MAKING THE MOST OF CONTINUOUSLY MOVING BED POLISHING (BIO)FILTERS FOR N AND P REMOVAL, USING SAND-CYCLE REMOTE CONTROL

Wouters, J.W.[1,4] , Heslegrave, C. [2], Sutman, P. [3, 4], Opijnen, E. Van[4],
[1]BW Products BV, The Netherlands, [2] Aquabio Ltd, United Kingdom, [3]University of Applied Sciences Van Hall Larenstein, The Netherlands, [4]Brightwork BV, The Netherlands,
Corresponding Author Email h.wouters@bwproducts.nl or Chris.Heslegrave@freudenberg-filter.com>

Abstract

More stringent effluent criteria for N and P has led to the increased implementation of tertiary moving bed biofilters to (simultaneously) remove phosphorus and nitrogen.

In order to meet these stringent criteria it is important to optimize day-to-day operations, reduce down-time of equipment, have access to real-time status updates and act quickly to remedy failures. Field surveys however reveal that many plants suffer from non-optimal operating conditions, which may last long before being detected. This will seriously impact actual performances.

In order to optimize the use of these assets an "internet-of-things" based monitoring and control system is successfully implemented. A sophisticated remote control system has been developed in the Netherlands, based upon radio frequency ID mote technology. It is applicable to all currently operating continuously moving bed (bio)filters, but has a much broader range of applications. Implementing this mote technology in MBFs will allow operators to optimize the output of the plant, with less effort. Real time dash boards are available for plant operators, indicating current status conditions and clear instructions for detected malfunctions.

Keywords

Continuous sand filter, moving bed filter, data analytics, effluent polishing, filter control, motes, nitrification, phosphorus removal, remote control, RFID

Introduction

Asset management is a key issue for water utilities. Simultaneously the waste water treatment assets should be capable of meeting the requested process performance targets at the lowest possible operational expenditures. In the last centuries utilities have invested heavily in process equipment, including effluent polishing processes to meet more stringent criteria for suspended solids, BOD, nitrate-N, total-N and/or phosphorus. These assets are now challenged to meet even more stringent effluent targets. But operator attendance is reduced and operator tasks are intensified. This paradigm requires a significant shift in monitoring and control strategies. Remote sensing, expert judgement and big data analysis are key to support the optimization of the assets. This paper describes the implementation of smart monitoring tools for operating moving bed continuous sand filters (MBFs), to illustrate the relevancy of smart monitoring in day-to-day operations of waste water treatment works.

Moving bed bio-filtration and key operating features

Moving bed (bio) filtration (MBF) is a mode of filtration based upon uninterrupted filter operation. Filter media cleaning is continuously taking place while the filter is in operation and hence a 24/7 availability of the process is guaranteed. MBFs are used both in process and drinking water production and waste water polishing schemes. Thousands of plants have been equipped with various makes of MBFs, functioning in a wide variety of applications and operating windows.

In figure 1 the MBF filter is shown, the water to be treated flows in an upward direction through the sand bed. During the upward filtration process both impurities are retained within the pores of the filter bed and biological conversion of ammonia or nitrates may take place.

The filtrate is discharged in the upper part of the filter via a fixed overflow weir. Simultaneously the filter bed is constantly moving downward (typically with velocities of 0.3 – 0.8 m/h), as it is sucked into the airlift at the center bottom of the filter. The suction of sand and retained solids is induced by the airlift principle: feeding a small amount of compressed air into the airlift pipe starts the suction process, forcing a mixture of dirty sand and water upward through a central pipeline.

The intensive scouring movements separate the impurities from the sand particles. At the top of the pipeline the sand grains are released in the washer section and start to settle in a hydraulic washer. The grains are finally washed by a small amount of clean filtrate, flowing counter currently through the washer assembly.

An essential feature in MBF is the homogeneous sand circulation over the full filter area. Therefore it is crucial for the sand to be sucked into the airlift evenly from all directions.

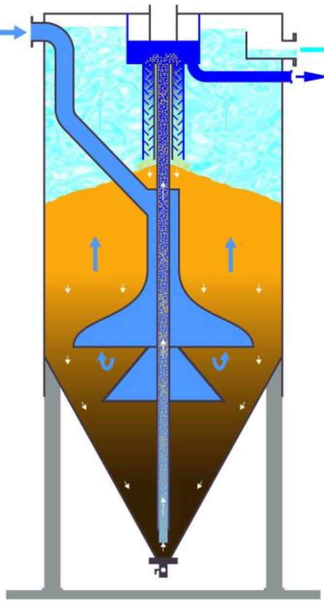

Figure 1 MBF Filter

Due to the continuous sand circulation the filtration process is time-independent: with a constant feed water quality the filtrate quality will also be constant in time. The actual sand circulation rate affects the filtration efficiency for both solids removal and biological conversion processes in the filter bed. Monitoring and controlling the actual sand circulation rate is therefore key to optimize plant performance and reduce plant malfunctioning and down-time. The present tools to monitor and control MBF plants are quite basic and require regular operator interference. The tool (Sand-Cycle), which has been developed, tested and implemented, proved to be an excellent platform to help operators to keep the plant in good shape and to take specific actions, based upon the automated feedback (Wouters 2015).

