FILTERCLEAR – ADVANCED SOLIDS REMOVAL TECHNOLOGY

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Abstract

The water industry is facing more stringent Environmental Quality Standards (EQS) as the Water Framework Directive (WFD) dictates good chemical and ecological status in all water bodies. In the meantime, Ofwat's rigorous pricing approach requires high efficiency from the water companies, with a particular focus upon whole life cost (WLC) and reducing both embodied and operational carbon emissions. Water companies are incentivised to outperform and deliver the low Totex solution that is also robust and reliable.

Most of the consent requirements, such as TSS, COD, BOD, Total Phosphorus (TP) and Total Iron (Fe), all rely on a very low effluent suspended solids concentration. Therefore, efficient solids removal technology is becoming increasingly critical in AMP6 for many sites with stringent consent limits.

Bluewater Bio's FilterClear has been selected on Anglian Water's Framework for Tertiary Solids Removal after comprehensive trials. Three FilterClear plants have since been installed and commissioned, treating FFT from 5 L/s to over 50 L/s.

Because of its excellent solids removal capability and low Totex, it is anticipated that FilterClear will be a suitable option for TP removal in AMP 6. The package plant design and offsite manufacturing enables quick installation and mobility, also makes FilterClear perfectly suited for troubleshooting and emergency response.

Keywords

Filtration rate, media stratification, Totex, Runtime, Backwash, Water Framework Directive, Carbon emissions, Removal of TSS, BOD and TP

Introduction and Regulatory Background

The current water policy (such as Urban Waste Water Treatment Directive and Drinking Water Directive, etc.) was considered to be fragmented, and only tackling individual issues (Environment Directorate-General, European Commission, 2015). The Water Framework Directive (WFD) was adopted and came into force in December 2000, aiming to achieve "good ecological and chemical status" for all waters, inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwaters.

One advantage of the WFD approach is that it will rationalise and streamline the water legislation by replacing seven directives, including; the freshwater fish, shellfish waters, groundwaters and dangerous substances directives (Environment Directorate-General, European Commission, 2015).

The Water Framework Directive was transposed into UK law in 2003. The Agencies are now reviewing the River Basin Management Plans for the 2nd cycle (2015 – 2021), and developing new or revised environmental standards based on the latest understanding of scientific and technical evidence (Defra, 2014).

Among many revised standards, the UK Technical Advisory Group (UKTAG) found the standards for phosphorus in rivers set in 2009 were not sufficiently stringent. *"In 75% of rivers with clear ecological impacts of nutrient enrichment, the existing standards produce phosphorus classifications of good or even high status."* (Defra, 2014) The proposed new phosphorus standards are accordingly more stringent than the existing standards.

Regarding discharges from sewage treatment works (STWs), most of the consent requirements, such as TSS, COD, BOD, Total Phosphorus (TP) and Total Iron (Fe), rely on a very low effluent suspended solids concentration. Therefore, efficient solids removal technology is becoming increasingly critical in AMP6 for many sites with stringent consent limits.

Over the past 30 years, a wide variety of treatment technologies have been developed and applied for the removal of the residual contaminants in secondary treated effluent. Removal of organic and inorganic colloidal and suspended solids is typically achieved by filtration. The filters used for wastewater can be classified into three categories (Metcalf & Eddy, 2004): depth filtration, surface filtration and membrane filtration.

To achieve a BOD concentration less than 10 mg/l, the particulate BOD has to be less than about 7 mg/l, allowing 3 mg/l soluble BOD. This means the effluent TSS has to be below 10 mg/l, which will require a suitable tertiary solids removal process. In general, such stringent BOD and TSS consents will entail MBR or deep bed sand filters in many water companies' process selection matrices.

MBR, although it will guarantee good solids removal, will render most of the existing assets redundant, and is considered to be a high Capex and Opex option. Deep bed sand filters (rapid gravity filters) are expensive to build, occupy a relatively large footprint and cannot always guarantee the required effluent quality. The development of continuous backwashing filters (CBFs) in the 1990s offered some advantages over traditional rapid gravity filters in terms of a smaller footprint and reduced construction costs, particularly for smaller sites, but CBFs have high operating costs and will seldom be the lowest WLC solution.

Depth Filtration

In a conventional downflow depth filter, wastewater is applied to the top of the filter bed. As the water passes through, the suspended solids are removed by a variety of mechanisms including: sieving (or straining), sedimentation, inertial impaction, interception, adhesion and flocculation. Sieving (or straining) has been identified as the principal mechanism for removal of suspended solids from settled secondary effluent from biological treatment processes (Tchobanoglous and Eliassen, 1970).

As the solids accumulate within the media, the headloss through the filter will start to build up. The end of the filter run is reached when the suspended solids in the effluent start to increase (break through) beyond an acceptable level, or a limiting headloss occurs, and the filter must be backwashed. Backwashing is accomplished by reversing the flow through the filter at a sufficient flow rate to expand the filter bed. The suspended solids accumulated in the filter are removed by the shear forces created by backwash water. Air scouring is often used to enhance the backwash.

Media size is the principal filter characteristic that affects the filtration operation and performance. If the media are too large, many of the small particles in the influent will pass directly through the bed. If the media are too small, much of the driving force will be consumed in overcoming the frictional resistance of the filter bed.

