Enhanced Nutrient Removal Using a Continuous Backwash Filter for Secondary Effluent Denitrification

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ABSTRACT:
As effluent discharge permit limits become more stringent, utilities are constantly searching for efficient and cost-effective methods to meet these tighter restrictions. One effluent parameter that is drawing increased scrutiny is nitrogen, usually measured as either nitrate-nitrogen (NO_3-N) or total nitrogen (TN). Many different technological strategies have been developed that attempt to address this growing concern. This paper illustrates the refinement of an established wastewater process to accomplish biological nitrogen removal, describing the design, pilot testing and start-up of a full scale, continuous backwash denitrifying filter which utilizes an innovative process control system to regulate the sand circulation rate to maintain an optimum biomass concentration within the media.

THE PROCESS:
Continuous backwash filters (CBF) have been successfully employed for many years to remove solids from secondary effluent. Figure 1 shows the typical operation of a CBF. Secondary effluent is transported into the filter by means of an Influent Pipe (1). The water enters the Filter Bed (4) through the Feed Pipe (2) and the Distributors (3). The dirty water flows in an upward direction where solid particles are trapped within the sand filter media and purified filtrate (10) is discharged from the top of the filter through the Effluent Pipe (5). The filter bed is continuously moving downward as the water flows up. Sand circulation is accomplished using an airlift to force the dirty media (6) from the bottom of the bed upward through a central airlift pipeline (7). The Sand Washer (9) is positioned around the top of the airlift pipe. The sand particles fall through the washer and the intense scouring action within the airlift wash-box separates most of the contaminating biomass from the sand filter media, discharging dirty water from the top of the filter (8) and depositing washed, clean sand back to the top of the media bed.

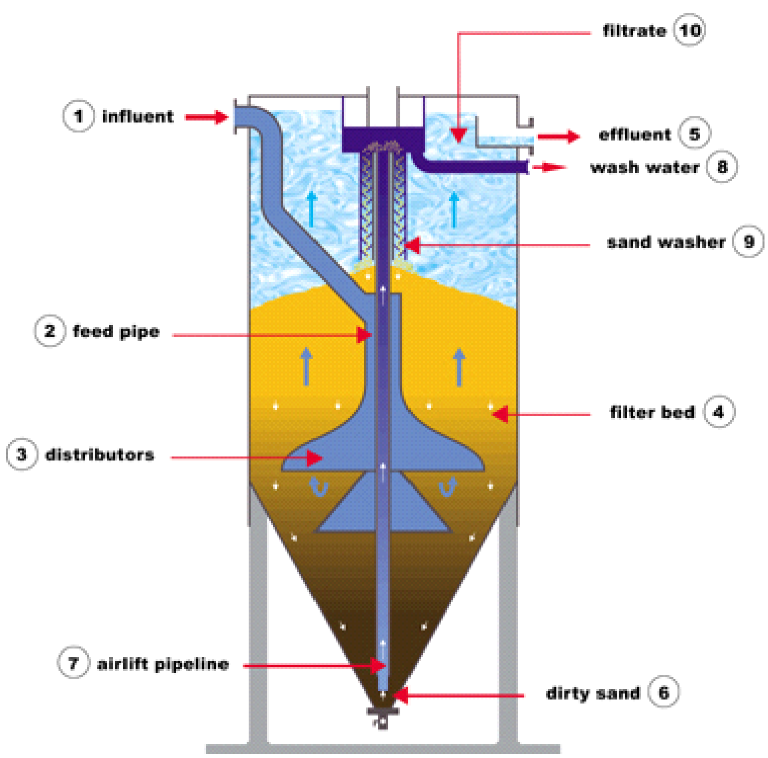


Figure 1: Operation of the ASTRASAND Filter

DENITRIFICATION:
The basic configuration and operation of a CBF can be utilized as a bioreactor to achieve biological denitrification. Within the filter bed anoxic conditions prevail, enabling the denitrifying biomass to grow on the surface of the sand grains and in the pores of the bed. The sand filter media acts to support heterotrophic bacteria which use an external carbon source

