water injection nozzles; (4) a flotation zone fitted with an orifice plate floor for proper hydraulic distribution; (5) a surface scraper for sludge evacuation; (6) a mobile overflow weir allowing for the adjustment of the water level in order to facilitate sludge evacuation; and (7) a sludge retention tank (with agitator in the case studied). Each GreenDAF™ BWW unit has a flotation zone of 18 m² corresponding to the perforated floor area.

![Figure 2](image_url)

**Figure 2** | GreenDAF™ BWW high-rate flotation unit.

Instrumentation includes an inline magnetic flowmeter on the raw water feed as well as suspended solid meter probes based on optical density measurement on both the inlet and outlet pipes.

The DAFs are designed to be operated at a constant hydraulic loading rate (HLR) with a range from 19 to 25 m.h⁻¹ (raw water flow on the flotation zone area, thus excluding the recycled pressurized water flow). A variable speed drive was installed on the DAF feed pumps in order to investigate operation performance under different HLRS. At the maximum 25 m.h⁻¹ loading rate, the coagulation and flocculation hydraulic retention time (HRT), respectively 2 and 2.5 minutes, are comparatively very low in contrast to the 10 to 20 minutes’ flocculation time used in conventional DAF applications (Edzwald 2010). As global DAF unit volume is approximately 137 m³, the global HRT in the GreenDAF™ BWW unit is around 18.3 minutes.

Pressurization conditions during the full-scale trials were 5 to 5.5 bars operating pressure and a recycling rate of 10.5 to 13.5% of BAF backwash water flow, respectively for a HLR of 25 and 19.4 m.h⁻¹ over the floating area. Reagents used were FeCl₃ and a high molecular weight acrylamide-based cationic polyelectrolyte (PE).

Regarding the nitrifying BAF treatment units, backwash cycle initiation control was based on high head-loss threshold detection or after 35 hours of production, whichever came first.

**Aim**

The aim of the trial was to: (1) optimize the DAF chemical reagent consumption (FeCl₃ and/or PE); (2) confirm that a TSS value of less than 30 mg·L⁻¹ could be achieved for the treated water (local discharge standard) at 25 m.h⁻¹ in order to allow for direct discharge into the receiving water body so as
to ultimately eliminate this recycle flow stream from the treatment process instead of recycling it at the head of the BAF plant; (3) achieve the thickest floated sludge possible in order to validate the need or not for additional thickening steps prior to anaerobic digestion or dewatering in future designs; and (4) assess the time taken for the system to achieve performance after start-up in relation with its expected on-off operation at a fixed flowrate.

Test protocol

The test campaign lasted for 10 weeks, each week corresponding to a different DAF operational condition in terms of chemical reagent(s) and dosing rates. Both FeCl₃ and PE dosing were controlled by flow proportioned fixed setpoints. Table 1 displays, together with the results, the different operational condition investigated with details on the chemical reagent dosing rates applied each week, as well as the hydraulic load applied and the solid load rates (SLRs) encountered in the BAF backwash water during each week of the test campaign.

