Phosphorus Removal AMP5 Programme

United Utilities' £16.5m programme at WwTWs across the north west of England aimed at reducing the release of phosphates in the environment

by Géraud Ramond MAPM RPP & David Ridge MSc CSci CEnv CWEM

United Utilities is the regional water company for the North West of England, delivering water and wastewater services to seven million people from Cheshire to the Scottish border. The company's Phosphorus Removal AMP5 programme is a £16.5m programme of work intended to control the release of phosphates to the environment from 16 (No.) wastewater treatment works (WwTWs) across the North West of England. This will prevent the eutrophication of controlled waters as set out in the Urban Wastewater Treatment Directive (UWWTD). A risk based approach validated by full scale live trials was used to determine the required scope of work at each location. This included the design, off-site fabrication and on-site installation of 24 (No.) transportable and self-contained chemical dosing system/rigs. It also included the design of an advanced chemical dose rate control system based on the predicted diurnal phosphorus load incoming to the WwTWs to ensure an efficient chemical usage. The programme has been delivered on time and below budget with all 16 sites now being compliant with their new Environmental Permit (EP).

Hyde WwTW: Installed ferric sulphate dosing rig - Courtesy of United Utilities

Regulatory Driver

Under the UWWTD, 16 WwTWs (ranging from 10,000 to 60,000 population equivalent (PE)) across the North West of England had been included in the Environment Agency National Environmental Plan (NEP) and were required to comply with a phosphorous (P) discharge consent of 2mg/l based on an annual mean by September 2014.

Programme approach

Early in AMP5, it was decided to deliver the 16 projects as a sub programme of work managed by a single project team in order to deliver a common, efficient approach for delivery and a common solution for all sites. This also enabled the project team to manage effectively the numerous project stakeholders spread across a large geographical area in a consistent manner.

Concept phase and scope of work identification

Early in the concept phase of the programme, the option to remove phosphorus from the effluent with a biological process was discounted purely on capital expenditure considerations.

A more cost effective solution of using a chemical removal process using iron salts (ferric) to precipitate the phosphates in the primary settling tanks was taken forward.

Project Site	Trial Site	Phosphorus Removal Process (Iron Salt dosing)	Alkalinity Control Process	Solid Removal Process	Project Site	Trial Site	Phosphorus Removal Process (Iron Salt dosing)	Alkalinity Control Process	Solid Removal Process
Alsager WwTW	X	X	X		Kidsgrove WwTW		X	X	
Congleton WwTW	X	X		X	Middlewich WwTW		X		
Biddulph WwTW	X	X	X		Mossley WwTW		X	X	
Ashton-Under-Lyne WwTW		X	X		Sandbach WwTW		X	X	
Dukinfield WwTW	X	X	X		Saddleworth WwTW		X	X	X
Glazebury WwTW		X			Tyldesley WwTW		X		
Holmes Chapel WwTW		X	X		Worsley WwTW		X		
Hyde WwTW	X	X	X		Westhoughton WwTW	X	X		

The ferric/phosphorus chemical reaction consumes alkalinity present in the crude effluent. Depending on the sites and their respective crude effluent quality, it was therefore identified that alkalinity control process stages may be required at some of the sites to maintain a UU standard level of 50mg/l alkalinity in the effluent. This minimum alkalinity level is required to ensure effective nitrification in the secondary and/or tertiary process stages downstream.

In addition to this, it was identified that some of the iron salts dosed in the primary tanks may be carried over under a solid form through the downstream processes. Some of the sites without an existing tertiary solid capture process stage and which have a low iron residual discharge consent limit (below 2mg/l Iron) , may therefore require a tertiary process stage to ensure robust compliance.

A risk based approached based on the type of process, the crude effluent quality and the existing EPs at each site was used to rank the sites according their likelihood to require an alkalinity control stage and a solid capture stage to robustly comply with their discharge consents.

The sites were then grouped according their similarities with each other again in terms of process type, existing consent limits and crude effluent quality. It was decided to carry out full scale live trials at 6 sites selected for their likelihood to require additional process stages and for their similarities with other sites. From the results of the trials at these 6 sites, the scope of works for all 16 sites in terms of process stages requirement would be extrapolated. On completion of the trials, the scope of work was identified as shown in the table above.