RFID tagging

To monitor the movement of sand grains in a MBF passive RFID tags are applied. In figure 2 an RFID tag used for Sand-Cycle is displayed next to a five-euro cent coin to get an idea of its size. RFID tagging is an ID system that uses small radio frequency identification devices for identification and tracking purposes. An RFID tagging system includes the tag itself (the transponder), a read device and a host system application for data collection, logging, processing and transmission. A passive RFID tag is briefly activated by the radio frequency scan of the reader. The electrical current is small - generally just enough for transmission of an ID number.

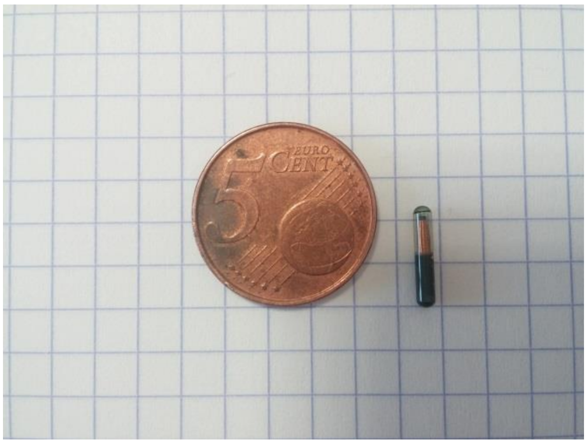

Figure 2 Illustration of the size of an RFID tag (right) on 0,5cm graph paper

The electronic identification system consists of two basic elements: the transponder and the reader. The transponder (ID tag) is attached to the object to be identified or – in the case of MBFs mixed up with the sand grains in the filter bed. It contains no batteries and is hermetically sealed in a housing designed to survive harsh environmental conditions. It is completely maintenance free and has an unlimited life span. The reader energizes the transponder by means of an electromagnetic field, which is emitted by the antenna. It then receives the code signal returned by the transponder and processes it. The reader excites the transponder inductively by means of a polarized low frequency electromagnetic field. Transponders can be read irrespective of their orientation to the reader. Transponders can be read submerged in liquids and can be used in all weathers. They can be molded into items and completely hidden in items, since they can be read through most materials.

Each transponder has a unique code, once the code is programmed at the time of the transponders manufacture. The code cannot be duplicated or tampered with. A unique and positive identification is guaranteed. Although RFID tagging is used in many applications, such as tracking wildlife and livestock, the use in MBFs is new and creates powerful options for monitoring and control.

In the MBF demonstration project we have applied transponders ID-1001H by Trovan Ltd for the purpose of monitoring the sand movement in the MBF. This tag has also been used in medical applications for more than a decade. The transponders consist of a glass tube with a copper coil inside which creates a unique electromagnetic field. The transponders are operating at a frequency of 128 kHz and at temperatures from -40 °C to +75 °C (e.g. Dorset 2015). The dimensions are 11.5 mm x 2.1 mm (length x diameter).

Each transponder is detected while passing the reader, which is integrated in the airlift structure. The codes, dates and times of the passing transponders is transmitted to a decoder, collecting the data from multiple readers. The decoder is connected to a data logger both displayed in figure 3, which is used to store data received from the decoder in readable formats.

The data logger is equipped with a GPRS modem to transmit the data to the back end of the online data server.

The Sand-Cycle data server is converting the raw field data into relevant output data, by using dedicated algorithms. Output is available 24/7 for the operators via the data server front office and is presented in various dash boards.

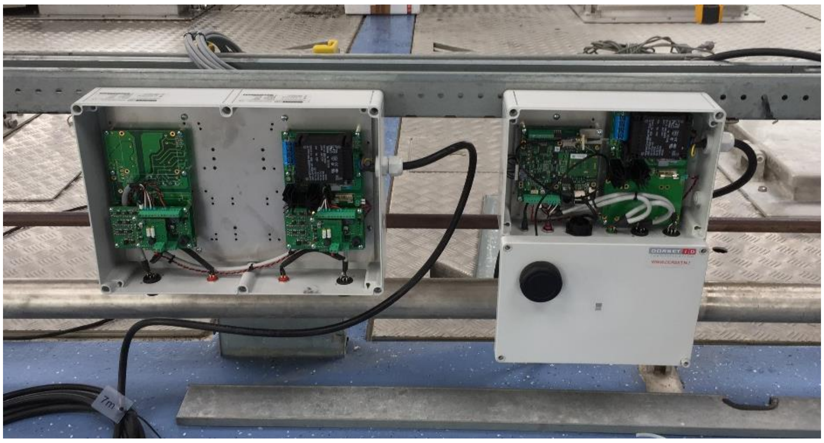

Figure 3

Decoder (left) and data logger (right) installed at WwTW Franeker.