Table 1 | Tests operating conditions and averaged results

<table>
<thead>
<tr>
<th>Test Week nb. unit</th>
<th>Hydraulic load rate (HLR) m³.h⁻¹</th>
<th>FeCl₃ dosing rate mg.L⁻¹</th>
<th>PE dosing rate mg.L⁻¹</th>
<th>Temp. °C</th>
<th>[TSS] - DAF inlet mg.L⁻¹</th>
<th>[TSS] - DAF outlet mg.L⁻¹</th>
<th>TSS removal %</th>
<th>Floated sludge concentration as DS g.L⁻¹</th>
<th>Solid Load Rate (SLR) kg.TSS.h⁻¹.m⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.44</td>
<td>27.30</td>
<td>0.00</td>
<td>14 (0.3)</td>
<td>89 (20)</td>
<td>29 (6.8)</td>
<td>67 (8.86)</td>
<td>45.9 (1.3)</td>
<td>1.73 (0.4)</td>
</tr>
<tr>
<td>2</td>
<td>25.00</td>
<td>27.30</td>
<td>0.00</td>
<td>14.1 (0.3)</td>
<td>101 (12)</td>
<td>25 (10.3)</td>
<td>76 (7.66)</td>
<td>41.6 (1.4)</td>
<td>2.53 (0.3)</td>
</tr>
<tr>
<td>3</td>
<td>25.00</td>
<td>0.00</td>
<td>0.68</td>
<td>14.2 (0.3)</td>
<td>64 (15)</td>
<td>10 (2.3)</td>
<td>84 (2.93)</td>
<td>47.6 (2.8)</td>
<td>1.59 (0.4)</td>
</tr>
<tr>
<td>4</td>
<td>25.00</td>
<td>0.00</td>
<td>0.67</td>
<td>14.1 (0.4)</td>
<td>82 (24)</td>
<td>11 (0.8)</td>
<td>85 (5.01)</td>
<td>44.7 (0.6)</td>
<td>2.06 (0.6)</td>
</tr>
<tr>
<td>5</td>
<td>25.00</td>
<td>0.00</td>
<td>0.50</td>
<td>14.7 (0.4)</td>
<td>67 (3)</td>
<td>22 (2.1)</td>
<td>67 (0.15)</td>
<td>42.3 (1.4)</td>
<td>1.67 (0.1)</td>
</tr>
<tr>
<td>6</td>
<td>25.00</td>
<td>0.00</td>
<td>0.50</td>
<td>16 (0.5)</td>
<td>197 (32)</td>
<td>15 (4.1)</td>
<td>95 (0.89)</td>
<td>45.6 (2.7)</td>
<td>4.92 (0.8)</td>
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<tr>
<td>7</td>
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<td>0.00</td>
<td>1.50</td>
<td>16 (0.2)</td>
<td>147 (40)</td>
<td>5 (1.3)</td>
<td>96 (2.46)</td>
<td>46.8 (2.1)</td>
<td>3.67 (1.0)</td>
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<tr>
<td>8</td>
<td>25.00</td>
<td>5.00</td>
<td>0.70</td>
<td>15.8 (0.2)</td>
<td>100 (11)</td>
<td>11 (2.6)</td>
<td>88 (3.32)</td>
<td>43.9 (0.3)</td>
<td>2.51 (0.3)</td>
</tr>
<tr>
<td>9</td>
<td>25.00</td>
<td>5.00</td>
<td>0.50</td>
<td>16.5 (0.1)</td>
<td>109 (8)</td>
<td>18 (5.3)</td>
<td>85 (5.85)</td>
<td>43.6 (0.5)</td>
<td>2.74 (0.2)</td>
</tr>
<tr>
<td>10</td>
<td>25.00</td>
<td>15.00</td>
<td>0.75</td>
<td>17.1 (0.3)</td>
<td>108 (21)</td>
<td>15 (1.8)</td>
<td>85 (2.70)</td>
<td>41.7 (0.5)</td>
<td>2.70 (0.5)</td>
</tr>
</tbody>
</table>

Note: values in brackets () are standard deviation – values without bracket are average of the available data of this test week.

*24-hour flow proportional composite samples.

Some TSS measurement inline probes (E+H Turbidimax CUS51D-11F2/0), installed at the inlet and outlet of the DAF units, also helped to assess the performance profile from start-up and onward.

Sampling and analyses

Two sampling points were used, at the inlet and the outlet of the DAF process, each equipped with a 24-hour flow proportional composite automatic sampler. As BAF backwash water pollution is mainly constituted of detached biomass, the DAF treatment efficiency was assessed solely based on TSS analysis. Phosphorus removal rate, that could have been improved by metallic salts addition, was not studied, as there is no effluent requirement on this parameter at Aquapole WWTP.

