Brightwork

How to cope with stricter effluent criteria

UK experiences with continuously moving bed aerated bioreactors

How to cope with stricter effluent criteria

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Abstract

Within the UK a large number of sewage treatment works will have to be upgraded, to meet more stringent criteria. Special attention will have to be paid to suspended solids, ammonia and BOD. The use of an aerated tertiary moving bed reactor as a add-on polishing step tends to be a good and reliable option: BOD and suspended solids are removed by physical sand filtration, while ammonia is converted biologically by nitrifying biomass, present on the sand grains.

Performance data of Moving Bed aerated filters (ATSF) are given, illustrating stable process conditions, reaching (new) consent levels. Attention has been paid to the specific nitrification characteristics within the reactor, conversion rates, biofilm development and handling of shock loadings, all based upon operating plants, which have been constructed in the UK in the last four years. The results indicate the reliability of this process operation unit for tertiary treatment of municipal waste water.

Introduction

Within the UK a large number of sewage treatment works will have to be upgraded, to meet more stringent criteria, which are implemented in England and Wales through Acts and Regulations. Within the UWWT, freshwater fish and bathing water directives improvements to the receiving water quality are required with respect to nutrients. The final focus will be the extensive removal of total nitrogen and phosphorus. In this paper the focus will be to highlight experiences with tertiary aerated continuous filtration to cope with more stringen criteria for TSS, BOD and ammonia-N.

To improve the overall plant performance a number of sites have been equipped with continuously moving bed aerated bioreactors. Performance data, both with respect to normal operations and shock loadings, and biofilm characteristics are highlighted.

Typical STW set-up: present situation

A typical STW for smaller capacities (say less than 5,000 pe) consists of:

- inlet screening (typically 6 mm)
- primary settling
- biological filter (either plastic media or stone filters)
- humus tank
- sludge holding tank and pumps
- storm tank
- final effluent recirculation (for wetting the biological filter)

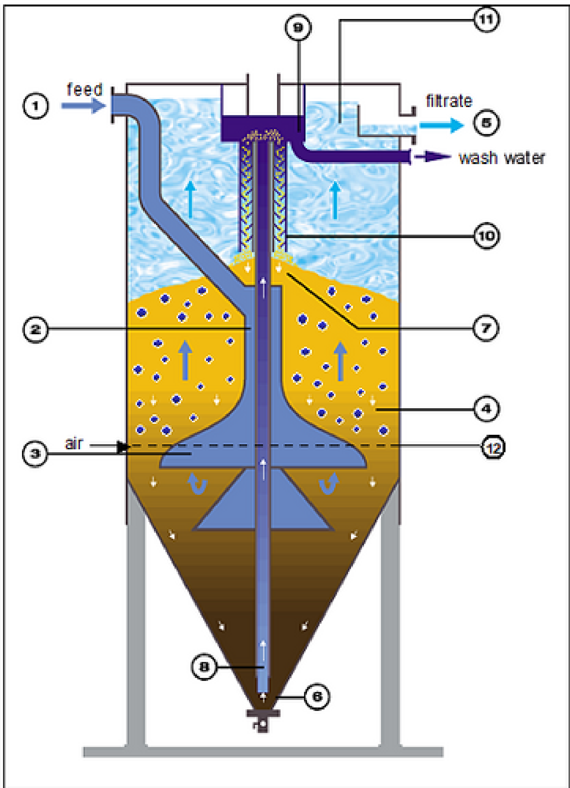
Typical consent levels to meet (on a 95%ile basis) at present are summarized in table 1. Expected future consent level ranges for sensitive areas (under the regulations of one of the Directives) are indicated in the table as well. Some WwTWs already have to meet these stricter criteria.

Table 1 Typical consent levels and possible future level ranges for effluent discharge (95%ile basis)

Parameter		Present consent	Future consent indicative
TSS	mg/l	30 - 40	10 - 20
BOD	mg/l	20 - 30	8 - 15
NH_4^+-N	mg/l	10 - 15	2 - 5
Total-P	mg/l		0,25 – 1,0

Potential upgrading of the existing works tends to focus upon improvement of storm water tank storage to avoid hydraulic overloading, implementation of automatic desludging strategies (to prevent instantaneous release of ammonia), operational improvements on the biofilters and/or dosing of flocculants (to improve settleability and removal of phosphorus).

