Nitreat®

Developments in the control and design of nitrate removal plants during AMP4 and AMP5

Nitrates washed into watercourses from agricultural sources such as slurry and commercial fertilizers are an issue for water treatment plants across around 60% of England, focused mainly on the south-east, east and the Midlands. As a result, water companies in 'Nitrate Vulnerable Zones', as such areas are designated under the EU Nitrates Directive, face the challenge of ensuring that this pollutant is removed during treatment to comply with the 50mg/litre requirement of the 2007 amendment to the Water Supply (Water Quality) Regulations 2000.

Keldgate WTW (Yorkshire Water) Nitreat installation - Courtesy of ACWA Services Ltd

Introduction

During AMP4 (2005 to 2010) around half of all new builds of nitrate removal plant in the UK water industry used ACWA Services' NITREAT® process, and in AMP5 so far 90% of the new plant installed has adopted this system. Taking advantage of the early operational experience and in close collaboration with its utility partners it has proved possible to optimise the process to provide significant CAPEX, OPEX and embedded CO_2 gains.

Early plants were designed to cater for a worst case 2025 design horizon, with a 5:1 turn down – that is, the minimum flow to the plant was fixed at 20% of the design (maximum) flow. The design also adopted a conservative 180g L^{-1} level of salt use, factors that together meant that at the nitrate levels found at the time, the plants were occasionally operating inefficiently on a day-to-day basis when actual works flows and loads were very low. During AMP5, a number of improvements have been made to the process.

The treatment process

The NITREAT® process was introduced into the UK in 2004. It is a counter-current continuous ion exchange process for nitrate removal that incorporates a patented multiport distribution valve. Depending on the conditions – works flow and raw NO_3 load – the multiport valve's internal process disc periodically indexes (rotates), effectively moving every vessel forward one position in the process cycle. There is no external movement, as all flow redirection takes place within the multiport valve.

A full cycle of 20 indexes will entail every column going through every position, and being exhausted and regenerated once.

Adsorption zone

In the adsorption zone (positions 1 to 14), the vessels are operated in parallel. Here, resin is loaded with NO_3, and to a lesser extent SO_4 ions.

The 'freshest' vessel will produce almost nitrate-free water, while the last vessel will be almost 'exhausted', producing water with over 10mg L^{-1} NO_3. However, averaged across the entire zone, the treated water produced will contain less than 5mg L^{-1} NO_3.

Displacement zone

An 'exhausted' vessel moves out of the adsorption zone and into the displacement zone. This zone contains one vessel and has three purposes. It has an upflow configuration, unlike the rest of the process, which is designed to minimise compaction and channeling; it backwashes accumulated debris out of the vessel to waste; and it displaces hard water in the vessel with soft water to prevent scaling.

Regeneration and regeneration rinse

As the process continues the vessel moves into the three-vessel regeneration zone followed by the two-vessel rinse zone. All five vessels operate in series, moving from right to left through the five available positions. This improves utilization of the brine and enables higher resin capacities.

Liquid flow

The soft water passes via the multiport valve to process the vessels in position 15 and then 16, after which the soft water is mixed with a 26% brine stream to produce 9% brine for the regeneration of the resin. This mixture feeds process position 17, 18 and finally 19 and from there via the multiport valve to waste.

Resin flow

The direction of 'flow' of the resin is counter to that of the liquids in these two zones. Exhausted resin from the displacement zone (position 20) passes into the regeneration zone and through positions 19, 18, and 17, contacting with progressively more concentrated brine. The NO_3, SO_4 and other anions present in the resin are replaced by chloride ions.

The brine is then rinsed from the vessels in positions 16 and 15. At this point, the vessel is fully regenerated and ready for reuse – its next move will be back into the adsorption zone.

Developments

The reliability of the earliest plants across a range of sizes indicated that there was an opportunity to improve the efficiency of day-to-day operations, and this was progressed with a key UK user of the process. A multidisciplinary 'optimisation team' was created with the aim to increase the operating efficiency and develop the skills and capability of personnel to enable ongoing improvements.

The challenge was to balance a complex range of factors to enable reductions in salt use. Simply reducing salt use to 160g L^{-1} would have been ineffective, as the PLC calculations of the plant control system would have resulted in the calculated brine and other flows falling below the 5:1 turn-down limit.