The DAF floated sludge holding tanks were completely drained at the beginning of each new week prior to operational changes, so as to collect representative floated sludge corresponding to each dosing condition. Floated sludge grab samples were collected each day for dry solid (DS) analysis. As the retention time within the DAF sludge holding tank was approximately 12 h, and because of the presence of a mixer within this tank, the floated sludge grab sampling was considered representative of the daily sludge quality.
RESULTS AND DISCUSSION

Overall results

The results obtained substantiated DAF's capability of achieving a 95th percentile residual TSS of less than 25 mg.L$^{-1}$ when treating nitrifying BAF wash water, with an HLR of 25 m.h$^{-1}$ and a 10.5% recycling rate at 5.5 bars for pressurization, provided that the reagent dosing includes polymer. Those results were obtained even with reagent dosage as low as 0.5 mg.L$^{-1}$ PE (see weeks 2–3 and 6–9 in Table 1). Performance varied according to the reagent used, as developed below. Figure 3 summarizes the 10 weeks' campaign results repartition on floated water and floated sludge, results being sorted according to the chemical reagent combination used (FeCl₃ only, PE only or combination of both). The chart displays the minimum, 1st quartile, median, 3rd quartile and maximum results obtained for each category.

The floated sludge concentrations observed ranged from 3.95% to 5.13% with an average dryness of 4.4%, similar to that reported by Backer et al. (2007) for DAF treating mixed backwash waters from both carbon removal and nitrifying BAF. Sludge concentration also tended to rise with the use of polymer as highlighted in Figure 3 where the dryness repartition showed results up to 4.56 and 5.13% respectively for coagulant and polymer used alone.

Velocity impact (week 1 vs week 2)

The first point assessed was the impact of a greater HLR on the TSS removal and outlet TSS absolute values. The DAFs were operated during week 1 & 2 with a fixed FeCl₃ dosing of 27.3 mg.L$^{-1}$ (no PE added), with two different HLRs: 19.4 and 25 m.h$^{-1}$. As previously reported by Odegaard (1995), DAF showed robustness to changing HLR: the results highlighted in Table 1 did not indicate any significant differences between the two operating conditions. Although higher velocity displays better results in TSS removal, this gap is only resulting from the higher SLR in week 2. Dispersion of the outlet TSS analysis however did not led to the conclusion that the performance is comparatively degraded with a 25 m.h$^{-1}$ HLR operation. Slightly higher floated sludge concentration was observed at lower HLR and SLR (see Table 1 for sludge concentration results).

Due to inlet feeding pump capacity limits, a higher HLR could not have been tested.

Figure 3 | Box plot of treated water TSS, solid removal and floated sludge concentration values according to reagent combination.

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DAF quickness to start

Online TSS measurement probes, installed at the inlet (prior coagulation) and outlet of one of the DAF units, helped assessment of the rapidity of the system to reach a stable operation. Figure 4 exhibits a typical TSS concentration profile entering and leaving the DAF unit from start-up onwards. Despite an initial small outlet TSS spike, the operation is virtually steady right from the start, with an immediate TSS removal efficiency above 90%. Outlet TSS online measurement values remained pretty stable along the production cycle. The removal efficiency of the unit therefore collapses at the end of the production cycle only due to the lower TSS concentration entering the DAF unit as the BAF backwashing cycle reaches the end of the rinsing phase.

![Figure 4](https://example.com/figure4.png)

**Figure 4** | GreenDAF™ BWW inlet and outlet TSS measurement profile during a production cycle.

The rapid achievement of performance at start-up enables an on/off operation consistently at nominal HLR (in contrast to the widespread variable flow continuous operation), thus helping in optimizing the energy usage as the recycling rate for pressurization is therefore kept minimal.