(typically methanol) injected into the influent stream to convert nitrate into nitrogen gas. In this so-called "moving bed biofilter" (MBBF) the sand is continuously washed and the excess biomass produced by this biological reaction is continuously removed. The airlift rate for media washing must be carefully controlled to insure optimum biomass retention, especially under fluctuating hydraulic and nitrate loading conditions. Media washing at too aggressive a rate may reduce the effective bacterial population within the bed and may result in inefficient biological activity and nitrate breakthrough.

THE DESIGN:

The discharge permit for the 27.5 MGD De Groote Lucht wastewater treatment plant in the Netherlands was modified to include a total nitrogen limit of 10 mg/L as an annual average. The basic plant treatment scheme consisted of headworks screening and primary clarifiers, followed by two stage aerobic treatment for BOD and ammonia removal. In order to meet the more stringent discharge limits for nitrogen, both an expansion/upgrade of

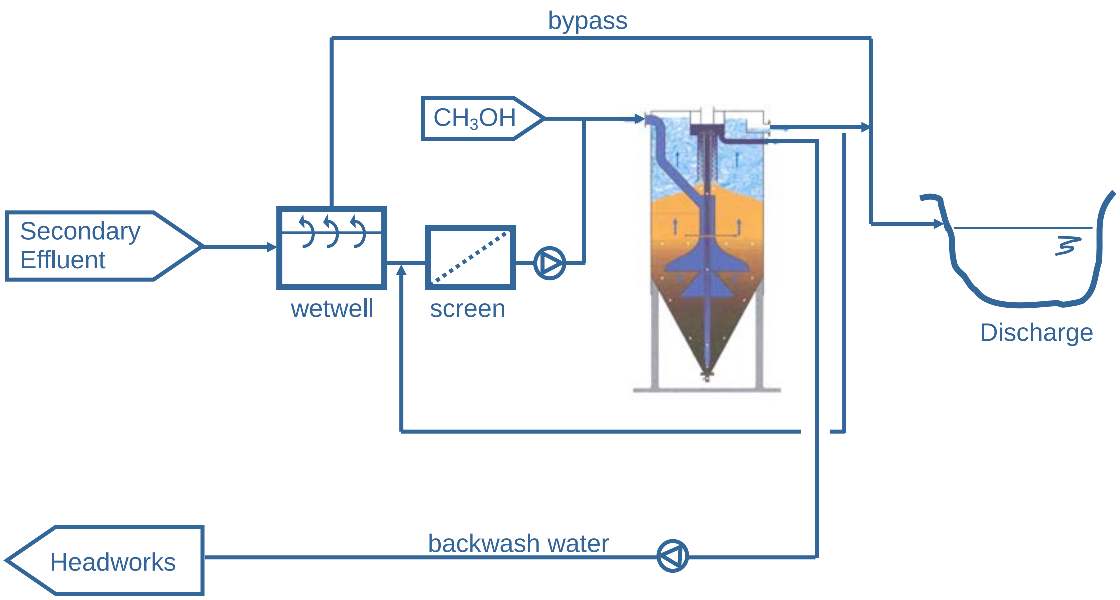


Figure 2: Tertiary Treatment Scheme

the original process and an addition of tertiary post-denitrification treatment were considered. Tertiary filtration was selected over plant process expansion based on a restricted footprint, easier planning and construction as there was no interference with the existing plant process during construction, and the lower capital investment and operating costs. An ASTRASAND MBBF was installed as a post-denitrification stage in order to meet these new effluent limits.