WwTW Franeker demonstration site

WwTW Franeker is a municipal waste water treatment plant operated by Wetterskip Fryslan in the Netherlands (Figure 4). The plant is designed for 60,000 PE, design flow: 2,500 m^3/h, average daily flow: 14,400 m^3/day) (e.g. Wetterskip Fryslan). The water line consists of presettling – mineral filters – post settling and has been extended in 2008 by MBFs for simultaneous N and P removal.

The MBF plant is designed to treat 1,300 m^3/h and will therefore treat the dry weather flow and part of the rainy weather flow. If flows to the waste water treatment plant exceed 1,300 m^3/h the excess will

Figure 4 Arial photo of WwTW Franeker (Wetterskip Fryslan), MBF building on the right

be bypassed and mixed with the filter effluent. The overall effluent consent levels of the plant are set for COD (125 mg/l 95%ile), BOD (20 mg/l 95%ile), suspended solids (30 mg/l 95%ile), total N (10 mg/l annual average) and total P (2 mg/l rolling average in 10 consecutive daily samples).

Average filter feed concentrations are typically 16 mg/l NO_x-N, 2 mg/l NH_4-N, 5 mg/l N_{org}, 23 mg/l N-total and 2 mg/l total-P. Due to the bypass mode at high flows the target levels for NO_x-N and total P in the filtrate are 2 mg/l and 0.6 mg/l respectively.

The MBF plant consists of 6 concrete filter units, each equipped with 4 filter cells. Each filter unit is 5 x 5 m (length x width) and contains a bed height of 4 m. As seen in figure 5 the filter cells in each filter unit are not separated and hence each filter unit acts as one filter.

In the feed to the filter plant both $FeClSO_4$ and bio-ethanol is dosed for phosphorus removal and denitrification. Bio-ethanol is dosed flow proportionally and proportional to the actual feed NO_x-N concentration and the actual feed oxygen concentration. $FeClSO_4$ is dosed proportional to feed flow and feed PO_4-P concentration.

The filter plant is designed for a maximum filtration rate of 11 m/h.

The plant operators have optimized the plant to minimize chemicals and energy consumption. Part of this optimization is the operation of the moving bed filters at sand circulation rates as low as practically possible. A low sand circulation rate promotes both the biological conversion of nitrates into nitrogen gas ánd the removal of suspended solids and flocked phosphorus. Continuous monitoring of the sand circulation rate helps the operators to control the process adequately. However, the monitoring tools used at the plant did not indicate stable data and required frequent operator attendance.

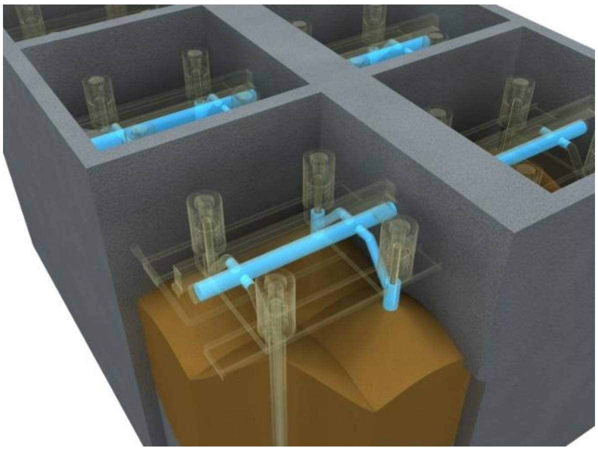

Figure 5 Visualization of the 4-filtercells in one concrete tank at WwTW Franeker.

Monitoring results

As from May 2016 the new Sand-Cycle monitoring system has been implemented in one of the filter units. Each filter cell of the unit was equipped with readers to pick up the transponders codes. Approximately 400 transponders have been used for monitoring, which results in a large enough dataset for proper statistical analysis, allowing appropriate and timely feedback to the operator.

The interpretation of the dataset may reveal near real time plant operating information which will allow the operator to interfere directly if anomalies are detected. It will prevent periods of underperforming of the plant. The data set will also reveal longer term offsets which would not have discovered otherwise.

For the filter operators the information is available and accessible at a dedicated web data server, where the data is visualised in various dashboards, which are briefly described below.