Alsager WwTW: Installed chemical dosing rig -Courtesy of United Utilities

Full scale live trials other outcomes

Ferric was dosed prior to the primary settlement tanks (PSTs) and, where possible, was mixed using the standing wave downstream of existing flow measurement flumes or existing areas of turbulent flows.

Site sampling and monitoring (including on-site testing and accredited laboratory analysis) was carried out on the crude effluent, primary effluent and final effluent for the following as appropriate:

- Total iron.
- Total phosphorus.
- Ortho phosphorus.
- Suspended solids.
- pH.
- Alkalinity.
- COD.
- Ammonia.

The chemistry of phosphorus removal is complex. Iron (ferric) ions can combine with the orthophosphate ions to form Iron phosphate as follows:

$$Fe^{3+} + PO4^{3-} \longleftrightarrow FePO_4$$

This gives a theoretical 1:1 mole ratio of iron (FE):phosphorus (P). Since the molecular weight of iron is 55.85g and the molecular weight of phosphorus is 31g, 1.8g of iron is required to precipitate 1g of phosphorus. A larger amount of Iron is required in actual situations than the chemistry of the reaction predicts and initially a 2:1 mole ratio of Fe:P was assumed. The chemical used was ferric sulphate ($Fe_2(SO_4)_3$) at 12.5% (Fe).

It became apparent from the trial site data that at the sites with activated sludge plants (ASP), the 2mg/l phosphorus consent limit was readily achievable with relatively low Iron residual concentrations (<1mgl/) in the final effluent. This was achievable with primary ferric dose rates of typically less than 2 molar ratio Fe:P as expected.

The phosphorus removal at sites with rock media trickling filter secondary treatment stages were seen to require a much higher Ferric dose rates up to 4 molar ratio Fe:P. At these higher dose rates it was apparent that some sites would be unable to reliably achieve the Iron consents specifically those 1.5mg/l and less.

At all sites performance of the final settlement stages was critical to capture both iron and phosphorus associated with suspended solids. It was also somewhat surprising to see that at most sites a small proportion of P was removed across the PST stage and the larger proportion being removed across the secondary treatment stage.

In response to the unsatisfactory trial performance at some trickling filter sites United Utilities engaged with the Environment Agency (EA) to continue the trials using aluminium coagulants. Jar testing of both chemicals showed the improved performance of aluminium coagulants over the ferric product.

Poly aluminium chloride was selected as the trial chemical and it was successfully applied at two sites. Supported by the full scale aluminium trial data, three of the 16 (No.) project site solutions were changed to aluminium dosing.

Chemical dosing rig design

United Utilities strongly advocate the approach of off-site manufacturing which increases quality and consistency, whilst reducing health and safety risk, costs, customer impact and construction time on site. Embracing this approach, the project

Alsager WwTW: Delivery of the fully fabricated, tested and commissioned chemical dosing rig - Courtesy of United Utilities

Hyde WwTW: Installed lime dosing plant Courtesy of United Utilities

Sandbach WwTW: Installed ferric sulphate and sodium hydroxide dosing rigs - Courtesy of United Utilities

Congleton WwTW: Dosing rig and disc filters Courtesy of United Utilities

Dukinfield WwTW: Lime dosing pumps inside lime rig
Courtesy of United Utilities

Congleton WwTW: New intermediate pumping station lifting flows to the disc filters - Courtesy of United Utilities

Saddleworth WwTW: Ferric digital dosing pumps inside rig
Courtesy of United Utilities

Saddleworth WwTW: Disc filters - Courtesy of United Utilities

team worked collaboratively with Nomenca Chemical Dosing Solutions (a leading UK chemical dosing systems design and manufacture business) and deviated from the United Utilities asset standards dosing systems to design a self-enclosed and transportable dosing rig which also acts as a secondary bund for the chemical storage tank inside.

An initial modular signature design was produced and was subsequently modulated for the various WwTWs in function of their respective chemical storage volumes and dose rate ranges requirements.

To reduce the size of the rigs, several United Utilities Asset Standards were successfully challenged by the project team to enable, for example, the use of digital dosing pump which do not require pump starters or the provision of 14 days chemical storage tanks (rather than the United Utilities standard of 28 days).

These units are built, tested and commissioned at a manufacturing facility and then transported to the receiving WwTWs where they are dropped on pre-constructed slabs and connected to services. It is literally a 'plug and play' system.

