ERADICATING WASTEWATER WOES PART 2

Stephan Mrusek, Johanna Ludwig, and Lucas León, akvola Technologies GmbH, Germany, continue their evaluation of a refinery wastewater reuse project, and present the results of the proposed ceramic membrane treatment field trials.

In a world of increasingly stringent environmental regulations and rising wastewater discharge and disposal costs, many refineries are turning to advanced technologies to reduce their water footprint cost effectively. Unfortunately, 'state of the art' polymeric membrane-based technologies (e.g., membrane bioreactor [MBR] and ultrafiltration [UF]) cannot always cope with the high fouling that the complex and highly varying refinery wastewaters generate, rendering them economically infeasible.

This article presents the successful results of a four month field pilot carried out with akvoFloat™, a flotation-filtration technology based on novel ceramic membranes, for a full wastewater reuse project for a German refinery (250 m^3/hr), and the design and Opex calculations for the full scale solution derived from it. These pilot trials followed a technology screening study and bench-scale tests, the results of which were published in the September 2016 issue of *Hydrocarbon Engineering*. The goal behind these field trials was two-fold:

- Prove that akvoFloat is technically and economically suitable as a reverse osmosis (RO) pretreatment in real conditions (thereby showing that it overcomes the limitations of polymeric membranes seen during previous field pilots at this refinery).
- Gather all data required to design and build a full scale plant.

Background and approach

The pilot system presented in this article treated the effluent of the existing wastewater treatment plant in the refinery, composed of a biological treatment (activated sludge) followed by a sand filter as the final treatment steps. The operator is currently discharging this water into a nearby river, and is looking for a solution in order to reuse it as boiler feed water.

The technology screening study showed diverse water impurities with the need of reduction. Major pollutants are: suspended solids and colloidal matter (turbidity), microbes (CFU) and organic matter (TOC). It was discovered that the organics were mainly high molecular weight humic substances and breakdown products. Some metals (aluminium, iron, manganese, barium and strontium), free chlorine, nitrates and sulfates need to be treated chemically, but were of minor interest in the executed field pilot test.

Since the operator chose RO for the desalination step, the scope of the project was to develop a treatment train that could meet the demanding RO feed quality requirements, both consistently and reliably. The preliminary laboratory test indicated an almost complete removal of turbidity and microbes, and a significant reduction of the organic load with the akvoFloat process. To further remove the organic load, a granular activated carbon (GAC) filter was favoured over advanced oxidation processes (AOP) as a polishing step, due to complexity and costs. A field pilot system was established for four months in the refinery in order to validate the laboratory test results and collect information about long term behaviour, fouling and operational parameters.

The core technology

The akvoFloat technology is a flotation-filtration process based on novel ceramic membranes. The unique akvola MicroBubble Generator™ generates 50 - 70 micron gas bubbles to float suspended matter and organic flocs, outperforming conventional flotation technologies in terms of energy and equipment needs. The filtration is performed by novel flat sheet ceramic membranes with a pore size of down to 0.1 microns. The fouling control is solved by akvoClean, a proprietary membrane cleaning method based on fast oxidation, which has proven successful even with the most challenging industrial wastewater. The combination of these elements enables akvoFloat to deliver high permeate quality reliably with low capital and operating costs.

Pilot system: description and operation

The pilot equipment was located in a container and included an akvoFloat unit, a granular activated carbon unit and an RO unit (Figure 2). Figure 1 shows a flow diagram of the process.

A submerged pump continuously supplied water from the sand filter effluent basin to the pilot container at a feed rate of about 2 m^3/hr. The akvoFloat process used ferric chloride sulfate as a flocculant. The optimal dosage for good flocculation was at 10 ppm. The additional dosage of a polymer as a flocculant aid did not generate additional benefits. The air flow rate of the akvola MicroBubble Generator was in the range of 60 l/hr at an air pressure of around 1 bar. The flux of the akvoFloat ceramic membranes was varied throughout the pilot phase up to 200 l/m^2/hr. The akvoFloat pilot unit was followed by a barrel filled with 200 l

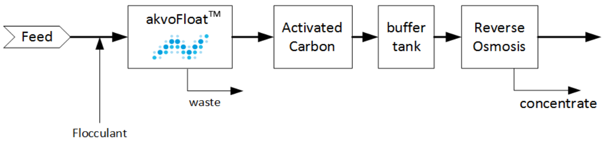

Figure 1. Process flow diagram.

Figure 2. In order (L to R): containerised plant, akvoFloat unit, GAC unit, RO unit.

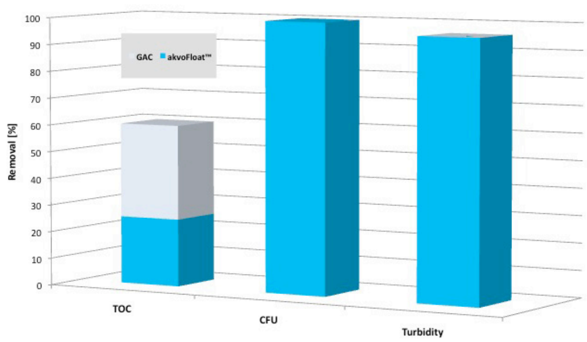

Figure 3. Removal efficiencies of the akvoFloat pilot system.