As the discharge limits are related to annual average N-levels, it is not necessary to treat the full wet weather flow of 27.5 MGD. As can be seen in the flow schematic in Figure 2, flows exceeding the maximum design flow bypass the filter and are discharged directly to the receiving stream. The required hydraulic capacity of the filters was determined to be 15,850 gpm, with a specific hydraulic load of 6.1 gpm/ft^2 based on an expected denitrification efficiency of 88%. Design data for the filter is outlined in Table 1. The installation consists of six concrete filter units, each with 430 ft^2 of filter area. The effective bed height for filtration 12 ft, resulting in a bioreactor volume of about 32,000ft^3.

Table 1: Filter Design Data

Parameter	Value
Hydraulic Load (gpm)	15,850
Dosing Rate (gpm/ft^2)	6.1
Filter Area (ft^2)	2,580
Bed Height (ft)	12
Bed Volume (ft^3)	32,203
NO_3-N Load (lbs/day)	3,500

The process was designed to achieve an effluent nitrate nitrogen concentration of less than 10 mg/L and a removal efficiency of greater than 88%, as well as effluent suspended solids concentrations less than 10 mg/L and a COD increase, due to over feeding methanol, no greater than 20 mg/l.

PROCESS CONTROL:

Due to the normal differential pressure between the bed headloss and the airlift, an increased hydraulic load automatically results in higher sand circulation (backwash) rates without adjusting the compressed air flow to the airlift. Therefore, the sand circulation rate can be considered to a large extent to be self-regulating. However, in some cases, such as applications with broad variations in process conditions or one with strict effluent limits, it may be useful to amplify this self regulating function by employing automated control of the air flow to the airlift.

Wide fluctuations in hydraulic loads are often experienced at this plant. In order to achieve optimum filter performance and avoid nitrate breakthrough, a process control system has been developed to maintain high biological activity within the filter at varying loading conditions. The key element of this control system is the automatic adjustment of the sand recirculation rate (or backwash rate) based on the desired biomass content in the filter bed. The volume of solids and/or biomass present in the bed is directly related to the headloss over the filter bed. The principle of this strategy is to maintain a sufficient amount of denitrifying biomass, measured principally by headloss, in order to anticipate increasing nitrate loads during the day. By continuous measurement of headloss and other important process parameters such as feed flow and water temperature, the compressed air flow to the airlift is regulated by means of calibrated process algorithms within a local PLC.

During the pilot phase of operation, various automation strategies were tested in order to determine the relative contribution of denitrifying biomass to the measured headloss in terms of denitrification efficiency. The data in Table 2 demonstrates the results of the effort to optimize the control methodology.

Table 2: Optimizing Backwash Control Strategy

Period	Feed NO_3-N (mg/L)	Filtrate NO_3-N (mg/L)	Efficiency (%)	Filter Control
1	23.1	2.98	87.1	No Control
2	26.5	1.80	93.2	Moderate
3	20.3	0.52	97.4	Enhanced
4	30.1	0.60	98.0	Optimized

The prevention of nitrate breakthrough during periods of fluctuating hydraulic loads by automated control of the sand recirculation or backwash rate is demonstrated in Figures 3 and 4 showing denitrification performance under two different control strategies. The data in Figure 3 demonstrates the denitrification performance with no automated airlift control, simply allowing the self-regulating mechanism described above to take place. As can be seen, there are significant periods of excessive nitrate breakthrough due to the insufficient volume of biomass within the bed and the resultant inability to respond to fluctuating loads. When the control algorithms are utilized to automatically adjust the backwash rate to maintain an optimal amount of denitrifying biomass, nitrate breakthrough was eliminated, as demonstrated in Figure 4. This indicates the filter's ability to handle high nitrate loads and easily adapt to volatile swings both hydraulic and nitrate loads.

