DISSOLVED AIR FLOTATION AS SUPERIOR PRE-TREATMENT FOR MUNICIPAL WASTE WATER TREATMENT

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Abstract

A pilot-scale dissolved air flotation (DAF) system was placed at the municipal WWTP of water board Rijn and IJssel in Olburgen, the Netherlands to investigate the potential of DAF as alternative to conventional pre-sedimentation tanks. In two tests the pilot system treated either the influent or the effluent of a pre-sedimentation tank. Flocculation/flotation gives the following improvements when compared to a pre-sedimentation tank (PST):

- increase of TSS removal from 25-40 % in a traditional PST, to 70-80 % for a DAF system with polymer and >90 % for a DAF system combined with polymer and coagulant dosing.
- increase of COD removal from 20-25 % in a traditional PST, to 50-60 % for a DAF system with polymer and 60-70 % for a DAF system combined with polymer and coagulant dosing.

This pilot research proved that DAF systems can be applied as an alternative for pre-sedimentation tanks for municipal waste water. The investment and total yearly costs for DAF without chemical dosage are lower compared to a traditional PST. When operational aspects are compared, the DAF system shows advantages in regard to the removal efficiency of TSS and COD, footprint and less effect of variations in TSS load on the effluent quality. Moreover, DAF can be better adjusted compared to PST by adding chemical dosage to reach a high removal efficiency in order to meet future restrictions on effluent discharge demands.

Keywords

COD removal, dissolved air flotation, energy recovery, flocculation, primary sedimentation, suspended solids

Introduction

END-O-SLUDG (www.end-o-sludg.eu) is an EU FP7 project that aims to provide novel system solutions for municipal sludge treatment. Energy and sludge volume reduction are key issues to be addressed in order to lower the operational costs of waste water treatment plants (WWTP's). Conventional waste water treatment typically takes place in two stages. During the first or primary treatment step the waste water is commonly treated in a series of settling tanks that remove the readily settle-able solids and give rise to the so-called primary sludge (PS). The settled waste water, containing the dissolved solid fraction of the wastewater, colloidal matters and fine suspended solids, is treated biologically in the second stage which is often an activated sludge process (ASP). The ASP is energy intensive due to the extensive aeration requirement. Sludge from this secondary treatment, known as secondary sludge or surplus activated sludge (SAS), and biological sludge is more difficult to digest compared to primary sludge. Typically, only 15-35% of the organic content of the SAS can be reduced to biogas in a digestion process compared to 55-60% of PS.

Dissolved air flotation (DAF) can also be applied as a first treatment step instead of the conventional settling tanks. DAF is more efficient in capturing fine suspended solids and colloidal matters compared to pre-sedimentation and this removal can reduce the organic load on the ASP up to 50%. This results in a significant reduction in the energy requirement of the ASP. Furthermore, the sludge generated by DAF fraction is more easily digestible than the surplus activated sludge, yields more biogas and less residual solid for disposal.

The aim of this study was to investigate the application of DAF as alternative for conventional primary treatment of waste water. Flocculation/flotation experiments were performed on both laboratory and pilot scale. The removal efficiency of total suspended solids (TSS), chemical oxygen demand (COD) and total phosphorus (TP) were investigated. In addition, a calculation was performed for the investment and operational costs of a DAF system in comparison to a conventional primary treatment system. Finally, the two systems were compared quantitatively.

Methodology

Experimental setup

Figure 1 depicts the three system configurations which will be discussed in this paper; the conventional PST as reference case, and the two configurations for a flocculation/flotation system. The latter were tested during this study at pilot scale and are referred to as Test 1 (Figure 1 B) and Test 2 (Figure 1 C).