The size distribution of the filter media is usually determined by sieve analysis using a series of decreasing sieve sizes. The cumulative percentage passing a given sieve size is used to describe the media. For example, size d_{10} is defined as the 10% media passing (based on mass), i.e. 10% of the media is smaller than this size. d_{10} is also referred to as the effective size of the selected filter media, as it governs the solids removal capability. The uniformity coefficient (UC) is defined as the ratio of d_{60}/d_{10}.

One of the biggest drawbacks of a conventional rapid gravity sand filter is that, during every backwash, the largest grains of sand migrate to the bottom of the filter bed whilst the smaller grains tend to end up at the top. The effect is that most filtration occurs in the top layers of a sand filter, leading to a rapid rise in pressure and the need to backwash frequently. Most of the removal occurs in the upper few millimetres in a mono-medium filter, leaving the majority of the filter bed not being fully utilised (Tchobanoglous and Eliassen, 1970).

FilterClear – Four Media Depth Filtration

Multimedia filters were developed to allow the influent suspended solids to penetrate further into the filter bed, and thus use more of the solids-storage capacity available within the filter. The deeper penetration of the solids into the filter bed also permits longer filter runs because the buildup of headloss is reduced (Metcalf & Eddy, Chapter 11, 2004).

FilterClear is a multimedia downflow depth filtration technology, containing up to four different media, which, in order of decreasing grain size and increasing density, are anthracite, silica, alumina and magnetite. The layers are arranged with coarse and light grains at the top of the filter and the fine and heavy layers at the bottom, so the solids are removed progressively through the entire depth of the filter bed. Total media depth is 900 mm.

All media are manufactured by crushing the raw material, hence the shape is jagged which increases the voidage of the filter bed and provides a higher solids holding capacity and longer runtimes. More importantly, these characteristics of the media enhance the filtration mechanisms, especially because both the alumina and the magnetite layers contain particularly small particles; down to 0.35 mm, much finer than a conventional sand filter. As a result, filtration efficacy by straining (sieving) and interception is improved, and filtered effluent is of better quality. FilterClear filters are capable of producing an average effluent TSS of 3 - 5 mg/l.

Figure 1: FilterClear – Four media depth filtration

The media are carefully selected in terms of their density and grade (size distribution) allowing the backwash to stratify the different media into separate layers. Stratification is considered necessary to obtain the high filtration performance and longer runtime.

FilterClear uses enclosed filter vessels, made of GRP or rubber-lined steel depending on the application. FilterClear can operate at maximum differential pressures of up to 1.5 bar. As the feed water enters FilterClear from the top and passes through the filter bed, the suspended solids are retained within the media layers and the headloss through the filter starts to build up. For tertiary treatment, the influent is normally pumped to the filter at pressures of 0.2 – 1.0 bar (less than the typical pressure required by a continuous backwashing sand filter), depending on solids loading rate and required runtime This applied pressure ensures the higher filtration rate and longer runtime, giving the benefit of smaller footprint and lower backwash water consumption when compared against conventional sand and dual-media filters. This reduces operational carbon emissions.

FilterClear can operate at filtration velocities of 25 m/h and more, which is significantly higher than conventional sand filters. This equates to a filter area roughly one third the size of a conventional sand filter, meaning that a FilterClear plant needs fewer, smaller filter vessels, less media materials and occupies less space. This reduces embodied carbon emissions.

The key to successful long-term operation of a filter is an effective backwash. FilterClear uses a four-phase backwash cycle comprising a pre-wash, partial drain-down, air scour and finally a main wash. During the wash phases, clean water is pumped in reverse through the media bed at 60 m/h, expanding all four layers by 30-40%. The air scour, again at 60 m/h, creates a high turbulence condition, helping to dislodge the solids sticking to the surface of the media and remove any biofilm growth, allowing FilterClear to operate successfully with flows containing a high BOD concentration.

There is a wide range of vessel diameters, so the filter package can be better matched to the needs of a specific site, providing a more cost effective solution. Other features of the FilterClear design, such as the design and distribution of filter floor nozzles, contribute to an extremely effective backwash, which uses the minimum amount of water to keep the filter clean.

Total Suspended Solids (TSS) Removal

In order to find a low Totex solution to achieve stringent BOD consents, Anglian Water and @one Alliance piloted several innovative technologies, with effluent quality and operational parameters closely monitored and compared. From these trials, Bluewater Bio's FilterClear has been selected on the Tertiary Solids Removal Framework.

For tertiary solids removal, FilterClear can be used downstream of any settlement tanks. The figure below shows the performance of the FilterClear demonstration plant at Cambridge water recycling centre (WRC), installed on the trickling filter stream, downstream of the humus tanks. The average humus tank effluent TSS was 19 mg/l, and the average FilterClear effluent was 5 mg/l. As can be seen from the graph below, the performance of the FilterClear filter was consistent under various hydraulic loading rates, and the average TSS removal was 74%.