These actions appear to be successful to a certain extent, but will not be able to cope with the lower required concentrations for ammonia and BOD. Therefore water utilities are looking for tertiary processes, which can be added to the works without any interference with the present operations. A particularly useful process for this purpose appeared to be the tertiary continuously moving bed aerated biofilter (abbr. ATSF). A description of the biofilter operation is indicated in figure 1.



In the moving-bed filter, the water to be treated enters the device via feed pipe (1), supply pipe (2), and distributor (3). It flows in an upward direction through the sand bed (4) in a cylindrical vessel. The filtrate is discharged in the upper part of the filter (5).

The filter bed is continuously moving downward. In the bottom of the filter dirty sand (6) is abstracted from the sand bed and washed, after which it is released back on the top of the sand bed (7). The sand circulation is based on the airlift principle, forcing a mixture of dirty sand and water upward through a central pipeline (8).

The intensive scouring movements separate the impurities from the sand particles. At the top of the pipeline the air is released and the dirty water is discharged (9).

The sand settles in the washer (10) with its well-designed hydraulic features. The grains fall through the washer, where they are finally washed by a small amount of clean filtrate, flowing through the washer countercurrently. That flow is generated by a difference in discharge levels between the filtrate (11) and the wash water (9).

Air is fed into the filter using an air grid introducing small air bubbles into the filter. The oxygen is used by the biomass to convert ammonia into nitrates. The biomass will grow on top of the sand grains while excess biomass will be washed off due to the sand washing.

Figure 1 ATSF bioreactor operational featurest

ATSF moving bed bioreactor performance

In order to deal with the criteria set in table 1 a tertiary bioreactor preferably combines nitrification, BOD removal and retention of suspended solids. Therefore the unit operation should be a combination of a biological process and a physical solids filtering process. A process which combines the advantages of a fixed bed reactor and a suspended carriers reactor is the moving bed aerated biofilter, of which the typical operational features are highlighted in figure 1. The specific characteristics will be highlighted in more detail below.

Based upon a number of operational plants performance data have been gathered for ammonia, BOD and suspended solids. The data indicated below show typical feed and filtrate concentrations during normal operations.

Ammonia

In figure 2 ammonia data are given for municipal waste water treatment works (WwTW) effluent, which is treated by an ATSF moving bed reactor.

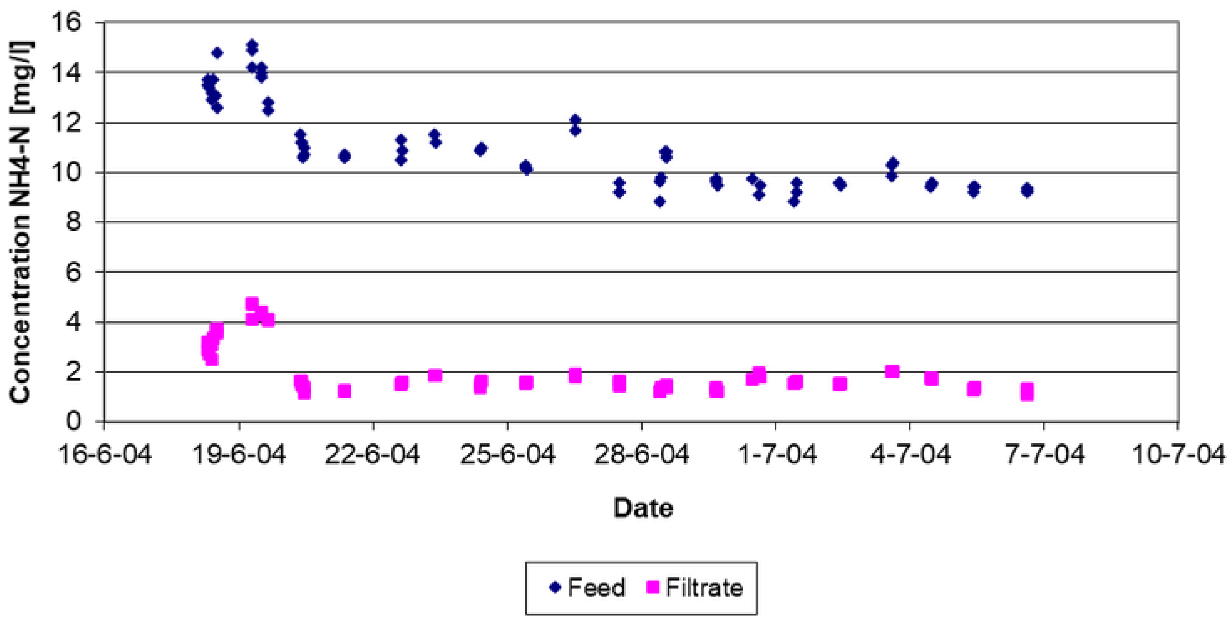


Figure 2 Ammonia spot sample data: ATSF feed and filtrate.