Optimizing filter performance

In figure 6 the actual average sand circulation rate is displayed. In combination with the turnover rate of the sand bed and the actual filter bed resistance and feed flow the average sand circulation rate is a controlling parameter for optimizing removal efficiencies and biological conversions.

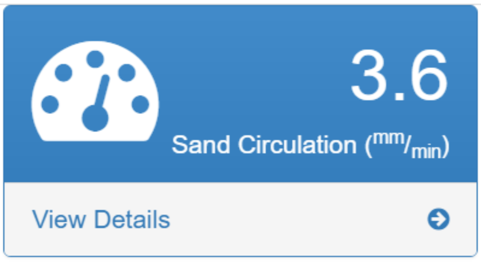

Figure 6 Display of the Sand Circulation on the Sand-Cycle dashboard

Operating conditions

The huge number of data generated per unit of time allows very accurate statistical analysis of the operating conditions of the filter plant. Hence any anomalies may be detected in an early stage and appropriate actions can be determined immediately.

Homogeneous sand circulation rate

Average sand circulation rates are recorded over time and history logs are stored. The standard deviation of the sand circulation rate, indicating the variation of the sand bed movement over the cross section of the filter bed is recorded as well. In figure 7 the average sand circulation rate is visualized for a 48-hour period, the three lines indicate the average circulation speed in mm/min and the upper and lower standard deviation. The more homogeneous the sand circulation rates, the better the process performance generally is. If the recorded deviations are outside a particular range this may be an indicator of particular anomalies: e.g. filter bed clogging.

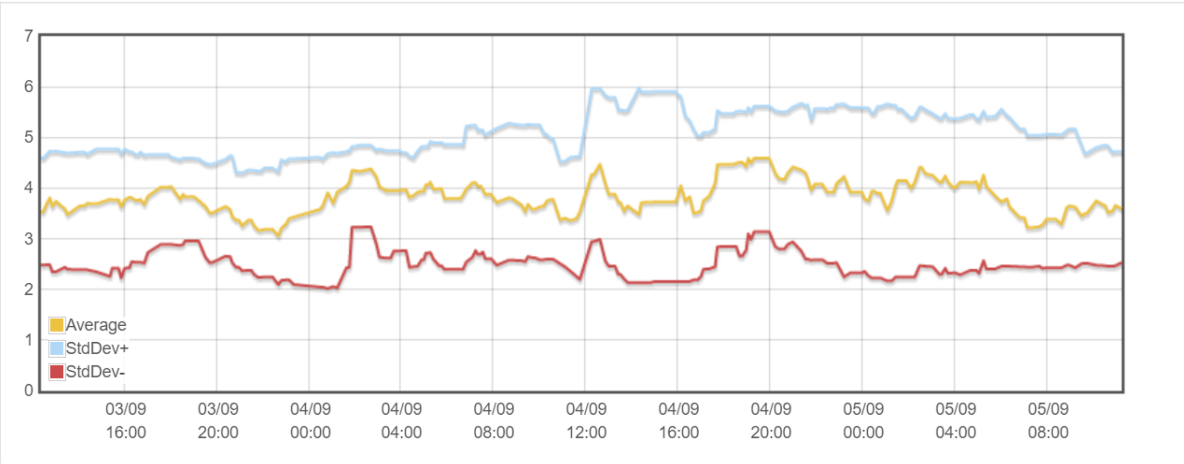

Figure 7 4-hours moving average of sand circulation rate in mm/min at WwTW Franeker (last 48 hours)

Early warning

Long term trending of sand circulation rates may be correlated to the normalized airlift sand turnover. Decreased turnover is an indicator of wear and tear of the airlift. Airlift replacement may be scheduled to minimize energy costs for sand lifting.

Sand loss

Loss of filter sand is indicated by loss of transponders. By continuous monitoring it becomes possible to detect any initial loss of sand at an early stage. This allows the operator to execute inspections in order to avoid the loss of huge sand volumes. Sand loss is normally caused by a malfunctioning of the washer assembly. If not detected in an early stage severe loss of sand may lead to decreased filter performance and blocking of wash water piping.

"Dead" filter zones

In a concrete rectangular MBF layout with multiple filter cells (as in the case of WwTW Franeker) we are able to identify and to quantify the "dead" zones in the corners of the filter bed. In these zones the movement of the sand grains is considerably slower and hence these zones should be discarded in the determination of the active filter area. In figure 8 the circulation time of the trasnponders in hours is displayed on the x-axis versus the count of measurements on the y-axis. This figure shows the circulation time for the tags in the sand filter at the WwTW at Franeker in the period of April 27th 2016 until August 30th 2016. The figure indicates that the major part of the tags has a circulation time around 19 hours with a long tail, indicating a lot of sand grains has a much longer circulation time, with a circulation time counting multiple times the mean value.