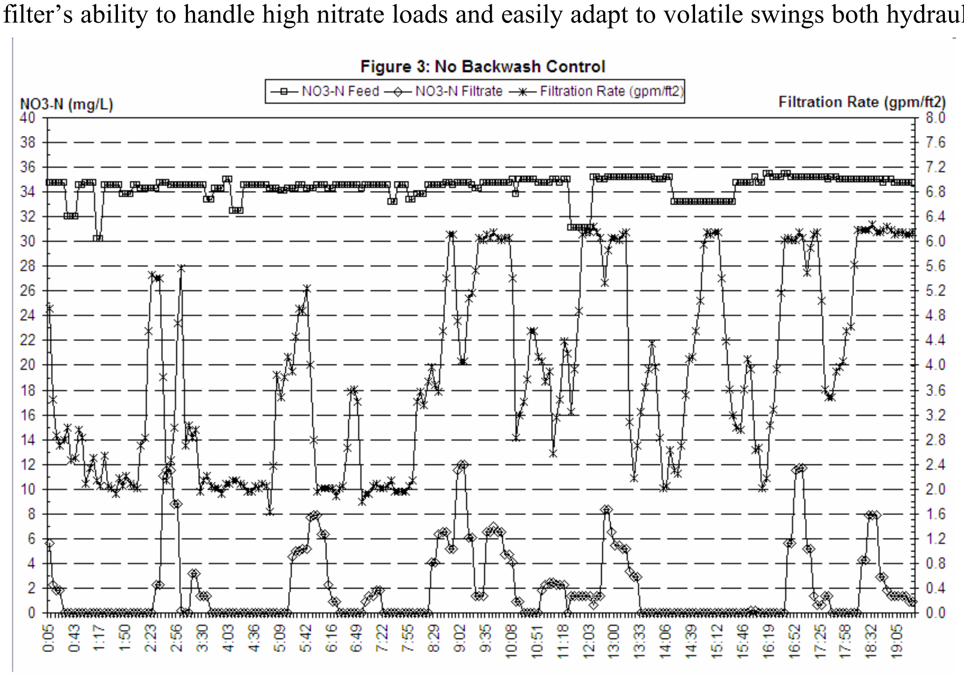
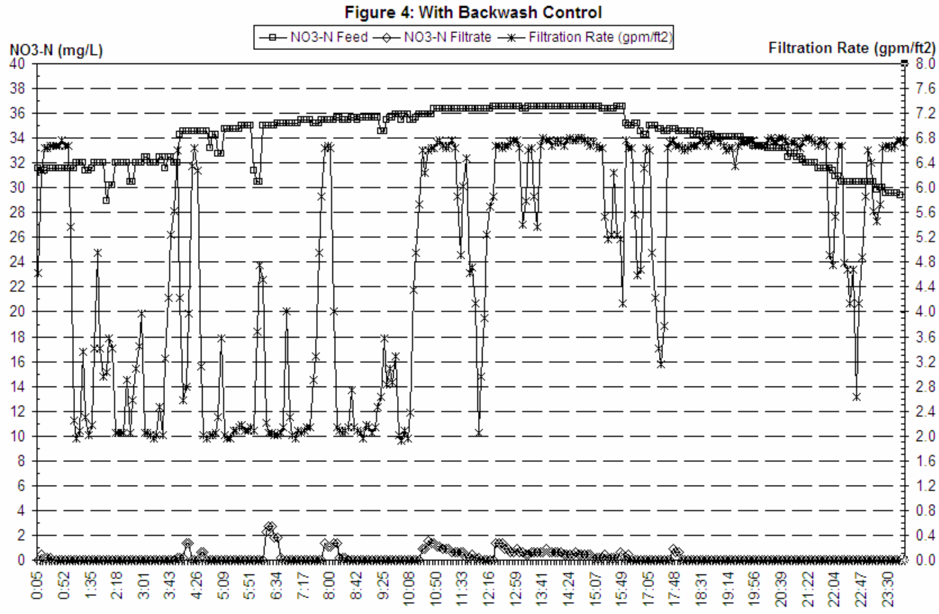


Figure 3: No Backwash Control



PERFORMANCE DATA:

The full scale installation was completed in February 1999 and started up biologically in April 1999. Full denitrification was established in about four weeks. Table 3 shows results of a representative period in August 1999.