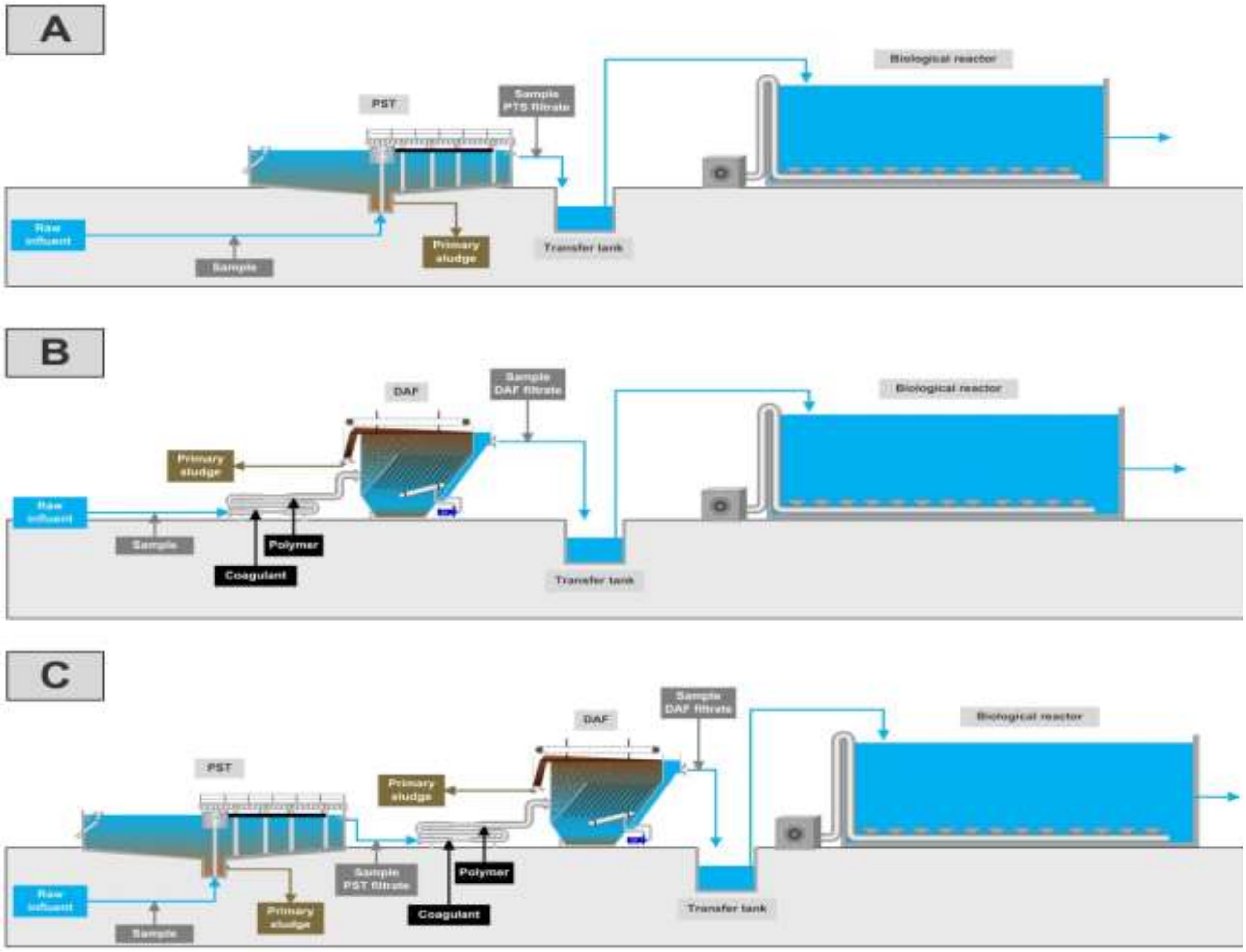

Figure 1: Schematical representation of a PST followed by an aerated biological reactor (conventional treatment, A), a flocculation/flotation system followed by an aerated biological reactor (Test 1, B) and a PST and a flocculation/flotation system followed by an aerated biological reactor (Test 2, C).

A DAF pilot installation was built inside a 40” container and tested at the municipal WWTP of Rijn and IJssel at Olburgen, the Netherlands (Figure 2) from January to March 2012.

Figure 2: The pilot DAF set-up inside the 40" at OlburgenWWTP (left picture: pipe flocculator with chemical dosing, right picture: DAF pilot).

