11th European Waste Water Management Conference - Leeds, UK, 3-4 October 2017

Tertiary DAF combined with i-DOSE for maximum removal of phosphorus from municipal wastewater effluent

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Abstract

United Utilities undertook a phosphorus removal trial as part of UKWIR's Chemical Investigations Programme Phase 2 (CIP2) Innovation Fund trials using Tertiary-Dissolved Air Flotation (T-DAF) technology from Nijhuis Industries. The T-DAF with intelligent real-time control 'i-DOSE phosphorus' was constructed for modular installation and trialled for 6 months under the supervision of United Utilities at Macclesfield WwTW located near Manchester in the United Kingdom. Phosphorus removal is achieved by chemical precipitation and flocculation of phosphates prior to dissolved air flotation. The system utilised Nijhuis Industries' intelligent chemical dosing system (i-DOSE phosphorus) which controls the system in real-time based upon the incoming phosphorus load to ensure efficient phosphorus removal after the clarifiers is achieved for the lowest possible OPEX cost.
The T-DAF in combination with the 'i-DOSE phosphorus' is an efficient and robust technology for effluent polishing to remove phosphorus and has the potential to reach an average effluent concentration for total phosphorus (TP) of 0.4 mg/l without exceeding the discharge limits for iron. Also BOD, COD and TSS are greatly removed in the process. The produced sludge is expected to have an average DS% of 4%, which would save sludge processing costs downstream.

The presentation will provide an overview of the process, key design features, treated effluent quality results and operational observations.

Keywords

Tertiary Dissolved Air Flotation, Phosphorus Removal, i-DOSE, UKWIR, CIP2, United Utilities

Introduction

The Chemical Investigations Programme Phase 2 (CIP2) is co-ordinated by UKWIR in response to the challenges of the environmental quality standards (EQS) set out in the Water Framework Directive. In order to address the specific challenge of meeting the EQS for phosphorus, the UK Water Industry (under the co-ordination of UKWIR and in collaboration with the Environment Agency) initiated an evaluation of the likelihood of the effluents from innovative technologies to contribute to a reduction in phosphorus concentrations in wastewaters.

Phosphorus is currently the limiting factor preventing good chemical status under the Water Framework Directive for UK inland surface waters. Typically, aerobic wastewater treatment does not substantially reduce phosphorus concentrations and WwTW's can become a point source discharge unless additional treatment is applied. Diffuse sources are often also present, although these are often less controlled (for example through fertiliser runoff).

The removal of phosphorus from point source discharges into the water catchment can create real ecological benefits within waterways. This has driven new discharge consents and as a result technologies and methods have been developed to reduce effluent TP concentrations to sub 0.5 mg/l levels.

In 2009 preliminary pilot testing with a T-DAF was conducted for United Utilities at Grasmere WwTW. The results showed an average concentration for total phosphorus of 0.25 mg/l and an average sludge concentration of 4.1% DS can be reached using a T-DAF [Kluit, A, ter Horst, C, Crewdson, C, Crewdson, J., pilot unit test report WwTW Grasmere]. Since 2009 many innovations have taken place to improve the performance of the T-DAF as a separation technology and the first proof of principle for the Nijhuis Industries' intelligent chemical dosing system 'i-DOSE phosphorus' was conducted on raw influent of WwTW Eindhoven the Netherlands in 2014 [STOWA 2014]. Combined with intelligent real-time control 'i-DOSE phosphorus' a new T-DAF pilot plant was constructed for modular installation and trialled for 6 months under the supervision of United Utilities at the Macclesfield WwTW located near Manchester in the United Kingdom.

Material and methods

Phosphorus removal is achieved by precipitating phosphates with a chemical coagulant and subsequently the precipitated particles are flocculated together with other small particles using a cationic polymer. After coagulation and flocculation suitable flocs are formed that can be removed efficiently using dissolved air flotation. During the pilot trials at Grasmere WwTW the coagulant dosage was calculated based on grab samples on site that were analysed for phosphate (PO_4-P). Naturally the phosphate concentration varies over time due to changes in the influent characteristics and due to dilution during rainy weather. To prevent over (or under) dosage of the coagulant and to guarantee a good performance for phosphorus removal, an online dosing control was deemed a necessity.

The system at Macclesfield WwTW utilised i-DOSE phosphorus which controls the system in real-time upon both feed-forward (based on the incoming phosphate load) and feed-back (based on phosphate load of the treated wastewater) and by using a unique algorithm the chemical dosage was optimised at all times. The phosphate in the influent and effluent of the T-DAF was measured by using a Hach Phosphax analyser and a Filtrax sample filtration system. The site analyses for TP and ortho-phosphate (PO_4-P) were measured by using Hach cuvette tests (LCK349/348/350).