This meant that it was necessary to simultaneously modify the maximum and/or minimum ranges for a spread of operational parameters. The maximum allowable turndown was changed to 10:1 (subject to control issues such as the limiting effect of minimum pump speeds) so that the reduced amount of salt could still be effective at the low end of the operating range.

Design review

At the end of AMP4, OFWAT set all water utilities an efficiency challenge for the AMP5 period. Responding to this a team was set up to tackle this challenge from the outset, with the objective of confronting preconceived design standards through innovative and creative workshops.

In these, every aspect of plant design, performance and criticality were discussed, stripping away 'nice to have' extras and rationalising use of instrumentation and redundancy.

Lyng Forge WTW (Anglian Water) Nitreat plant - Courtesy of ACWA Services Ltd

Keldgate WTW (Yorkshire Water) Nitreat plant schematic Courtesy of ACWA Services Ltd

Babraham WTW (Cambridge Water) Nitrate removal technology - Courtesy of ACWA Services Ltd

Results: CAPEX savings

The in-depth design review produced significant CAPEX savings. One key means of achieving this was a reduction in overall redundancy. Eleven of the first twelve AMP4 plants had been designed as two 100% duty streams, with the remaining plant designed as a single 100% stream. Operating experience had proved that the plants were remarkably reliable, so a decision was taken to opt for full redundancy on only the most critical AMP5 site. The remaining sites were designed as a single 100% stream and two 50% streams.

The reduced need for redundancy, coupled with other design changes, meant that the plant room sizes could be reduced, giving subsequent savings in civil works costs. A considerable amount of instrumentation was successfully engineered out of the original AMP4 design, also with significant cost savings. For example, on sites with extremely steady nitrate levels, the raw water nitrate monitors were deleted from the scope resulting in a considerable cost saving.

The reductions in the mechanical and electrical scope and civil works, as well as the reduced programme, led to an estimated 22% saving in embedded CO_2.

Results: OPEX savings

Significant savings were achieved in salt consumption and subsequent waste production. During 2010 and 2011 the required operational modifications and revised software were rolled out to the other operational sites.

The design changes and new philosophy were adopted before commissioning the remaining AMP4 schemes and have been carried forward into AMP5, where the new plants have been designed with all the necessary process modifications incorporated to ensure more efficient operation.

Predicting raw water nitrate values

This is an inexact science, but a methodology was adopted in which the baseline increase in annual nitrate concentration for any groundwater source was determined, along with the maximum seasonal variation. The combined figure was used to predict raw water nitrate values into the future, to enable five and 10-year predictions that would allow future AMP programmes to be developed.

Further developments

Optimisation and monitoring tools have been developed, both through local SCADA (Supervisory Control And Data Acquisition) systems and through a remote telemetry system from which it is possible to monitor the performance of sites centrally via computer terminals.

Data taken from various process instruments is used to determine the current state of the nitrate removal plants. Local optimisation teams were created, consisting of an operational technician and a scientist, forming an 'expert' group of operators charged with reducing salt usage.

Raw water and plant outlet nitrate values are monitored either by online instruments or through laboratory spot samples. Salt use is monitored as the kilograms of salt used per kilogram of nitrate removed, data that is available locally through the HMI (Human machine interface) screens and remotely via the regional SCADA system.

When the software changes were being rolled out, additional advanced operator training was implemented and a range of KPIs set to help operational staff monitor and manage day-to-day operational plant efficiency. Monthly operational reports highlight salt use and salt costs per plant, with the aim of reducing monthly costs without creating any risk in terms of final water nitrate concentration. A further range of KPIs are based on local monitoring of items such as evidence of corrosion, hours run per skid and hours in temporary resin reduction mode.

Conclusions

The plant settings will be reviewed each year by ACWA after an up-to-date operating analysis is received. The ongoing optimisation programme has provided greater understanding of the process and setting KPIs will ensure routine re-optimisation going forward as operating conditions and priorities change.

Users of the technology now include Anglian Water Services, Thames Water, Severn Trent Water, Cambridge Water and Yorkshire Water, the largest site being Yorkshire's Keldgate works near Hull (90 million litres per day).

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