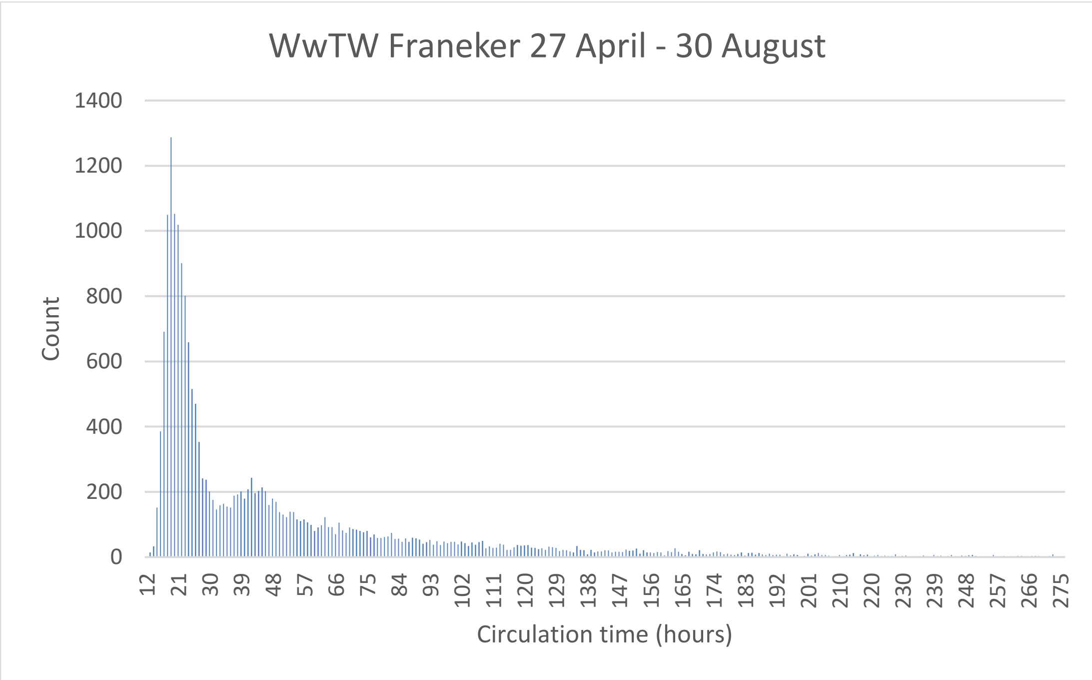

Figure 8 Circulation time in hours for WwTW Franeker (April 27th - August 30th 2016)

Additional monitoring has been executed in a standard stand-alone cylindrical MBF tank, with a diameter of 2.5 m. The filter area is 5 m^2 and the bed height is 3 m. In figure 9 the typical circulation graph is shown. The mean value is higher due to higher sand circulation rates, typically around 13 hours. More interesting though the distribution curve more resembles a normal distribution in contrast to the concrete plant at WwTW Franeker.