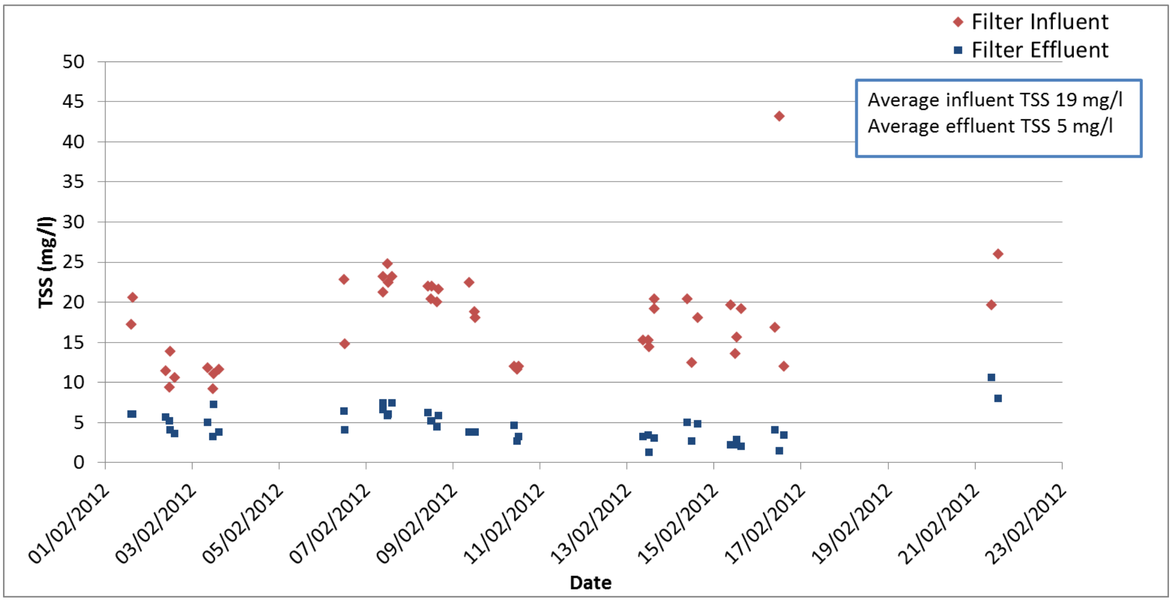

Figure 2: **TSS Removal by FilterClear downstream of the Humus Tank (at filtration rate from 18 to 31 m/h)**

To test how the FilterClear filter would cope with high solid concentration during the trickling filter sloughing season, it was decided to bypass the humus tank, and feed FilterClear plant with the un-settled trickling filter effluent directly. It can be seen from the graph below that, as the influent TSS averaged around 100 mg/l and up to 200 mg.l, the average effluent TSS from the FilterClear filter was 9 mg/l, demonstrating a high removal efficiency and reliable performance under high solids concentration conditions.

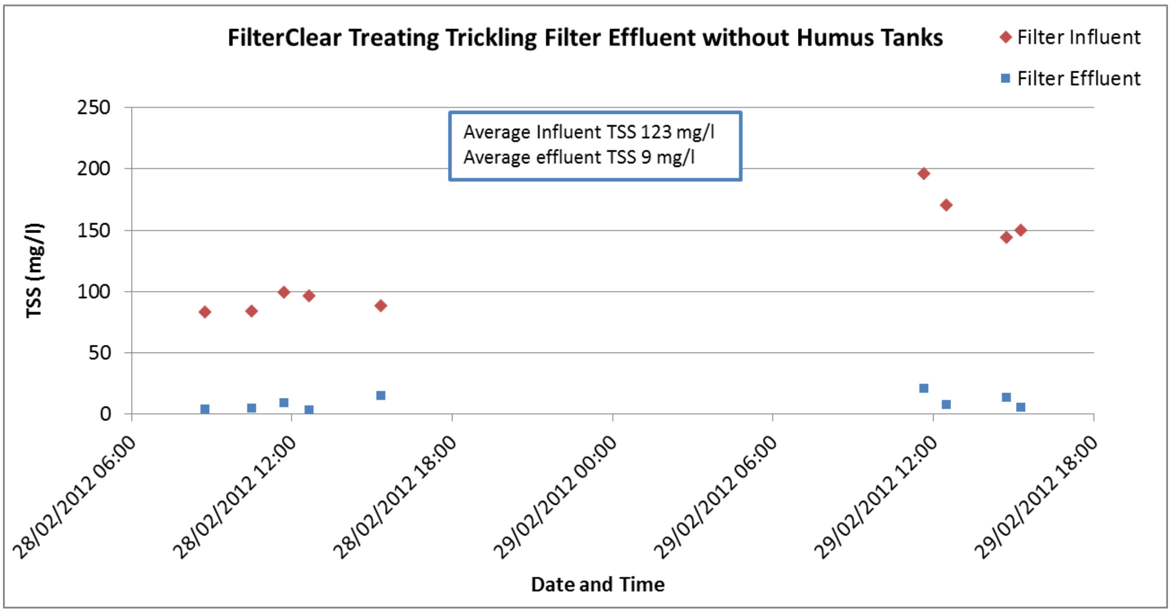

Figure 3: TSS Removal by FilterClear without Humus Tank

It was evident that FilterClear was very effective in handling the rise in TSS concentration. It needs to be pointed out that, when treating the trickling filter effluent without the humus tank, the flow throughput was reduced to give a filtration rate of 12m/h, and the filter backwash was increased to 8 times a day to handle the extra solids retained by the filter media.