Table 3: Results of Full Scale Installation (24 hour flow proportional composite samples)

Date	Feed NO_3-N (mg/L)	Filtrate NO_3-N (mg/L)	NO_3-N Efficiency (%)	Feed COD (mg/L)	Filtrate COD (mg/L)	Δ COD mg/L	Feed Total-P (mg/L)	Filtrate Total-P (mg/L)
8/16	16.42	0.43	97.4	39.0	44.0	+5.0	2.5	1.9
8/17	11.63	0.94	91.9	26.0	24.0	-2.0	1.5	1.0
8/18	9.70	0.46	95.3	30.0	31.0	+1.0	1.6	1.2
8/19	8.70	0.43	95.1	26.0	25.0	-1.0	1.5	1.2
8/20	9.05	0.17	98.1	22.0	21.0	-1.0	1.3	1.0
Average	11.10	0.49	95.5	28.6	29.0	+0.4	1.7	1.3

The results show an average nitrate removal efficiency of 95.6% with an average influent NO_3-N concentration of 11.1 mg/L. Methanol dosing employs feed forward control based on continuous measurement of influent nitrate concentration and flow. This assures an efficient chemical feed with limited COD increase in the effluent, as indicated by the slight average COD increase shown in Table 3, with the feed COD measured prior to methanol addition. An on-line effluent COD analyzer has also been used for feed back control of methanol addition to avoid over-dosage. The total phosphorus showed a slight decrease in concentration across the filter, mainly due to uptake by the biomass.

Over the next three years of operation, performance data was continually collected and is summarized in Table 4. Given that the plant is required to meet a 10 mg/L total nitrogen effluent limit on an annual average basis, with the average filtrate NO_3-N concentration of 2.5 mg/L and average nitrate removal efficiencies of 86%, the data recorded between 2000-2002 clearly indicates that the filter was successful in achieving this goal. Efficient methanol feed was also demonstrated, as indicated by the net negative change in COD concentration across the filter. Allowing for an average 10% consumption of methanol to remove the residual dissolved oxygen carried over from the secondary treatment process, the average specific methanol consumption of 3.3 mg CH_3OH/mg N removed is well within the expected range and demonstrates an efficient and effective organic carbon utilization by the denitrifying biomass contained within the filter bed. This is very important as the chemical cost for methanol is one of the single biggest expenditures in the operation of a denitrification filter.

Table 4: Long Term Performance Data

Period	Feed Flow (MGD)	Feed NO_3-N (mg/L)	Filtrate NO_3-N (mg/L)	NO_3-N Efficiency (%)	Feed COD (mg/L)	Filtrate COD (mg/L)	Δ COD mg/L	CH_3OH Consumed (mg/mg N)
2000	16.6	17.9	2.3	87.1	37.2	33.5	-3.7	3.2
2001	15.3	19.7	2.5	87.5	37.0	36.5	-0.5	2.9
2002	15.4	16.2	2.6	83.9	41.0	32.3	-8.7	3.8
Average	15.8	17.9	2.5	86.2	38.4	34.1	-4.3	3.3

SUMMARY & CONCLUSIONS:

Continuous Backwash Filtration (CBF) is a well established, effective and easy to operate tertiary solids removal process that has been successfully used for many years throughout the world. With the growing pressure to reduce nutrient discharges into many watersheds in the US, CBF has been taken to the next step and adapted to be an efficient nitrogen removal device as well. Utilizing the filter sand bed as an anoxic bioreactor and controlling the retention of the denitrifying biomass through the automation of the airlift, a conventional CBF becomes a Moving Bed Biofilter with exceptional capabilities to fulfill even the strictest of effluent nitrogen discharge limits.

Although data was not presented in this study, recent work has demonstrated that simultaneous nitrogen and phosphorus removal, through the addition of metal salt solutions, can be accomplished using this technology, achieving effluent phosphorus levels below 0.3 mg/L while maintaining filtrate total nitrogen level well below 3 mg/L.