Conversion rates, related to the data in figure 2, are in the range of 0.7-0.9 kg N/(m3.d). Filtrate levels of 2 mg/l ammonia-N are achieved consistently at conversion rates up to 0.8 kg N/(m3.d). Taking into account low water temperatures (down to 5 °C) and tight BOD effluent criteria typical design rates are 0.5-0.7 kg N/(m3.d).

BOD

In figure 3 BOD data are given for WwTW effluent, illustrating a fair removal rate. However in the lower range of BOD feed data the particulate (colloidal) fraction becomes higher; as this fraction is difficult to trap in the pores of the sand bed the removal rate for this part of BOD is expected to be low. As a result residual filtrate BOD tends to be in the range of 2-8 mg/l.

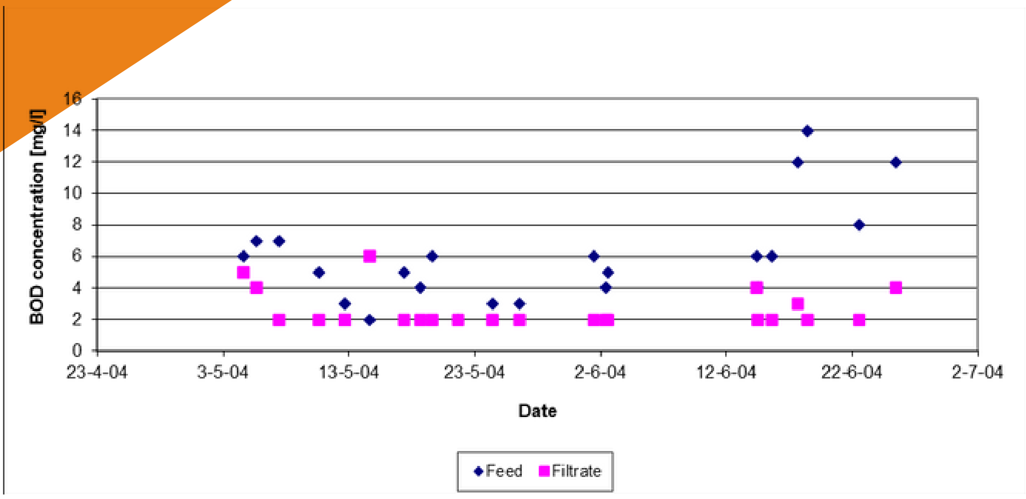


Figure 3 BOD spot sample data: ATSF feed and filtrate.

TSS

In figure 4 suspended solids removal efficiencies are summarized for two WwTW ATSF moving bed plants in the UK. Each line in figure 4 is composed of approximately 40 spot samples, which have been grouped in total suspended solids (TSS) ranges. The graph clearly indicates that the removal efficiency for TSS is correlated to ATSF feed TSS. The lower feed TSS, the lower the removal efficiency.