The FilterClear demonstration plant was also installed downstream of the activated sludge stream, treating final settlement tank (FST) effluent. The figure below illustrates that, in spite of a wide variation in the influent TSS (between 8 mg/l and 28 mg/l), the FilterClear effluent TSS was always below 7 mg/l, with an average TSS of 3 mg/l. The average TSS removal was 80%. Therefore, it can be concluded that FilterClear gives an even better solids removal when treating effluent from activated sludge process. This better performance was considered to be due to the nature of the solids. In general, solids from activated sludge process are better flocculated than those from trickling filter works.

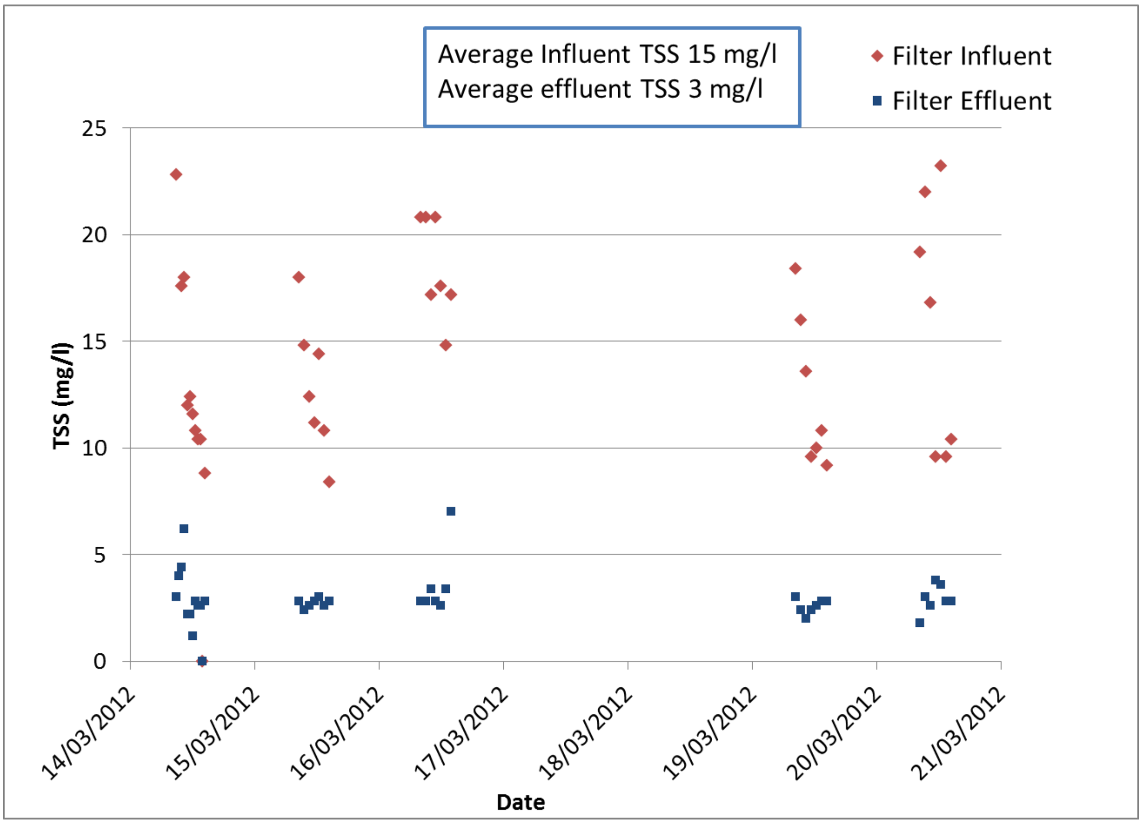

Figure 4: TSS Removal by FilterClear when Treating ASP Effluent (at 31m/h)

FilterClear can reduce the TSS to very low level, comparable to MBR effluent. This is advantageous in achieving other stringent standards required by the WFD. Not only it can be used as the last treatment stage to safeguard compliant, but also it can be used upstream of UV to improve transmissivity and UV efficiency to achieve the reduction of *E.Coli*.

BOD Removal

It is evident that particulate BOD will be removed together with the suspended solids. Data from Anglian Water's assessment of FilterClear indicated an average BOD removal rate of 53%, reducing humus tank effluent BOD from 11 mg/L to 5 mg/L. This will meet most of the stringent BOD consents.

Following the successful trials and an assessment of operability, carbon footprint and WLC, FilterClear was selected on Anglian Water's framework for tertiary solids removal. Three full-scale FilterClear plants were installed in Anglian Water under the flow compliance programme at the end of AMP5. This is to achieve the more stringent BOD consents (see table below) issued by the EA as a result of the increasing dry weather flow (DWF).

Table 1: Previous and new BOD consents

Water Recycling Centre	FFT (L/s)	Previous BOD Consent (mg/L)	New BOD Consent (mg/L)
Alford	26	23	13
Brington	5.2	25	10
Bugbrooke	52	23	14

All three sites are trickling filter sites, consisting of inlet works, primary settlement, trickling filters and humus tanks. Having evaluated several options, Anglian Water and @one Alliance decided that the most cost-effective and robust way to meet the new BOD consent would be to remove particulate BOD by tertiary filtration. FilterClear was selected because of reliable high effluent quality, ease of installation, low WLC and low carbon emissions. The performance can be seen from the graphs below, showing the FilterClear effluent BOD against the new BOD consent for each site.