This pilot system consisted of a pipe flocculator, chemical dosing pumps – for dosing of neutralizing chemicals, coagulant and polymer – and a dissolved air flotation unit. The influent waste water was pumped to the flocculator where the chemicals were dosed to the water flow. Depending on the pH value an acidic or a caustic agent was dosed, followed by a coagulant ($FeCl_3$; 33 % diluted to 5 %) and at the end of the flocculator a polymer (C494; 0.05 %) was dosed. From the flocculator the chemically pre-treated water entered the flotation unit. The flocks float to the surface of the unit; this floating sludge layer was continuously scraped off and pumped to a sludge discharge. Part of the treated water was recirculated and aerated to add buoyancy to the flocks, enhancing their floating characteristics. The treated water leaves the flotation unit via an overflow weir. During this pilot test the influence of varying $FeCl_3$ (0-100 mg/l) and polymer (0-4 mg/l) dosage rates were tested. Samples were taken from the influent and effluent and were analysed on TSS, COD and TP concentration.

Results

The pH remained neutral at 6.4 to 7.2 during the pilot tests at the WWTP Olburgen, and therefore, no neutralising agents were added during the tests. Table 1 shows the TSS, COD and TP removal flocculation/floatation during Test 1 (DAF before biological treatment). While TSS and COD concentrations were already reduced without polymer and/or $FeCl_3$ addition, this removal was increased to more than 90% TSS removal and 55-70% COD removal when these chemicals were added. The addition of the cationic polymer resulted in TSS effluent concentration below the measurement level. TP was not removed without the aid of chemical coagulant, but high TP removals of 85% were obtained when using $FeCl_3$ as a coagulant.

Table 1: The influent and effluent concentrations and removal efficiencies of TSS, COD and TP of Test 1 (flocculation/flotation before biological treatment) with and without polymer and $FeCl_3$ dosing.

Polymer dosing [mg/l]	$FeCl_3$ dosing [mg/l]	Influent TSS [mg/l]	Effluent TSS [mg/l]	Influent COD [mg/l]	Effluent COD [mg/l]	Influent TP [mg/l]	Effluent TP [mg/l]	Removal efficiency TSS [%]	Removal efficiency COD [%]	Removal efficiency TP [%]
0	0	131	79	238	182	4	4	40	24	7
0	0	91	50	397	319	6	5	45	20	13
0	0	165	88	398	340	5	5	47	15	15
0.8	0	153	46	632	316	13	8	70	50	38
1	0	292	55	646	325	12	7	81	50	42
2	0	180	50	413	202	8	5	72	51	38
2	0	325	61	613	307	12	7	81	50	42
4	0	180	48	413	211	8	5	73	49	38
4	0	169	47	437	223	7	4	72	49	43
2	10	171	< 5*	586	266	14	< 2**	97	55	> 85
2	20	248	29	586	266	16	2	88	55	85
2	100	200	38	587	179	14	9	81	70	40
4	100	181	16	590	137	14	10	91	77	30

* : measurement within error margin (± 5 [mg/l]) of balance

** : measurement below measurement range of 2 [mg/l]

Table 2 presents the TSS, COD and TP removal by flocculation/flotation following the PST in Test 2. During Test 2, slightly lower TSS concentrations were obtained in the effluent compared to test 1, due to the lower influent values after the PST. COD and TP concentrations in the effluent were comparable with the results of Test 1(flocculation/flotation before the PST). The influent concentrations of TSS, COD and TP decreased during the $FeCl_3$ tests because of maintenance work. The TSS, COD and TP concentrations in influent and effluent remain unaltered without the aid of chemical dosage. Due to the low influent concentrations after the PST, the effluent concentrations decreased below measurement levels when a cationic polymer and $FeCl_3$ were added. TP was removed when using $FeCl_3$ as a precipitant.