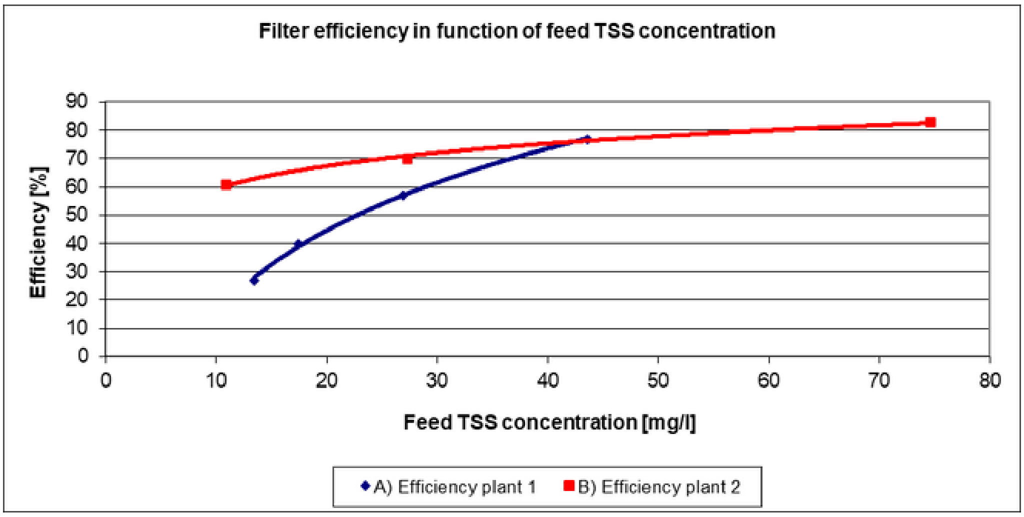


Figure 4 Suspended solids spot sample data: ATSF feed and filtrate.

The figure also points out the positive effect of controlling the sand circulation rate in function of the actual loading rate: the upper line represents a sand circulation controlled system, while the lower line represents an uncontrolled filter system. If strict effluent criteria are to be met for TSS (and BOD), the control system appears to be a valuable tool to improve overall performance.

Ammonia removal mechanisms

Generally biomass may be maintained within the biofilter, either by accumulation in between the pores of the sand grains or by attachment to the grains (biofilm development). In the ATSF moving bed reactor plug flow conditions will prevail, and therefore specific process conditions will vary over the depth of the reactor. This aspect has been studied in detail below.

Water quality profiles

The specific feature of an ATSF moving bed reactor is the continuous turn over and washing of the sand within the reactor. Sand turn over rates are in the range of 5 – 15 mm/minute, which means that each sand grain will pass the reactor every 2 - 13 hours (assuming a bed height of 2 - 4 m). With a doubling time of the nitrifiers in the range of 5 – 10 days it may become evident that biofilm development should be the most dominant driver for survival of the nitrifiers, due to their low growth rate. Only the excess biomass will be washed out together with the solids trapped in the pores of the sand bed.

These features are confirmed by a set of reactor depth profiles. In figure 5 an ammonia profile is given for three operating ATSF moving bed plants, with bed heights varying from 2 – 3 m.

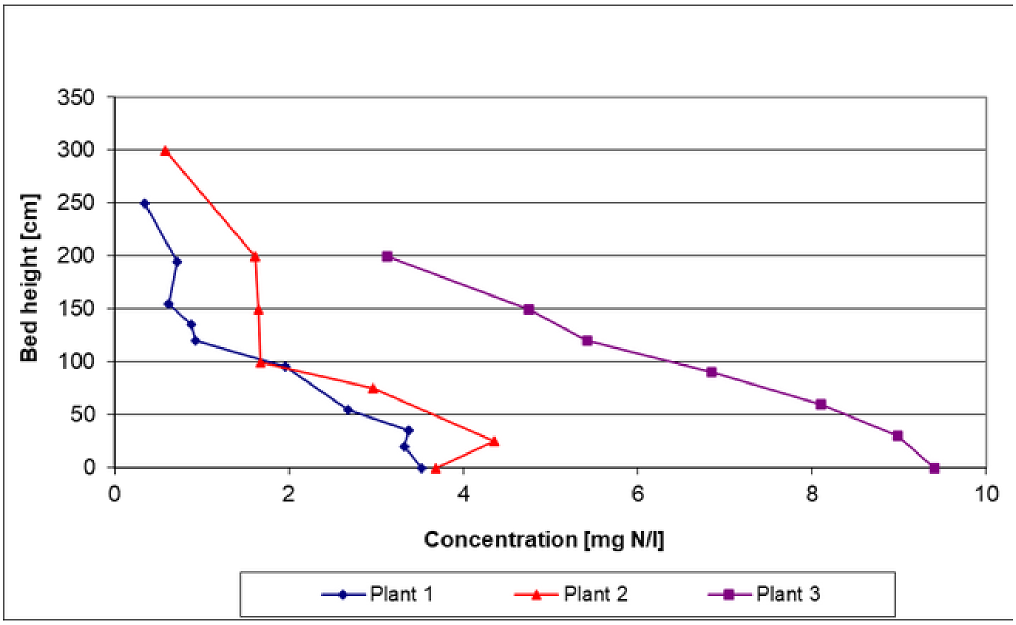


Figure 5 Ammonia profiles

From these data it may be concluded that:

- Nitrifying activity is present over the full reactor depth, and is not limited to the lower part; as only the lower part of the reactor contains biomass and suspended solids in the interstitial spaces, the presence of an active biofilm on the grains is most likely.
- Actual ammonia levels within the reactor dropping below 2 mg/l N is hindering the conversion; it is however emphasized that with sufficient biomass present within the reactor ammonia levels down to detection limits are reached with consequential lower actual conversion rates.
- The nitrifying activity appears to be somewhat lower in the lowest part of the reactor (0 – 0.3 m) if compared to the section on top of that layer; this is possibly caused by the presence of suspended solids in the lower section, preventing oxygen to be transferred to the biomass most optimally.