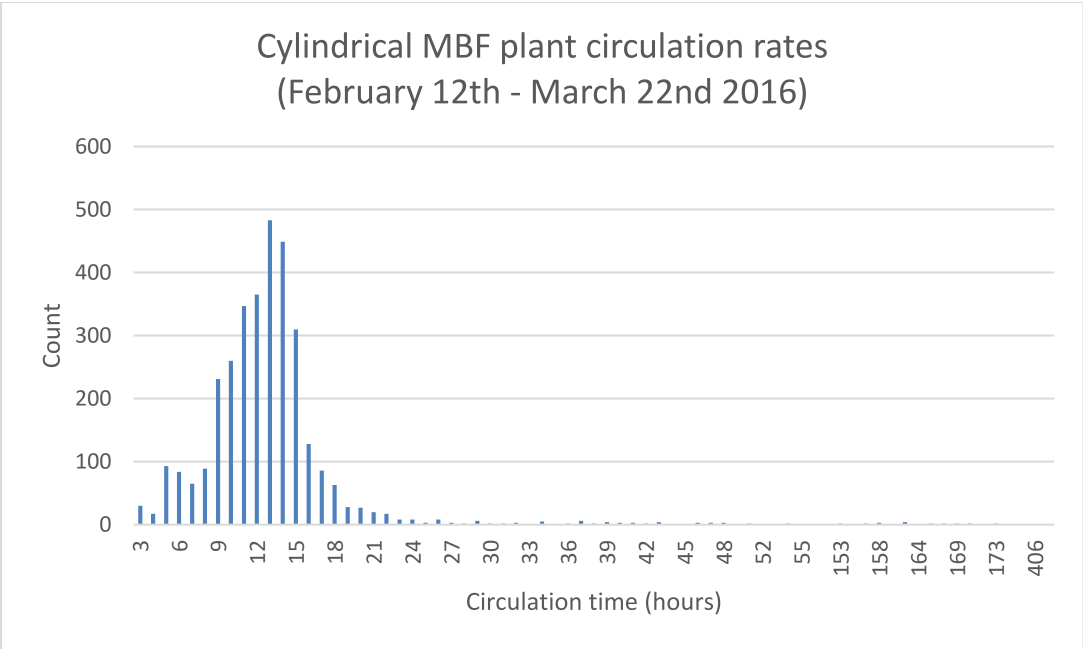

Figure 9 Circulation time in hours for a cylindrical MBF (February 12th – March 22nd 2016

On the dashboard this phenomenon is visualized with the active bed volume, in figure 10 the active bed volume for the Franeker plant is displayed. The percentage indicates the portion of the sand bed being in movement of the total bed volume, and therefor adding to the filter process.

Figure 10 Active bed volume indicating the percentage of filtering sand on the Sand-Cycle dashboard.

Sand migration

In a multiple cell MBF filter plant the sand may migrate from one cell to another during filter operation. The dataset of the Franeker plant has revealed the percentage of migration, which is related to the individual sand circulation rate of each cell. By fine tuning the air flow per filter cell the homogeneous sand circulation may be promoted. In figure 11 the turnover per cell is shown here the percentage registered tags of all registered tags are displayed for each filter cell for the last 48 hours.

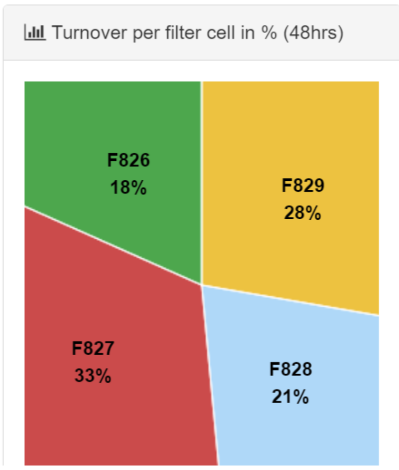

Figure 11 Indicating the turnover per filter cell displayed on the Sand-Cycle dashboard.

Big data, predictive monitoring and process control

Big data

Big data are described as large amounts of data that are available from disparate systems, such as condition monitoring systems. The term often refers to the use of advanced methods to extract value from data. With the advances in information technology we now have the capability to store and analyze a more complete picture of asset health, based on sets of data, drawn from various sources. The ever decreasing cost of electronics makes it more cost effective to fit equipment with sophisticated sensors which can do more than just measure a simple parameter, but can also do additional analysis and diagnostics on the equipment. When these sensors are connected to a communications backbone, this greatly increases the volume of data that is available for analysis, and also has the potential to enable real-time analysis.

The developed tool for real time monitoring of MBFs in water and waste water treatment plants is an example of how big data analytics has potential in the field of WwTWs. Introduction of the tool is a first step towards linking various datasets and finding relationships to make the process work better at varying operating conditions. The ultimate goal is to increase reliability (reducing plant failures) and optimizing plant performance. It also initiates options for advanced filter control, resulting in higher performances.

Big data represent a huge opportunity to improve equipment reliability and reduce maintenance and refurbishment costs. The advantage of cheap wireless technologies now means that sensor information can now be transferred wirelessly. Operation warnings and diagnostics can be shared quickly. If water utilities are receptive to this approach it will also bring in the expert judgment of the technology providers and boosting the know how to operate assets at the best possible conditions. With the objectives to meet ever more stringent effluent quality criteria it will make the difference between failing to meet these criteria or not.

Predictive monitoring

Sand-Cycle remote monitoring has been developed both as a tool for predictive analytics for operation and maintenance of the plant and as a basis for real time filter control under varying operating conditions. The reassurance of a safe operating condition leaves room for advanced filter control to stretch the filter performance.

Predictive analytics is used to avoid the consequences of in-service failures, as per the diagram indicated in figure 12.