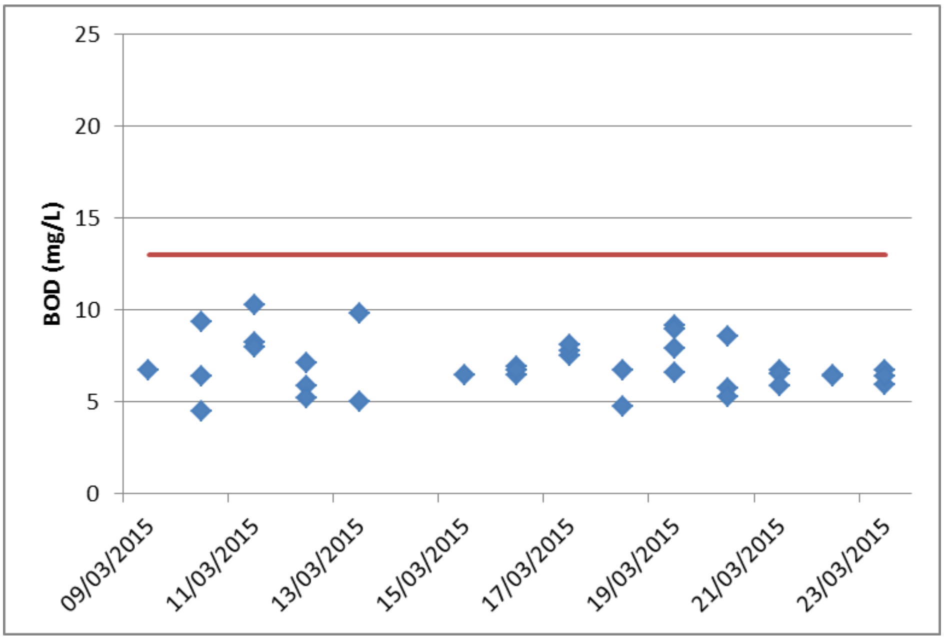

Figure 5: BOD Removal by FilterClear at Alford WRC

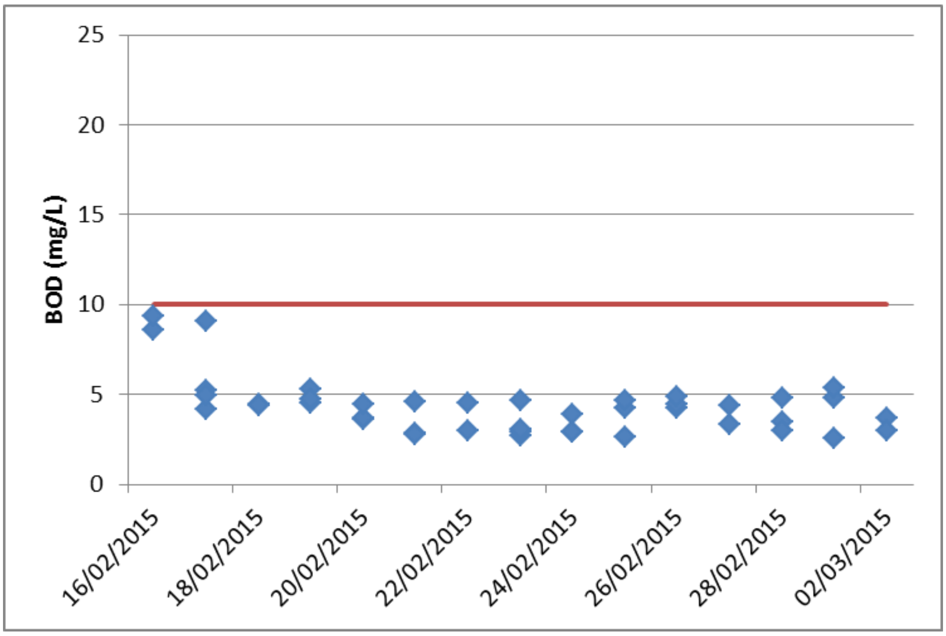

Figure 6: **BOD Removal by FilterClear at Brington WRC**

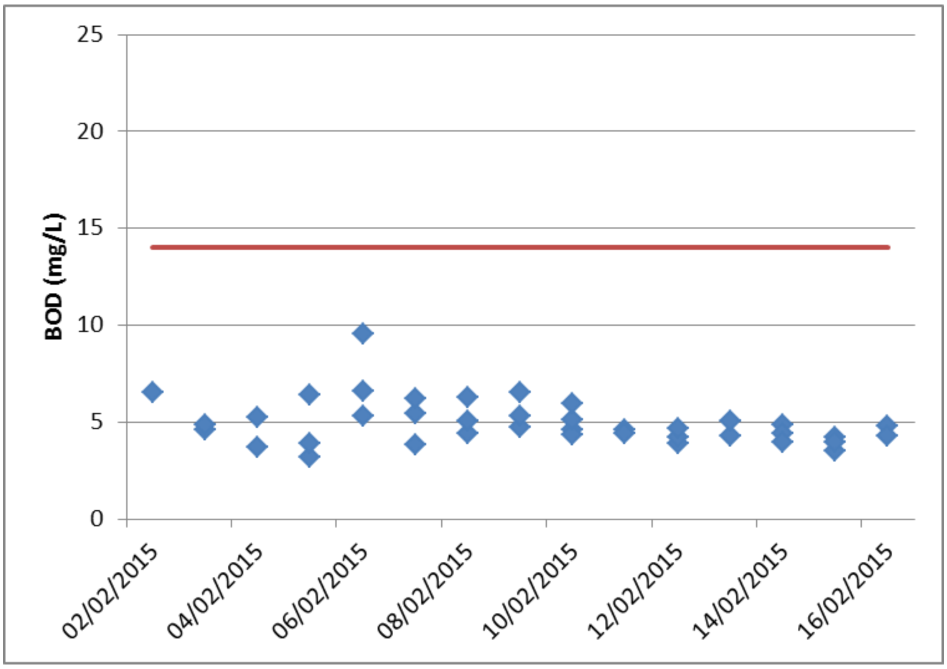

Figure 7: **BOD Removal by FilterClear at Bugbrooke WRC**

These installations demonstrate that FilterClear is an effective solution to achieve stringent BOD standards for both small and large sites. FilterClear plant is so compact that a system treating up to 50 l/s can be mounted on a single skid, which brings considerable savings in terms of project cost and programme, as well as providing operators and maintenance teams with a plant which has been designed, built and tested offsite with their needs in mind.

Total P Removal

Certain degree of TP removal has been demonstrated at the Cambridge WRC. At this site, ferric is dosed upstream of the primary settlement tanks. In the absence of second-point dosing, FilterClear has achieved a further 22% TP removal from the humus tank effluent as a result of removing particulate phosphorus with TSS. This can be very useful at sites when the effluent P is borderline with the consent requirement.

Further TP removal will be achieved by second point ferric dosing immediately upstream of FilterClear. The performance will be evaluated by the ongoing National Chemical Investigation Programme (CIP), managed by the EA and UKWIR (UK Water Industry Research). The objective of the CIP is to investigate the options and feasibility to achieve a TP of less than 0.5 mg/L as required by the WFD, and to understand the cost implications. The outcome of the CIP will inform the water companies' Business Plan for AMP7. FilterClear was selected by Yorkshire Water, and will be installed at Bolsover STW, treating a PE over 10,000.