**Different reagents, different results (week 1 to week 10)**

The various reagent dosage and combination investigated showed interesting trends with respect to treated backwash water quality and floated sludge concentration. Figure 5 displays the DAF outlet water TSS concentration repartition according to the reagent(s) used. Polyelectrolyte use, in

![Figure 5](https://example.com/figure5.png)

**Figure 5** | DAF outlet TSS distribution according to reagent combination.
combination or not with FeCl₃ coagulant tended to lower the discharged solid residual, and the targeted 30 mg.L⁻¹ TSS could only be secured with the use of polymer. Figure 6 shows the individual daily DAF outlet TSS results according to the DAF inlet TSS concentration. The disparity of DAF-treated water quality according to the reagent combination used can easily be seen on Figure 6. Indeed, at a comparable SLR range, the scatter plot shows distinct outlet quality ranges for the different chemical reagent combinations.

Metal coagulant impact

Adjunction of coagulant seemed to be ineffective in ameliorating the solid removal: all experiments showed that TSS removal was far better when no FeCl₃ coagulant was used, as highlighted in Figure 6 where the results for DAF outlet TSS are consistently better when PE is used alone.

Due to (1) the already flocculated nature of the suspended solids, i.e., detached biofilm, contained in the BAF backwash water along with (2) the fact it contains hardly any colloids to coagulate as the interstitial water used for backwash is treated water from the BAF discharge, it is supposed that the use of metal coagulant may be detrimental in this particular set-up and low flocculation time application.

All results obtained for the nitrifying BAF wash waters with adjunction of FeCl₃ displayed lower DAF performances, leading to the conclusion that coagulant was not needed for DAF and thus it could leverage a substantial Opex saving for the operator in not using metal coagulant. However, synergy of processes in the WWTP might still justify the use of iron coagulant on a global plant performance basis as it was the case in Grenoble WWTP where the complete removal of FeCl₃ from the DAF process impacted the H₂S released in biogas during the anaerobic digestion of the produced sludge.

Polyelectrolyte alone

In contrast to metal coagulant, the action of polyelectrolyte alone on the numerous fairly small particles contained in BAF backwash (Park 1994) was far more effective in enhancing TSS removal. Flocculation with cationic polyelectrolyte alone improved significantly the TSS removal for equivalent SLR (see Table 1 and Figure 6). With PE dosing alone, at dosing rates ranging from 0.5 to 1.5 mg.L⁻¹, DAF proved capable of achieving a treated water quality of less than 15 mg.L⁻¹ TSS on a 95th percentile basis for a nitrifying BAF backwash water ranging 50–250 mg.L⁻¹ TSS. Figure 7 emphasis the rather linear behavior of residual outlet TSS to the polymer dosing rate, with improving
quality as the polymer dose rises. Using polymer alone, the test campaign showed DAF is able to achieve less than 15 mg.L\(^{-1}\) TSS at a dosing rate of 0.75 mg.L\(^{-1}\) and above.

**CONCLUSIONS**

1) Treatment of nitrifying BAF backwash wastewaters with GreenDAF\textsuperscript{TM} BWW high rate flotation unit enabled its direct discharge into the receiving environment with a TSS residual of less than 30 to 15 mg.L\(^{-1}\) according to the reagent used. Implications are that lower hydraulic and solid return loads at the biofiltration stage could leverage capital cost optimization in future BAF plant design as well as lower operation costs in BAF plant refurbishment through a lower BAF backwashing frequency.

2) Clarification of nitrifying BAF backwash water with GreenDAF\textsuperscript{TM} BWW technology does not necessarily require the use of metal coagulant, which is thought to be detrimental for this specific application.

3) The obtainable dry solid concentration of floated sludge for this application is 4 to 5%, which enables its direct discharge to the downstream anaerobic digestion or dewatering step without prior thickening.

4) The fact that the DAF unit is practically efficient in removing TSS right from the start of the production cycle enables an on/off operation consistently at nominal hydraulic loading rate, which helps in minimizing the energy usage with a controlled and optimized recycling rate for pressurization.

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units, collecting water samples and performing lab analysis. Without his help, those full-scale detailed operational results could not have been reported.

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