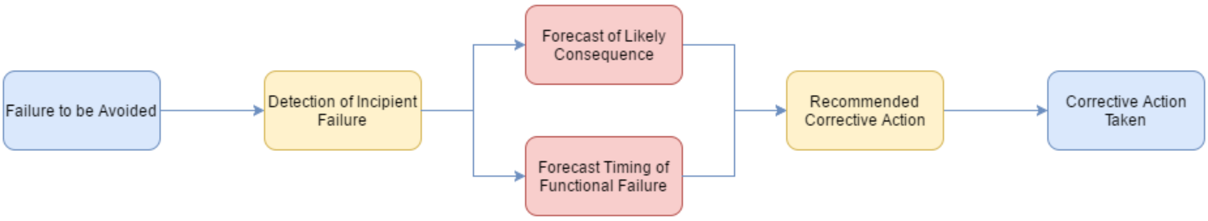

Figure 12 Operation and maintenance system

Predictive remote monitoring of MBF plants allows the operator to get access to status reports indicating both immediate failures and anomalies indicating longer term failures. Based upon this information actions may be scheduled. In figure 13 the predictive monitoring is illustrated. After initial proper functioning of (part of) the equipment the data interpretation generates an anomaly which is characterized as causing a failure within a certain timeframe. If, for instance, a fixed number of transponders is not passing the reader, this might indicate the loss of filter sand. The loss of filter sand is most probably caused by a blockage in the washer assembly, which needs to be rectified within a certain time frame in order to avoid major loss of sand and the effluent water quality to deteriorate below the required level. In today's practice sand loss is normally not detected in an early stage and hence the actual loss of sand is typically only detected while the effluent quality has deteriorated.

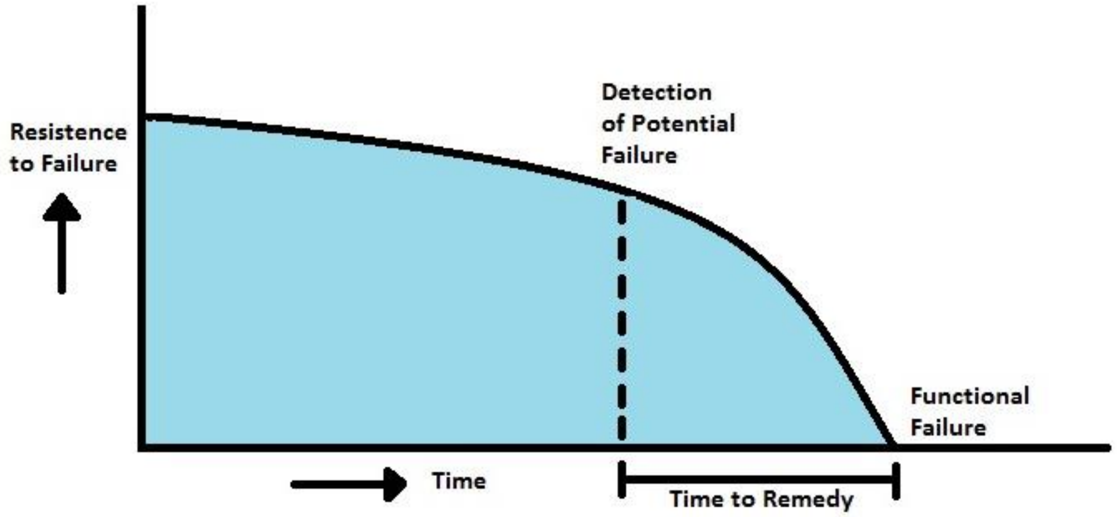

Figure 13 Failure identification and prediction

Filter control

If the monitoring tool is acting satisfactory the filter plant may be equipped with a dedicated control to optimize filter performance. The MBF filter control can be implemented in various ways, but the most simple control mode is described here. This control mode consists of keeping the filter bed head loss within a particular range, which allows the filter to keep sufficient biomass and suspended solids within the filter bed in order to achieve the highest possible performance levels for solids removal and biological conversion. If the plant is designed for both P and N removal this will simultaneously optimize chemical P removal, suspended solids removal and nitrification within the filter bed.

Keeping the filter bed head loss within the right range is established by adjusting the air supply to the airlift control cabinet. As a result the sand circulation rate is varied in order to compensate for the actual process conditions (high/low flow, high/low loads). The Sand-Cycle monitoring tool is a safeguard to prevent the operating conditions to go out-of-bounds.

More sophisticated filter control modes requires further sensoring, which may be worthwhile considering depending on plant capacity and targeted consent levels.

Economy behind MBF monitoring

In the last 20 years we have executed numerous surveys on MBF plants in order to optimize plant performances and to initiate refurbishment actions. Based upon these surveys an overall picture of the economy behind the consequences of plant malfunctioning may be drawn. Essentially four parameters may be quantified in this respect:

- Operator attendance, which requires regular manual monitoring of sand circulation rates, washer assembly. Lack of regular attendance is most often the reason for malfunctioning. Real-time monitoring is assisting the operator in the day-to-day inspections and will reduce the operator time to inspect the plant to a minimum.
- Sand loss is directly impacting the plant performance and sand wash out might block piping downstream of the plant. Identifying sand loss in an early stage will prevent this and avoids regular sand top ups.
- Energy (compressed air) for operating the airlift is continuously consumed. Due to wear and tear of the airlift energy consumption is increased. Hence timely detection of the status of the airlift is contributing to keeping the energy input for the plant operations within limits. Long term trends will indicate the actual airlift status and allow the operator to replace the airlift in time.
- Field surveys have revealed downtime of the MBF plants is occurring due to any of the reasons indicated above. This will result in temporary reduced effluent qualities and deterioration of the annual average performance of the plant.