The feed-forward phosphate control ensures that the coagulant dosage is appropriate to remove most of the incoming phosphate load. This is required to deal with fluctuations of phosphate in the wastewater. The feed-back control is a very slow control mechanism that adjusts the coagulant dosage to reach the desired effluent concentrations of phosphate. This double control strategy ensures an efficient final effluent phosphorus removal is achieved for the lowest possible OPEX cost.

Table 1 Design features pilot plant TDAF

Design feature	Value	Unit
Flow	5	m3/h
HRT coagulation	3-4	min
Type of coagulant	Fe2(SO4)3	
Concentration	12.5%	Fe
Maximum Fe:PO4-P ratio	4.5	
HRT flocculator	1	min
Type of polymer	Zetag 9014 (cationic)	
Concentration at dosing point	0.1	%
Aeration pressure	6	bar
PO4-P influent	4	mg/l
Goal TP effluent	< 0.5	mg/l

Figure 1 shows a schematic of the T-DAF pilot and Table 1 displays the key design features of the T-DAF pilot. The T-DAF comprises a reaction tank for coagulation with a hydraulic retention time of 3-4 minutes followed by a plug flow reactor where (in this specific case) a medium charged high molecular weight cationic polymer was added to flocculate the coagulated particles. The coagulant to phosphate molar ratio was limited to a maximum of 4.5 to prevent the total iron content in the effluent of the T-DAF increasing above the requested trial limit of 4.0 mg/l (95 percentile grab sample). The flocs are removed in the T-DAF by using dissolved air floatation resulting in a relatively low solids effluent (15 mg/l 95 percentile grab sample). The effluent is partially recirculated and aerated under pressure (approximately 6 bar) to create the microbubbles which are the driving force of dissolved air floatation. This so called white water is injected in both the flocculator and the T-DAF system in order to achieve the highest possible solid separation. Sludge is thickened and skimmed of the top and can be further processed by dewatering or digestion.

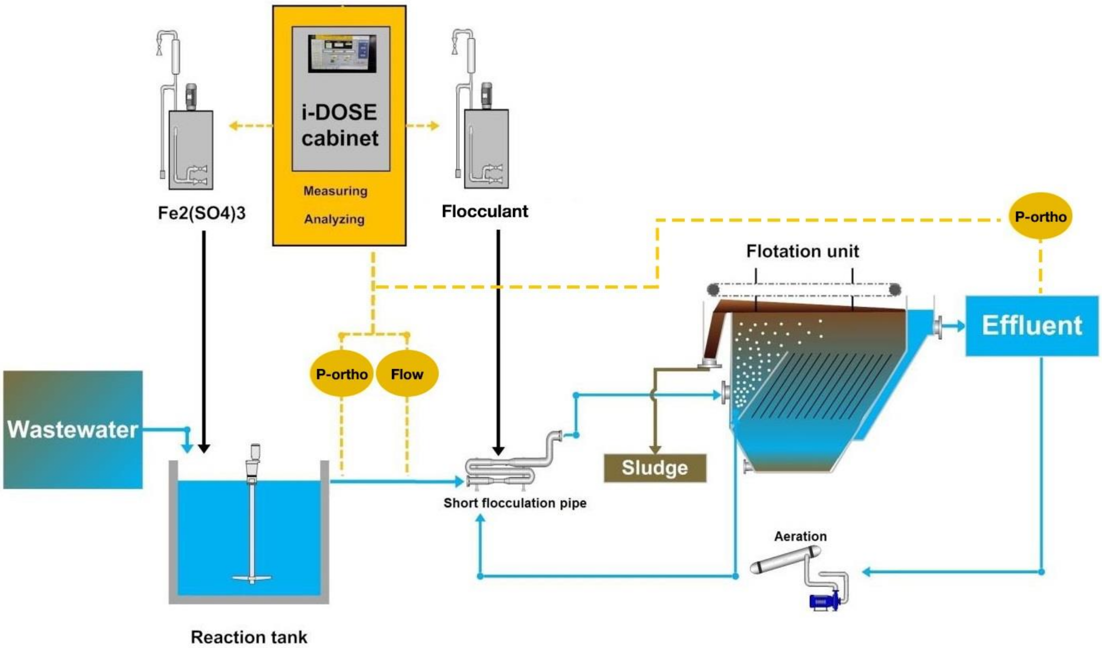

Figure 1. **Schematic overview of the T-DAF**

Results and discussion

During July and August the trial encountered issues with the activity of both the polymer and the ferric sulphate (a few weeks after 50-50 dilution of the ferric sulphate the activity degraded to less than 20% of the original activity). For these reasons a representative period of 5 weeks of the T-DAF trial was chosen for the graphic display. Table 2 represents the validated data over the trial period excluding the periods where the performance is not considered representative due to operational issues mostly due to a reduced activity of the chemicals.