Particle Size Analysis

Particle size was analysed during a seawater pretreatment trial to characterise the solids present in the filter inlet and effluent, and hence determine which sizes of solids the filter is capable of removing. The analysis was performed at Cranfield University Laboratories. Samples were analysed as swiftly as possible to minimise any changes to the characteristics of each sample.

Particle size analysis (PSA) was performed using a Malvern Mastersizer 2000. This equipment uses laser diffraction to determine the size of particles dispersed in the sample. This measurement gives a percentage volume of the total particles present.

Due to the very low concentration of solids in the samples the accuracy of the results may be compromised (optimum laser obscuration in the mastersizer should be between 10-20%, whereas the samples gave only 0-2%). To improve accuracy of the readings, several measurements were taken at different refractive indexes and the results compared and averaged.

The PSA shows that the particle sizes of the influent were between 2.0 to 240 µm, with most of particles around 80 µm. The particle size of the FilterClear effluent were between 0.14 to 1.1 µm, with most of particles around 0.5 µm. This removal was achieved without any chemical dosing.

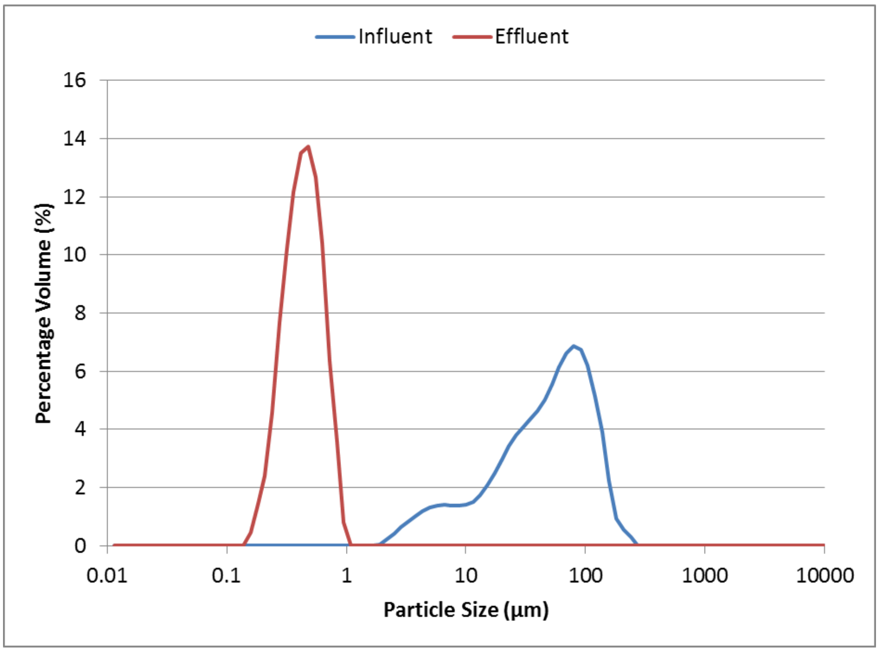

Figure 8: FilterClear influent and effluent particle size distribution

The results demonstrate that all particles greater than 1.1µm were effectively removed in the filter. Since particles with sizes below 2µm in the influent sample accounted for negligible amount (volume) of the total solids present in the effluent sample, the results suggest high suspended solids removal by the FilterClear without chemical dosing.