In order to quantify the economy behind the parameters indicated above, the annual estimated savings per parameter are indicated in figure 14 in function of the plant capacity in liters per second. The overall net savings in Euros over a 25 years lifetime of the plant have been determined as well. These savings have been calculated as the accumulated savings in 25 years minus the initial investments for Sand-Cycle hardware and annual service fees for data storage, handling and reporting.

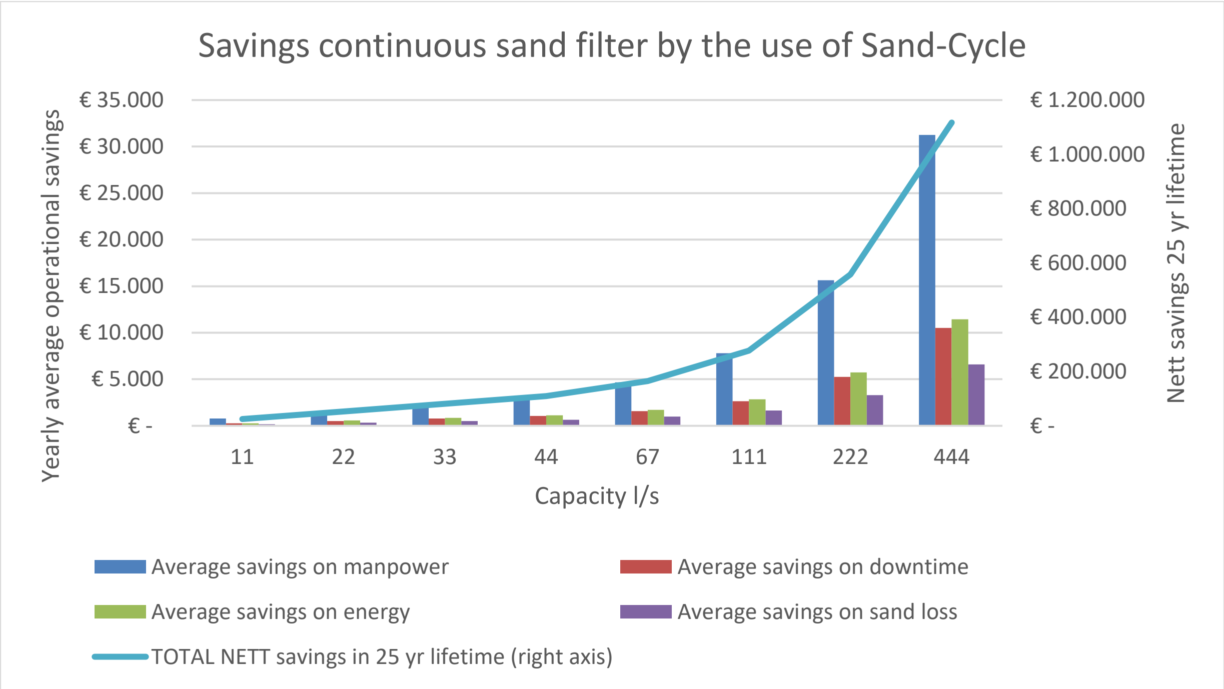

Figure 14 Estimated savings per parameter for 8 plant sizes.

Conclusions

Implementation of a remote real time tool for monitoring MBF plants has been successfully implemented. The field results reveal the following conclusions:

1. Big data predictive analytics using RFID technology is a powerful tool for real time monitoring of plant performance in general and for MBF plants in particular. Access to expert judgment from dedicated technology suppliers will support the output and the operating gains. The results obtained at WwTW Franeker showed excellent reproducibility and added value to the plant operators.
2. MBF plants equipped with the remote real time Sand-Cycle monitoring tool are likely to have increased asset reliability and improved uptime percentages. Early detection of process disturbances allow operators to reduce plant attendance without losing control.
3. MBF plants which are designed for more stringent effluent criteria for nitrogen and phosphorus removal require continuous monitoring to obtain good output results.
4. The return on investment of the tool allows the asset manager to justify the implementation of the technology immediately. RoI is typically less than 2 years.
5. Any off-sets causing consent levels not to be met will cause serious material and immaterial damages to the utilities. The risks will be higher as the consent levels are becoming more stringent. The RFID tool will help mitigating this risk.
6. The monitoring tool allows further reliable implementation of filter controls, which will optimize plant performance by measuring head loss and correlating actual head loss to the air supply for the airlift operation.

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