Table 1. Effluent parameters of the different stages

	Feed	akvoFloat effluent	GAC effluent	RO feed target
TOC (mg/L)	6.0 - 29.0 (9.6)	3.0 - 17.0 (7.2)	2.0 - 12.0 (4.1)	<3 - 5
CFU (CFU/ml)	18 200	0 - 59 (16)	0 - 3 (1)	<10
Turbidity (NTU)	1 - 4 (2.7)	0.01 - 0.5 (0.1)	0.01 - 0.3 (0.1)	<0.1 - 1

of granular activated carbon. Macroporous activated carbon was used as it proved to be the most suitable for the removal of high molecular weight organics, as well as showing the highest TOC removal rate during the technology screening study preliminary laboratory tests. The flow rate for the GAC was adjusted in such a way that a minimum contact time of 10 minutes was ensured. The RO skid, which consisted of a single membrane module, was installed to prove the efficiency of the pretreatment with akvoFloat and the GAC by not producing any biological fouling on the RO membranes.

Better than polymerics

Besides regular backwash procedures during normal operation, all membrane-based technologies use two types of periodic chemical cleaning to increase productivity and control fouling: chemically enhanced backwash (CEB) and chemical cleaning in place (CIP). These processes are key for the economics of a membrane solution, since they affect the downtimes, required membrane area, chemical consumption and amount of water waste.

The chemical and mechanical robustness of ceramic membranes, and many years of research and development (R&D), have allowed akvola Technologies to develop a new cleaning method, akvoClean, which removes foulants by fast oxidation. This method makes it possible to clean the membranes very aggressively, incorporating the effectiveness of CIP processes without the lengthy downtimes. Compared to the conventional cleaning methods CEB and CIP, the akvoClean takes up to 99.5% less time and uses 80% less chemicals than CIP, thereby reducing downtimes, product water loss and minimising operating costs.

A previous pilot test for an MBR, carried out at the refinery in question, showed severe and irreversible fouling occurring on polymeric membranes, leading to the destruction and failure of the pilot. For this reason, the evaluation of the fouling behaviour of the ceramic membranes was of major interest to the customer.

Results

The TOC levels and the turbidity of the feed (sand filter effluent), the akvoFloat effluent, the GAC effluent and the RO effluent were analysed on a regular basis, as they are the most crucial parameters for stable, long term operations. The amounts of microbes (CFU) in the aforementioned streams were analysed every two weeks. Figure 3 presents the average removal rates for TOC, turbidity and CFU during the field pilot test.

The removal of CFU and turbidity with akvoFloat is remarkably high (99.9% CFU removal and <0.1 turbidity [NTU] can be reached) and sufficient in terms of RO pretreatment. As concluded in the technology screening study, additional polishing is needed in terms of TOC. The TOC removal of akvoFloat is slightly lower than expected, based on the preliminary laboratory test results. In combination with the GAC filter, the total TOC removal is about 60%. Table 1 lists the minimal, maximal and average (in brackets) values of the important parameters and streams. The GAC filter operation was satisfying in terms of TOC removal. A TOC value of 4.0 mg/l is acceptable as RO feed, which could be reached at almost all times. The pressure drop of the RO element did not show any change, meaning that no fouling or scaling occurred during the pilot phase.

Unproblematic membrane fouling control

The current field study proved that the fouling could always be fully removed with productive cleaning processes, even during the worst water quality periods. The akvoClean process was carried out once a day and proved to be an effective cleaning process, as it was able to remove the fouling layer on the ceramic membranes in a minimal time period (Figure 4), while maintaining a stable continuous operation. A variation in the fouling behaviour of the membranes was observed and could be correlated with the highly fluctuating influent quality regarding the TOC composition. Extraordinary events ocurring upstream can lead to stress of the biological treatment. In case of such events, bacteria tend to excrete highly fouling substances such as biopolymers, also known as transparent exopolymer particles (TEPs) and extracellular polymeric substances (EPS), along with humic substances and building blocks. None of these events caused non-removable fouling problems, and the removal of the fouling layer was possible with akvoClean, restoring full permeability all the time.

Next steps

Given the success of the field trials, akvola Technologies started the design of the full scale solution in order to obtain an accurate estimation of the capital and operating costs. The 3D design of the akvoFloat system can be seen in Figure 5. The system will be implemented in three trains, and the current Opex estimations are 20% lower than those of the previously piloted polymeric MBR technology.

Conclusion

The field trials have shown that the proposed treatment chain (akvoFloat and GAC) can deliver RO feed water quality reliably, confirming the results of the technology screening study. The data collected during the tests have been used to design the full scale solution and validated its economic feasibility. All this was made possible through the combination of ceramic membranes, the microflotation pretreatment embedded in the akvoFloat process and akvoClean, which allowed the fouling layer to be removed completely and cost effectively at all times, guaranteeing a stable operation. This demonstrates that the technology is able to overcome limitations arising from irreversible fouling and membrane damage in polymeric membranes. It can enable industries with complex wastewaters, such as refineries, to deploy wastewater reuse strategies cost effectively.

Figure 4. Fouling layer on ceramic membranes before and after the akvoClean cleaning process.

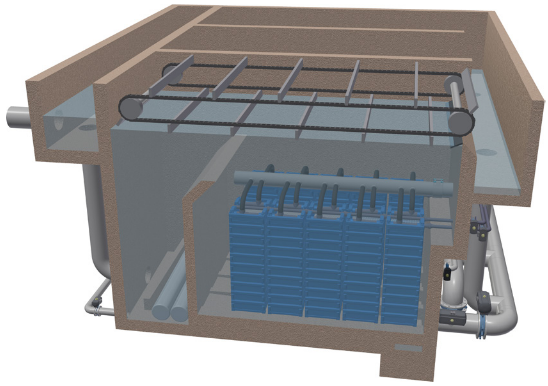

Figure 5. 3D design of a full scale akvoFloat plant.