Table 2: The influent, effluent and removal efficiencies of TSS, COD and TP of Test 2 (flocculation/flotation after PST) with and without polymer and $FeCl_3$ dosing/

Polymer dosing [mg/l]	$FeCl_3$ dosing [mg/l]	Influent TSS [mg/l]	Effluent TSS [mg/l]	Influent COD [mg/l]	Effluent COD [mg/l]	Influent TP [mg/l]	Effluent TP [mg/l]	Removal efficiency TSS [%]	Removal efficiency COD [%]	Removal efficiency TP [%]
0	0	59	40	492	493	12	11	32	0	4
0	0	50	32	518	508	11	12	36	2	0
0	0	22	15	542	502	12	12	32	7	0
0.4	0	61	24	372	327	11	10	61	12	10
0.5	0	25	< 5*	380	321	11	10	> 80	16	9
1	0	21	< 5*	400	312	11	9	> 76	22	13
2	0	42	8	395	238	11	9	81	40	15
2	10	20	< 5*	201	181	6	5	> 75	10	5
2	20	21	< 5*	205	179	6	6	> 76	13	3
2	100	25	< 5*	204	< 100**	7	< 2***	> 80	> 51	> 70
0.4	100	21	< 5*	204	< 100**	7	< 2***	> 76	> 51	> 70

* : measurement within error margin (± 5 [mg/l]) of balance
** : measurement below measurement range of 100 [mg/l]
*** : measurement below measurement range of 2 [mg/l]

In Figure 3 the TSS and COD removal efficiencies for the different process steps tested are schematically shown. The results approach the expected removal efficiency, as for instance shown by the TSS and COD removal exceeding 90% and 55-70%, respectively (as shown in Table 1).

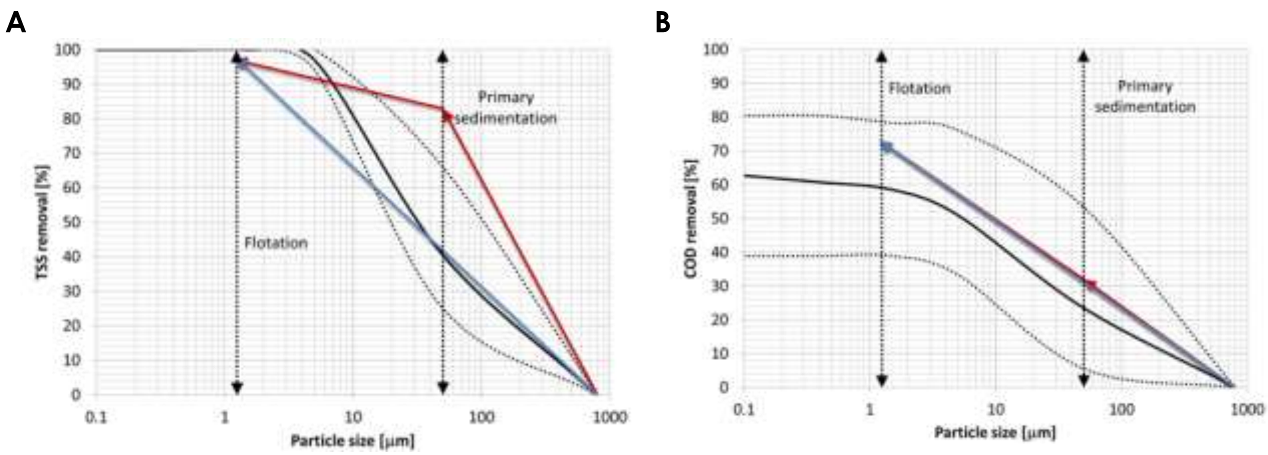

Figure 3: TSS removal efficiencies (A) and COD removal efficiencies (B) achieved by flotation alone (blue line) or by combining sedimentation and flotation (red line) using $FeCl_3$ as coagulant. Dotted lines are theoretical separation limits (Mels et al., 2002).

The overall TSS, COD and TP efficiencies of the combined sedimentation/flotation step (Test 2) are in line with a single flocculation/flotation step (Test 1). The lowest $FeCl_3$ and polymer dosing rates were 10 and 0.4 mg/l pure products respectively, for the combined sedimentation/flotation steps; which are a factor of 2 lower when compared to the single flocculation/flotation system.