Phosphorus removal

Figure 2 shows a graph of the online PO_4-P measurement of both the influent and effluent of the T-DAF, combined with lab measurements for PO_4-P and TP over a period of 5 weeks. The graph over this 5 week period shows that the T-DAF can remove TP to an average of 0.32 mg/l. The online influent PO_4-P measurement deviates approximately 0.5 mg/l compared to the site analyses and is usually lower than the actual value. The online PO_4-P measurement in the effluent is slightly higher than the site analyses. In this case the set point for PO_4-P of 0.15 mg/l is close to the detection limit (0.05 mg/l) of the analyser.

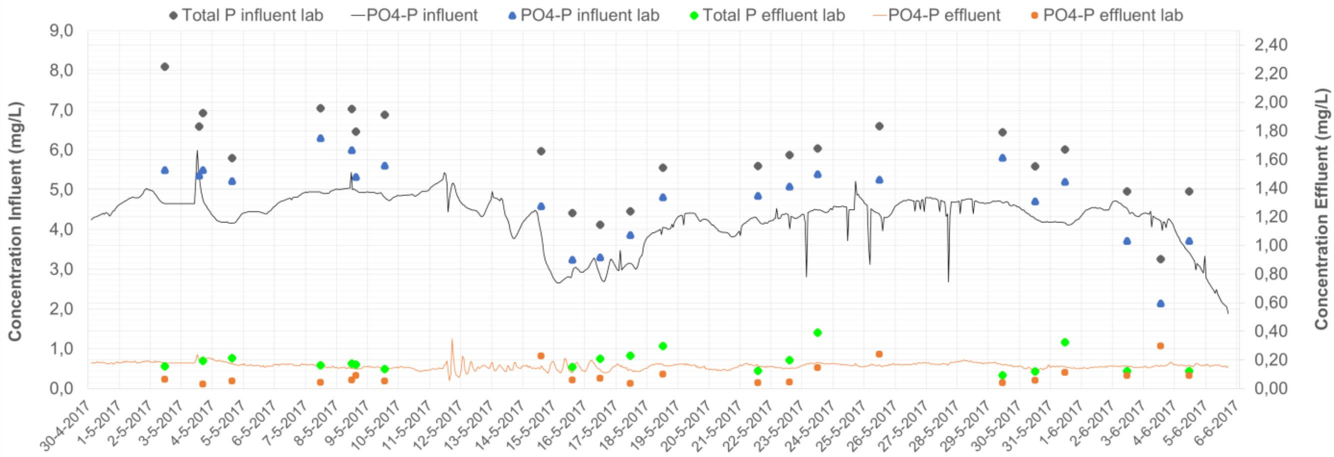

Figure 2 online PO_4-P and site lab measurements of PO_4-P and TP of influent and effluent T-DAF

Iron content in effluent

Figure 3 shows that the iron content of the T-DAF effluent increases due to the coagulation with ferric sulphate in most cases. The average influent iron concentration in Figure 3 was 1.47 mg/L and the average effluent of the T-DAF contained an iron concentration of 2.16 mg/L. The 95 percentile value for the total iron concentration in the effluent of the T-DAF is 3.6 mg/L. This is compliant with the request of United Utilities of a 4 mg/L 95 percentile limit on iron in the effluent of the T-DAF. In multiple measuring days the iron content does not increase. Further optimisation can be realised to reduce the iron content in the effluent to prevent peaks of iron above 4.0 mg/L in the effluent. During dry weather a lower metal (ferric) – phosphate (Me:PO_4-P) ratio [Szabó et al. 2006] can be used compared to rain weather conditions when the phosphorus concentration is much lower due to dilution with rain water.

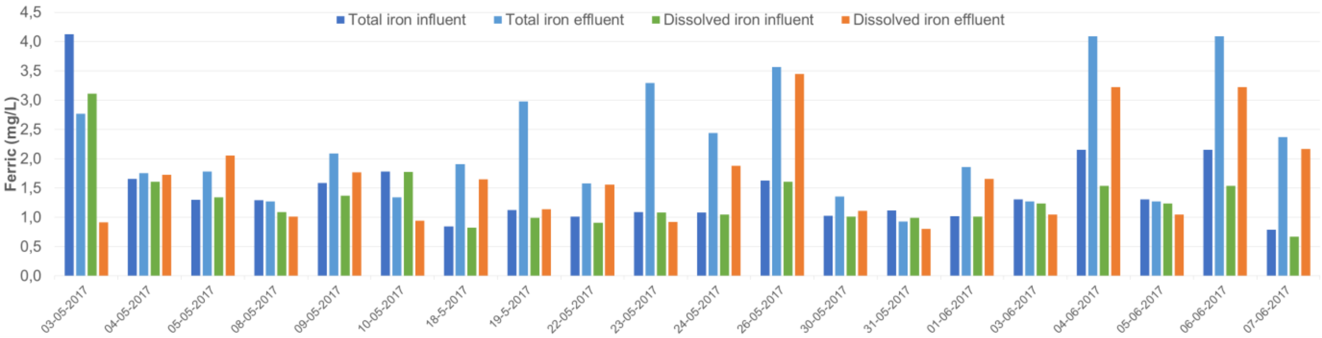

Figure 3 total iron and dissolved iron concentration of influent and effluent T-DAF