Two units were initially ordered and were used to carry out the trials at the 6 selected sites with the units being transported from site to site by lorry to eventually be permanently installed at 2 selected sites which United Utilities had decided to deliver ahead of the consent date.

The same signature design can be used for dosing various chemicals (ferric sulphate, ferric chloride, poly aluminium chloride, sodium hydroxide etc.) with little modification.

Dosing rate algorithm

To ensure the new dosing rigs operate at an optimal dose rate, the team developed an intelligent control algorithm. The new dose method predicts the crude ortho P concentration, which is determined from a crude P load profile that has been established by extensive monitoring of the crude effluent. This is then input into a load lookup table in the software.

The incoming concentration is then calculated from the load lookup table value and the instantaneous FTFT value. The algorithm calculates the 'load to be removed' based on 'target' ortho P concentration. This can then be fed into the specific chemical factors of the software.

The correct amount of chemical to add is continuously calculated and an appropriate signal sent to the dose pumps. The program contains minimum and maximum allowable values for calculated concentration and chemical efficiency to safeguard against any chemical overdose. The dose system closely follows the true ortho phosphate load to the works; therefore it is an efficient control system that can achieve phosphorus removal with minimal chemical cost. Periodically the crude P load profile must be verified to confirm there have been no changes in the catchment.

Advantages of the predicted load profile control is that there is no reliance on analytical instrumentation in a hostile environment that requires regular maintenance and care.

The software can dose with any commercially available chemical should other chemicals become financially viable.

A limitation to the system is if there is significant trade discharges into the catchment. This often results in irregular day to day P loading to the WwTW, in which case a diurnal profile cannot be built and used in the control system. In this scenario a crude effluent P concentration monitor is used. The output reading of the instrument is used directly by the control system.

Alkalinity control and solid capture processes selection

A whole life cost model was built to select the most appropriate chemical type for each candidate site, to control (increase) alkalinity levels in wastewater effluent:

- Sodium hydroxide (caustic soda) chemical dosing or
- Lime slurry chemical dosing.

The model indicated that for sites requiring higher dosing rates lime slurry dosing was the best option and for sites requiring lower dosing rates, the sodium hydroxide dosing option was the most cost effective.

The added benefit of using the sodium hydroxide dosing option was that the signature design created for the ferric dosing rigs could be reused with little modifications.

A whole life cost analysis was also carried out to select for the 2 candidate sites, between the two standard tertiary processes to capture solids in wastewater effluent: disc filters or COUFF sand filters. The disc filter option was identified as the cheapest option at both sites with a significant margin.

Implementation phase

The implementation phase of the programme was undertaken in phases.

Phase I included the enabling works for the trials at the 6 (No.) selected sites, the fabrication of the two initial dosing rigs used for the trials and their permanent installation at Worsley WwTW and Tyldesley WwTW once the trials were complete.

The package of works was competitively tendered among UU Minor Works framework contractors and awarded to Nomenca Ltd. Phase I and the trials were successfully completed in November 2012.

For effective resource management (financial and manpower resources) it was decided to split the main implementation phase into two packages of works:

- Phase IIA included the delivery of six of the 14 (No.) remaining projects/sites. This phase saw the fabrication and installation of 9 (No.) self-enclosed dosing rigs and 2 (No.) lime dosing plants. The package of works was competitively tendered and awarded to Kier MG Ltd in August 2012. Phase IIA was completed in 2013.

- Phase IIB included the delivery of the 7 remaining projects/sites. This phase saw the fabrication and installation of 12 self-enclosed dosing rigs and 2 disc filter process stages. The package of works was competitively tendered and awarded to Nomenca Ltd in February 2013. Phase IIB was completed in August 2014.

Timescales and outturn cost

The programme has been delivered ahead of the regulatory date of 30th September 2014. Upon operational efficiency considerations, the dosing rigs and associated assets delivered in 2013 and early 2014 had been safely and methodically switched off and mothballed once they had successfully passed their respective performance testing. They were then quickly re-commissioned during summer 2014 to be ready when the new phosphorus consent limits come into force on 30th September 2014.

The programme is on track to outturn at c£16.5m which is some £10m below the initial estimates.

The Editor & Publishers would like to thank Géraud Ramond, Senior Project Manager, and David Ridge, Senior Process Engineer, both with United Utilities Water Plc, for providing the above article for publication.

Saddleworth WwTW – Disc Filter (view of the rotating shaft)- Courtesy of United Utilities