Biomass profile and conversion rates

With a set of sand samples over the depth of the reactor conversion rates (line a and line b, in kg N/(m3.d)), biomass concentrations (in mg VLSS/kg sand) and ammonia concentrations have been determined and expressed in figure 6.

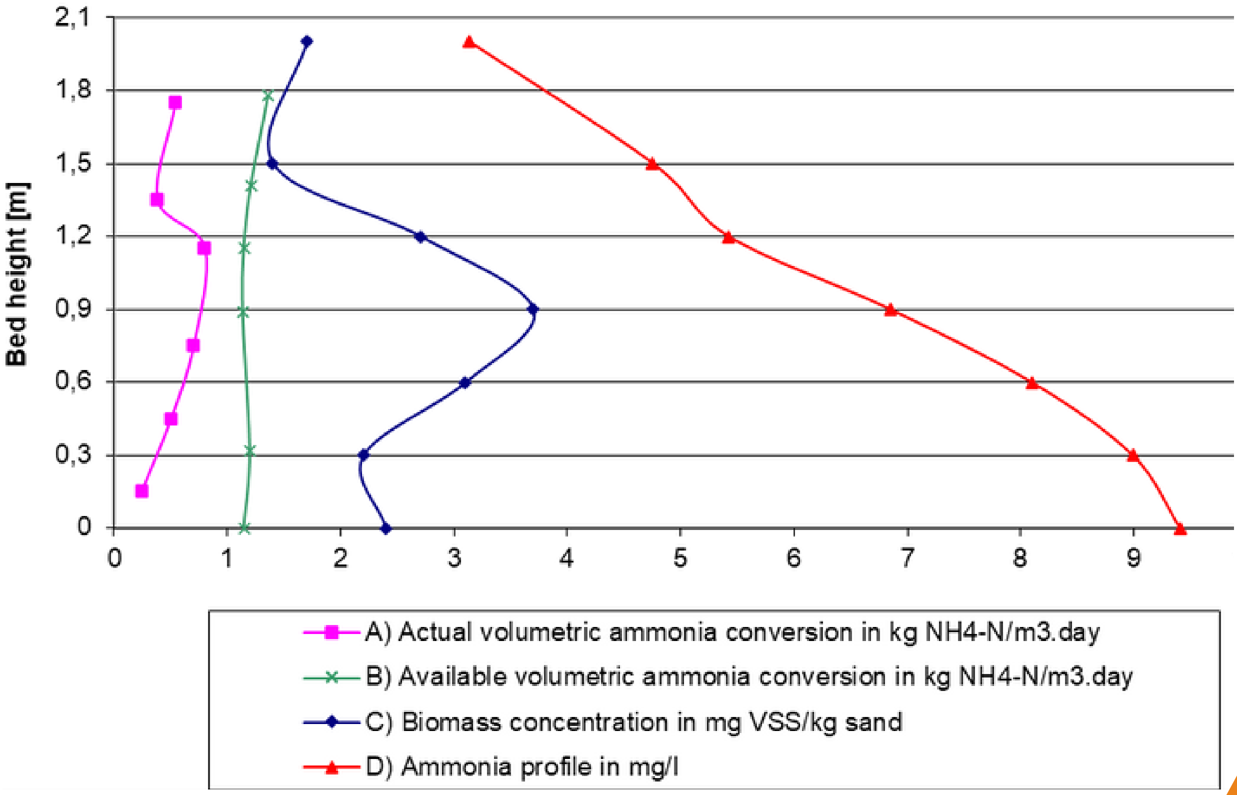


Figure 6 Ammonia conversion, biomass and ammonia concentration in depth.

The sand samples have been used to determine the ammonia conversion rates, using two separate methods. On one hand under ideal (laboratory) conditions, without ammonia and oxygen limitations and absence of suspended solids on the grains (line a). On the other hand under actual operating conditions, calculated by using the actual ammonia removal per layer of reactor (line b).