DS content of sludge after treatment

One of the major benefits of applying a T-DAF for phosphorus removal is that sludge can be concentrated to an average of 4% DS (results P trial Grasmere WwTW). This saves costs for sludge processing (less volume) and transportation. The reasons for the lower sludge dry solids content than expected were two-fold. Firstly during the pilot trials long piping (approximately 150 m) has been installed for sludge discharge from the sludge hopper combined with the sludge and sand drains on the bottom of the T-DAF installation. These long pipelines caused the water level in the T-DAF to vary because the sludge and sand drain could not discharge sufficient solids due to clogging and resistance in the pipe lines. Because of the changing water level in the T-DAF the scraper cannot be set to remove the sludge at a high DS%. Secondly the in order to fit the unit within the container the design of the slope of the sludge hopper was adjusted which prevented sludge freely flowing. To prevent sludge build-up in the hopper the water level in the T-DAF has been increased in order to scrape more water off the top resulting in a lower DS%. Both of these effects resulted in varying sludge concentrations of less than 1% and up to 7.5% DS.

Optimisation of the plant has been carried out in order to improve the dry solid content at the end of the trial. Figure 4 shows the sludge on top of the T-DAF and after sampling following this optimisation. The sludge DS% will be closely monitored during the final stage of the pilot trials to prove the results for DS% (average 4%) of the trials at Grasmere WwTW can be replicated.

Figure 4: Sludge layer on top of the T-DAF and after sampling

Removal efficiencies of all components

Table 2 represents the validated data (both site analyses for TP and PO_4-P as regulatory analyses for BOD, COD and TSS throughout the trial period.
Alongside TP other components such as BOD, COD and TSS have been monitored throughout the trials and are displayed in Table 2 below. Next to a high removal rate for TP of 93%, BOD, COD and TSS are greatly reduced by (78%, 67% and 74%). The ammonium concentration before and after the TDAF have been monitored, but as to be expected since ammonium will not be coagulated, there is no removal of ammonium.

Table 2: Removal and removal efficiency for TP, PO_4-P, BOD, COD and TSS

Parameter	Unit	Influent T-DAF average [min-max]	Effluent T-DAF average [min-max]	Removal Efficiency
TP	[mg/L]	5.09 [2.2 - 8.1]	0.36 [0.09 - 0.99]	93%
PO4-P	[mg/L]	4.2 [1.9 - 6.3]	0.10 [0.03 - 0.34]	98%
BOD	[mg/L]	14.3 [7.5 - 33.2]	3.1 [0.9 - 8.2]	78%
COD	[mg/L]	75 [32-106]	25 [2 - 40]	67%
TSS	[mg/L]	29 [20 - 55]	7.5 [3 - 16]	74%

Operational features

The T-DAF in combination with the ‘i-DOSE phosphorus’ is an efficient and robust technology for effluent polishing to remove phosphorus. During the 6 month period some mechanical problems have occurred of which none would cause issues for full-scale application. Most issues that occurred were related to a low dosing flow of the coagulant, causing air locks in the piping and sludge not flowing down properly in the sludge hopper caused by the limitation of the slope of the sludge hopper due to placement in a container.

Conclusions

Utilising the T-DAF technology with the i-DOSE phosphorus led to an average effluent concentration of approximately 0.36 mg/L TP in the validated data set presented. After addition of ferric (sulphate or chloride) the iron concentration naturally increases in the effluent. However by applying an intelligent dosing control the iron concentration was within the 4.0 mg/L 95% percentile requirement.

Other components such as BOD, COD and TSS (78%, 67% and 74%) are significantly removed in the same process. Due to the low TSS content of WwTW effluent, the T-DAF is designed for hydraulic load and not for solid load. Application of a T-DAF therefore has the advantage that an extra safeguard is in place in case of sludge washout after the secondary clarifiers.

Another benefit when applying a T-DAF system is the DS% of the sludge. Because of pilot scale issues the sludge DS% varied <1% up to 7.5% has been monitored), the sludge in a full-scale application is estimated to be an average of 4% DS after treatment as shown in the pilot trails at WwTW Grasmere in 2009. Reducing the sludge volume has the potential to save OPEX for transportation and further processing of the sludge, depending on the local conditions of the WwTW

References

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