Pressure Profile and Backwash

FilterClear backwash can be controlled either on pressure or on timer. During the FilterClear trial, backwash was initiated when the inlet pressure reached 1.8 bar, as shown in the graph below. It can be seen that the runtime varied between 15 to 20 hours at a filtration rate of 25 m/h.

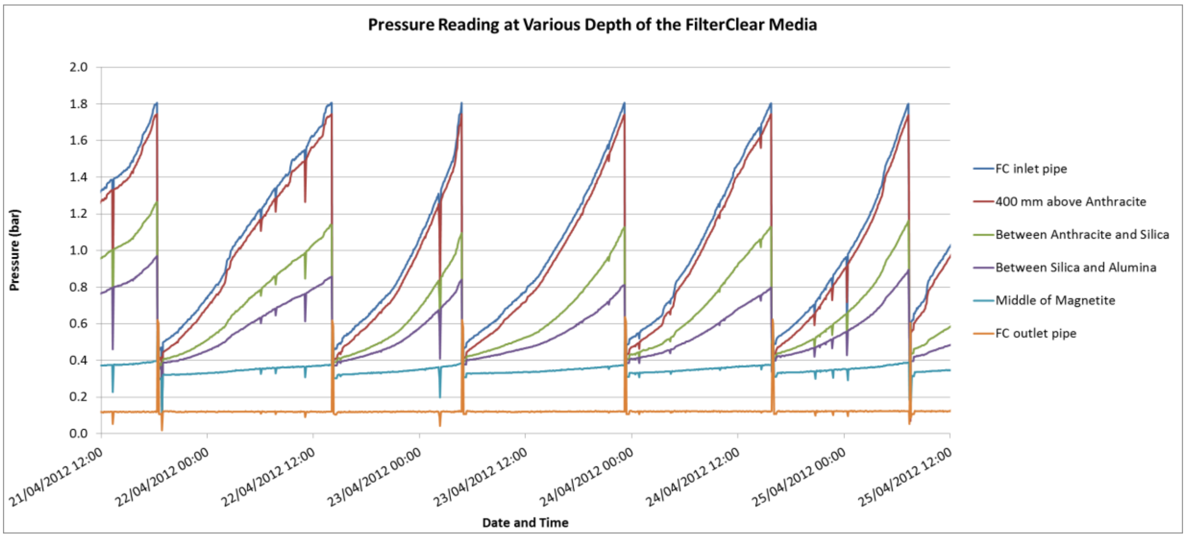

Figure 9: Pressure profile with pressure initiated backwash

The backwash was carried out at 55 m/h for 10 minutes. The backwash water consumption was between 1.8% to 2.4% of the treated flow.

For full-scale installations, timer controlled backwash is sometimes preferred by the operators, as this can be set to coincide with the daily low flow period, hence operation is least affected by taking one filter out of service for backwashing. The figure below shows the time controlled backwash at Brington. There are two filters on site, each one was backwashed once a day. As the flow rate was variable rather than fixed (as in the trial above), the inlet pressure between backwashes changed accordingly.