Discussion

Removal of TSS, COD and Total P

In this pilot study TSS, COD and TP average removal efficiencies were obtained of 90%, 55% and 85% respectively, when $FeCl_3$ and the polymer were added. These results are comparable the removal efficiencies of 91% for TSS, 70% for COD and 89% for TP of a small pilot setup with a flocculation and dissolved air flotation unit of 3-7 m^3/h at the WWTP of Eindhoven (Broeders et al, 2012). In this pilot research a single flocculation/flotation system was applied and the polymer $AlCl_3$ was dosed. A larger DAF (50 m^3/h) pilot was also tested at the WWTP Eindhoven in 2013 (STOWA, 2013). The removal efficiencies of 73% for TSS, 56% for COD and 60% for TP were slightly lower than the current study due to a lower dosage of the coagulant as a result of a controller for PO_4-P in the effluent.

Investment and operational costs

A calculation was made for a small WWTP of 50 m^3/h dry water flow from which the ASP is overloaded and a minimum of 25% of COD removal is needed to meet the discharge requirements. The influent was assumed to contain 291 mg TSS/l, 634 mg COD/l, 257 mg BOD/l, 8.5 mg Ptotal/l and 57 mg Ntotal/l. Table 6 presents the estimated removal efficiencies of this WWTP. With these results calculations were performed of the investment and operational costs of the traditional PST, a DAF without polymer dosing and a DAF with polymer dosing (Table 4). Biogas production was calculated by using the Chen-Hashimoto model (STOWA 2011).

Table 3: Estimated full-scale removal efficiencies for DAF and PST, based on pilot scale research

influent	Unit	DAF incl. polymer dosing	DAF without polymer dosing	PST without polymer dosing
TSS	%	65-75	40-50	25-35
COD	%	45-55	30-35	20-25
BOD	%	45-55	30-35	20-25
TP	%	10-15	5-10	5-10
PO_4-P	%	0	0	0
TN	%	10-15	5-10	5-10

Table 4 shows that the costs of a DAF system without polymer are similar to the combined investment and operational costs of a PST tank. The negative biogas yield in comparison to the WWTP in the current situation represents a saving in costs. Although an investment is required, the calculations show that the current operational costs of the WWTP can be reduced due to savings in sludge disposal (after digestion) and additional biogas yield because of extra primary sludge production, while the operational costs of DAF with polymer dosing is equal to the current situation.

Table 4: Financial starting points, investment and operational cost (20% inaccuracy) for DAF system with and without polymer dosing and a traditional PST for a small WWTP

Financial starting points	Unit
Energy costs (€/kWh)	0.10
Sludge disposal costs (after digestion; (€/m^3)	55.00
Polymer (€/kg active polymer)	4.00
Efficiency electricity production from biogas (%)	38
Price per kWh for biogas converted in energy (€/kWh)	0.80

Investment costs	Current situation without pre treatment	PST without polymer dosing	DAF without polymer dosing	DAF incl. polymer dosing
Mechanical costs	€ -	€ 55.000	€ 83.000	€ 106.000
Civil costs	€ -	€ 85.000	€ 18.000	€ 18.000
Costs electrical	€ -	€ 10.000	€ 30.000	€ 30.000
Total of additional costs	€ -	€ 74.000	€ 64.000	€ 75.000
Investment costs	€ -	**€ 224.000**	**€ 195.000**	**€ 229.000**
Investment costs [EUR/year]	€ -	**€ 21.000**	**€ 19.000**	**€ 22.000**
Operational costs	**Current situation without pre treatment**	**PST without polymer dosing**	**DAF without polymer dosing**	**DAF incl. polymer dosing**
Polymer	€ -	€ -	€ -	€ 3.000
Energy costs/savings	€ -	€ -3.000	€ -3.000	€ -5.000
Maintenance	€ -	€ 3.000	€ 4.000	€ 4.000
Costs disposal primary sludge	€ -	€ 9.000	€ 15.000	€ 21.000
Costs disposal secondary sludge	€ 38.000	€ 25.000	€ 21.000	€ 17.000
Extra yield biogas	€ -15.000	€ -20.000	€ -24.000	€ -27.000
Operational costs [EUR/year]	**€ 23.000**	**€ 14.000**	**€ 13.000**	**€ 13.000**
Total yearly costs [EUR/year]	**€ 23.000**	**€ 35.000**	**€ 32.000**	**€ 35.000**