The results indicate the lower rates at actual operating conditions, which is most likely to be caused by the indicated limiting factors and hydrodynamic conditions within the reactor.
The laboratory results (line b) show a fairly constant activity rate and no distinct relation with reactor depth. As a result a more or less constant amount of biomass present on the sand grains would be expected. The constant biomass concentration has been confirmed by other datasets for similar ATSF moving bed reactors.
The measured biomass concentration (line c), calculated by using N-Kj measurements, shows a variation of biomass concentration over the reactor depth. These results should be considered as indicative, but nevertheless clearly indicates the presence of biological activity even on the freshly washed sand at the top of the reactor.

As a result it may be concluded that the total reactor height will contribute to the nitrifying process, if necessary, and shock loadings tend to be handled smoothly.

Biofilm and media characteristics

The ATSF moving bed process incorporates a continuous sand washing which is in operation together with the filter operation. Due to the continuous sand circulation any dead zones within the filter are absent, and the chance of blockage within the filter because of accumulation of solids during the filtration process is negligible. Therefore relatively small grain sizes may be applied, which will lead to a bigger surface area for biomass growth, if compared to other types of tertiary bioreactors.

Another feature of the process which is directly linked to the continuous sand circulation, is the capability of adapting the sand circulation rate by the amount of compressed air supplied to the airlift. This leaves the process to be further optimised and adapted to varying process conditions. This control strategy has been developed and highlighted in more detail in ref [2] and has been successfully used at the existing references.

In the ATSF moving bed reactor sand is used as the biomass carrier, as this is inert, relatively heavy and cheap. Typical sand grain sizes applied are 1.2 – 2.4 mm with UC < 1.5. As a result an enormous surface area is available for biomass growth: typically in the range of 2,000 – 3,000 m2/m3. In comparison with other biofilter systems (e.g. Biocarbon, Biopur, Biostyr) the equivalent surface area is 2-10 times larger.
Based upon the biomass concentration data given in figure 6, we calculated a uniform biofilm layer of 20 – 50 μm, assuming spherical grains. It should be emphasized however that actual layers will not be homogeneously covering the grain.
An average biomass concentration of 4 kg/m3 reactor volume is derived; assuming a conversion of 0.5 kg N/(m3.d) the equivalent specific biomass loading is calculated to be 0.12 kg N/(kg VLSS.d).

Shock loadings

Sudden changes in ATSF feed water quality will affect a biological process and its process stability needs to be evaluated in that context, in order to avoid any plant failures.
Figure 7 demonstrates ATSF reactor performance in case of a shock loading. From 10.00 h until 12.00 h the ATSF ammonia feed concentration gradually increases from about 1 upto 10 mg/l N. At 12.00 h feed flow decreased from 35 to 22 m3/h; overall a sixfold increase of ammonia loading is generated. The hydraulic residence time coinciding with the hydraulic load of 35 m3/h is only 13 minutes.
During the shock loading ATSF filtrate ammonia levels only slightly increased, illustrating the reliability of the system for handling sudden changes in ammonia concentrations.

The reason why shock loadings tends to be easily dealt with in a moving bed ATSF is related to the presence of biomass over the full reactor depth, which is a specific feature of this process. As long as the maximum loading has not been reached ammonia will be removed in the lower reactor layers (reference is made to the ammonia profiles for plant 1 and 2 as expressed in figure 5). In the upper layers of the plug flow reactor however biomass will be present in the biofilms on the grains. This biomass will start its contribution to convert ammonia once the ammonia concentration in the passing water increases which happens automatically as a result of the downward movement of the media. This process will keep the biofilm in an active state; as soon as a sudden rise in the feed ammonia level will occur the upper layers will act as a buffer in order to remove the excess ammonia. It may be clear that this buffering capability is limited; however the example clearly indicates that even in case of a multiple ammonia increase the system is capable of smoothing out the peak to a very large extent.