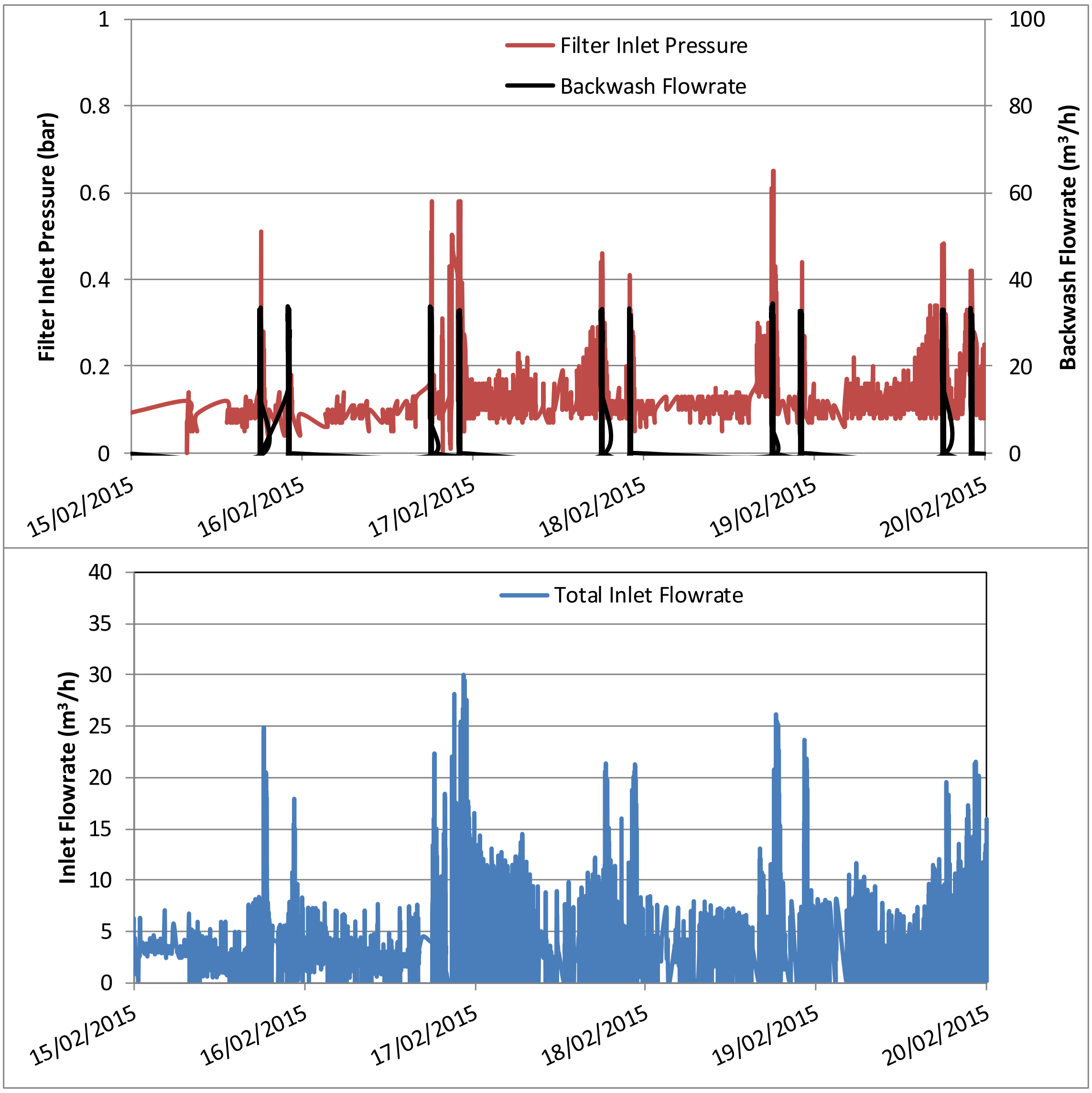

Figure 10: Flow and pressure profile with timer controlled backwash

In practice, the operating cost can be optimised by backwashing the filters on elapsed time to minimise the average operating pressure.

Power Consumption

The static head of a FilterClear filter is very low because the filter vessel and pipework are totally enclosed. The headloss through a FilterClear plant is effectively used to force the flow through the multi-media at a high filtration rate and produce good quality effluent, whereas the headloss of a typical Continuous Backwashing Filter (CBF) is normally wasted via static loss at the sand filter high-level discharge point. In addition, the air compressors of CBF, which continuously lift and wash the sand media add a significant amount of the power consumption. It is estimated that FilterClear only consumes 40% of the energy compared to a CBF.

As FilterClear plants are generally sized to treat FFT, the differential pressure across the filter vessel is significantly reduced at average flow conditions, especially at low flow periods during the diurnal cycle. The electricity consumption is reduced accordingly. The typical energy consumption of FilterClear varies from 0.04 kWh/m^3 to 0.05 kWh/m^3. This makes FilterClear a low opex and low operational carbon solution.

Offsite Manufacturing and Package Plant Delivery

FilterClear is well-suited to off-site construction as a skid-mounted package plant. Off-site assembly and testing of a filtration system allows significant savings to be made in both time and cost of a project. A FilterClear skid can be delivered, installed and connected within a week, and commissioning is reliably quick because the package is pre-tested in the factory.

Offsite assembly and testing reduces project risks, and risk has an associated cost. Programme risks are reduced because FilterClear is delivered as a single package, meaning that construction progress is less dependent upon the weather and on the coordination of different contractors. Health and safety risks are reduced because the complex work to assemble the package plant takes place in a dry, well-lit factory environment. The quality of the finished product is also assured for the same reasons.

Another benefit of this package plant approach is that it offers mobility, making it suitable for emergency response and on-site troubleshooting.

Conclusions

The Water Framework Directive has brought new challenges for increasingly stringent standards. Although the timeline has been shifting, the regulatory pressure remains. In addition, the scope has been expanded to cover all waters, meaning more treatment plants will be affected. It is therefore crucial for the water industry to have future-proof technical solutions that are flexible, robust and with low Totex. Bluewater Bio’s FilterClear has been proven to be fit for purpose to satisfy such demands.

FilterClear brings together proven principles of filtration within a compact package, ideally suited to upgrading existing treatment plants. The filtration rate above 25m/h is much higher than conventional sand filters, therefore it has a smaller footprint with minimum visual intrusion. The filter runtime is typically 1 day, and backwash water consumption is typically below 3% of the treated flow.

Most importantly, with over 75% TSS removal and over 50% BOD removal, FilterClear produces a superior effluent quality, almost comparable with MBR.

The effluent quality was proved to be steady under various hydraulic loading rates (9 – 31 m/h) and influent solids concentrations. FilterClear is also capable of handling high solids concentration up to 200 mg/l, which will meet the requirements during the trickling filter sloughing period.

Offsite assembly and testing methods result in low overall project costs and quick installation, also making it suitable for emergency response and troubleshooting. By moving away from conventional rapid gravity filters, water companies and industrial users can benefit from a reliably good quality of filtered water and low whole life costs.

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References

Department for Environment Food & Rural Affairs (2014) Water Framework Directive implementation in England and Wales: new and updated standards to protect the water environment.

Environment Directorate-General, European Commission (2015) Introduction to the new EU Water Framework Directive [http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm accessed on 29/9/2015]

Metcalf & Eddy, (2004) *Wastewater Engineering Treatment and Reuse.* McGraw-Hill, New York.

Tchobanoglous, G. and Eliassen, R. (1970) Filtration of Treated Sewage Effluent. *Journal Sanitary Engineering Division, ASCE,* 96 (SA2), 243