In Table 5, DAF is compared with a traditional PST tank on several parameters. A DAF without chemical dosing produces more primary sludge compared to the PST. A higher TSS removal results in a higher production of primary sludge, which has to be transported and disposed. The positive effect of this higher production of primary sludge is the decrease in production of secondary sludge, thus less aeration energy is required, and the higher production of biogas when digested (approximately 20%). The comparison also shows the following:

- A DAF gives substantial higher and more stable removal efficiencies for TSS and COD.
- Both systems score well on robustness.
- The footprint for DAF is approximately 15 times smaller than for a PST because of the higher surface load and the fact that DAF is built vertically.
- The sensitivity for hydraulic variations are comparable for both systems. DAF is able to deal with a slightly higher hydraulic load (30 m/h) then it is designed for without a decreasing in removal efficiency. A PST is able to process more waste water hydraulically, but the removal efficiency will decrease more compared to a DAF system. Thus the systems are rated equal for this matter.
- The DAF system is able to process wide variations in TSS load, while a PST is more sensitive for high peaks in loads compared to DAF.
- While both DAF and PST can be equipped with a dosing system to obtain high removal efficiencies, a PST will not reach as high removal efficiencies as a DAF system. In addition, equipping a PST with a chemical dosing system can have negative effects if combined with higher hydraulic variations.
- The PST scores higher than the DAF system for energy consumption as the DAF system requires more energy. Even when the extra biogas production of the DAF is converted to energy, a PST will still slightly score better.

Table 5: Quantitative comparison between DAF and pre sedimentation tank

Parameter	Unit	DAF without chemical dosing	PST without chemical dosing
Design parameters			
- Surface load	m/hr	25	1,5
- DM primary sludge	% dm	6	2
Operational parameters			
- COD and TSS removal efficiencies		+	0
- Robustness		+	+
- Footprint		+	0
- Effect of hydraulic variations on effluent quality		0	0
- Effect of variations in TSS loads on effluent quality		+	0
- Possibility for higher removal efficiencies with additional chemical dosing		+	+
- Energy consumption		0	+

Conclusions

This pilot research has proven that at a Greenfield situation, a DAF system can be an interesting alternative for PST. Moreover, DAF systems can be used as a (temporary) solution, for example during WWTP renovation projects. A single DAF system and PST step with a flocculation/flotation system gives both an improvement in removal efficiencies compared to a traditional PST. TSS removal increases from 25-40 % in a traditional PST, to 70-80 % for a DAF system with polymer and >90 % for a DAF system combined with polymer and coagulant dosing. The COD removal increases from 20-25 % in a traditional PST, to 50-60 % for a DAF system with polymer and 60-70 % for a DAF system combined with polymer and coagulant dosing.

Combining a PST step with a flocculation/flotation system reduced the chemical dosing by a factor of 2 in comparison to a single flocculation/flotation system. The combination of a PST and a DAF system is not a logical option, as a DAF system with polymer dosage achieves the same effluent concentrations compared to a PST and a DAF with polymer dosage. Combining a PST with a DAF without chemicals has no added value regarding COD and TP removal.

The investment and total yearly costs are lower for DAF without chemical compared to traditional PST. Secondly the DAF system shows advantages in regard to the removal efficiency of TSS and COD, footprint and less effect of variations in TSS load on the effluent quality. Moreover, DAF can be better adjusted compared to PST by adding chemical dosage to reach a high removal efficiency in order to meet future restrictions on effluent discharge demands.

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