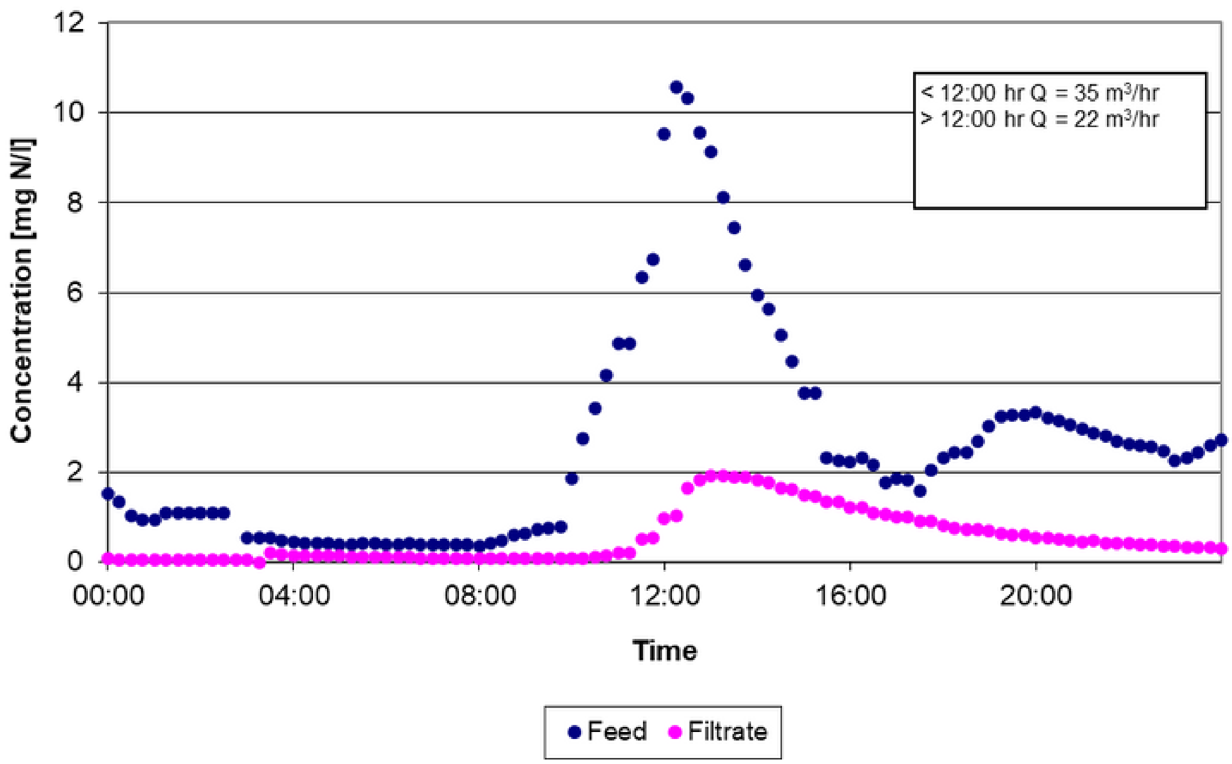


Figure 7 Process response to ammonia shock loadings

As well as the systems capability of handling shock loadings also low loading process conditions are not jeopardizing the process stability to a large extent. At low ammonia loading rates the biomass is confronted temporarily with some ammonia during every cycle of the sand in the lower layers of the reactor. This appears to be sufficient to maintain active nitrifying biomass.

Conclusions

The ATSF moving bed reactor has shown to be a reliable process unit to reach low ammonia, BOD and suspended solids levels, which are required at several municipal waste water treatment works under the European Directives. The combination of a physical filtration and biological conversion tends to be favourable to reach stable 95%ile TSS/BOD/ammonia-N levels in mg/l of 15/12/2 or even lower. The control of the sand circulation rate as a function of the actual loading rate appeared to be an effective tool to optimize the overall reactor performance.

A thin biofilm on top of the sand grains is developed within the ATSF moving bed reactor, which is present over the full reactor depth. This enables a stable nitrifying population to be maintained in the reactor under varying process conditions. Shock loadings will therefore be handled effectively. Furthermore the continuous sand circulation allows the biomass to nitrify even under low loading conditions, as the biomass will move at the same rate as the sand and will pass the lower layers - at which the feed water, containing ammonia is fed into the reactor - on a frequent basis.

If ammonia levels consistently below 2 mg/l N should be focussed upon, it is concluded that at these levels the conversion process is hindered, and therefore the design loading rate should be reduced to allow for this. However ammonia consent levels < 2 mg/l N have not been reported in the UK.

The described reactor type shows to be reliable for aerated biological processes after several years of operational experience. Furthermore maintenance and operation attendance is low, which makes it particularly suitable for smaller works, which tend to be unattended.

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