The *Store and Treat* process for sludge liquor management

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Abstract Process sewage from sludge dewatering is particularly suitable for separate partial-flow treatment owing to its highly concentrated components and mostly elevated temperature. The procedures normally foreseen are those offering an effective treatment plant discharge based on a simple operating method and at low cost. With the *Store and Treat* process developed by Hamburger Stadtentwässerung existing sludge liquor basins can be used for an additional biological partial-flow treatment at reasonable cost without abandoning the advantages of quantity management.

Keywords Nitrification; quantity management; sludge liquor

Introduction

The sludge liquor continuously occurring in Hamburg's Combined Waste Water Treatment Plants (CWWTPs) through the dewatering of digested sludge is approximately 150 m^3/h (see also Table 1). The nitrogen load supplied to the biological phase together with the sludge liquor makes up for approximately 25% of the total load of the CWWTP's, in relation to the TKN parameter. Owing to the fact that the effluent directly reaches the River Elbe, and finally the North Sea, nutrient elimination is of particular importance.

Therefore, Hamburger Stadtentwässerung have implemented a quantity management of sludge liquor since 1995. For this purpose, a 4,000 m^3 capacity basin was provided first, with a second one, of the same size, in 1999. In intermediate-storage sludge-liquor management the CWWTP's are able to safely comply with the required nitrogen effluent concentrations. The average nitrogen effluent load however, can hardly be reduced thereby (Ladiges *et al*., 2001). Looking for alternatives, the advantages and options of a separate partial-flow sludge liquor treatment have also been taken into consideration. Implementation on an industrial scale has proved impossible due to the high specific cost involved with the physico-chemical and biological processes tested to date.

This gave rise to the need of a sludge liquor management process suiting both objectives, i.e. increase of the purification rate and optimal economic efficiency. To start with, investigations were made to determine which theoretical savings potential can be achieved in the main flow, based on a separate sludge liquor pre-treatment. Such savings potential results mainly from the nitrification (aeration) of the already pre-treated ammonium load saved in the main flow, in connection with an increased denitrification (improved efficiency, extension of anoxic zone possible). The theoretical savings potential determined for the Hamburg-Dradenau WWTP was ca €0.35 per kg in the partial flow nitrified nitrogen.

Owing to the fact that the additional partial-flow treatment of the sludge liquor should be carried out without additional cost wherever possible, this savings potential has been taken as target value for the treatment costs to be foreseen. Based on the above, the following basic assumptions have been made.

- Partial and main flow treatment must be considered as a whole, and optimised. Therefore, the prime target of the partial-flow treatment is to achieve a relief in main-flow treatment, not however necessarily the complete degradation of the nitrogen load contained in the sludge liquor.

Table 1 Characteristics of the sludge liquor obtained from sludge dewatering (mean values at sludge liquor basin inlet)

Origin	Sludge liquor from digested sludge dewatering	
Influent	150 m^3/h	3,600 m^3/d
Temperature	30 to 40°C	
pH	8.0 to 8.5	
NH_4-N	1,250 mg/l	4,500 kg/d
COD_{filt}	1,400 mg/l	5,040 kg/d
$BOD_{5,orig}$	550 mg/l	1,980 kg/d
DS	0.5 g/l	
Alkalinity $K_{S\,4,3}$	115 mmol/l	

- Should the partial-flow treatment be limited to nitrification, denitrification will take place in the main flow. Thereby, dosage of an external C source will no longer be required in the partial flow, on the one hand, and, on the other hand, the oxygen contained in the nitrite/nitrate can be used for BOD-degradation in the main flow.
- It is intended to achieve a nitrogen elimination via nitrite (NO_2), instead of nitrate (NO_3), whereby the expenditure involved for oxygen supply in nitrification is reduced by ca 25%, the consumption of organic carbon in de-nitrification by ca 40%.
- The dosage of chemicals for pH control is reduced to the maximum extent for cost reasons, and it is also possible that no pH control whatsoever is affected from the outside. In the event that the acid capacity contained in the sludge liquor is fully utilised, ca 50% of the ammonium load can still be nitrified, theoretically speaking.
- The treatment plant design should be as simple as possible to keep construction cost and expenditure for operation and maintenance low.

A number of well functioning examples existed already both for nitrogen elimination via nitrite and exclusive sludge-liquor nitrification without pH control and with a following denitrification in the main flow (Grömping, 1999). The innovative aspect about it was the combination of quantity management and treatment of sludge liquor in one and the same basin, with quantity management still taking first priority.

Process description

The objective of the *Store and Treat* process is to combine sludge-liquor storage and treatment in a way that a maximum reduction in effluent loads is achieved at minimum cost. The increased ammonium concentration and temperature of the sludge liquor both permit a high growth rate of nitrifying bacteria, combined with a high conversion speed in nitrification. It is intended that full advantage be taken thereof through application of the above process.

For the combination of sludge liquor storage and treatment in one basin, the biological treatment must be cyclical whereby time and duration of the individual cycle phases are governed by the favoured quantity management. Thereby, various basin operating conditions with their related treatment phases are involved. These are given in Table 2.

At the beginning of a cycle, the basin is empty. In this phase only the activated sludge retained from the previous cycle is left inside the basin. This retained sludge makes up for approximately 10–20% of the storage capacity. When storage begins the sludge liquor influent mixes with the activated sludge, and nitrification starts with aeration. In this phase the sewage is treated in impounding operation.

When the basin is filled to capacity, treatment can be continued in continuous operation until the basin is emptied. The sludge liquor influent (marked by a high ammonium concentration) then continuously pushes back the treated basin content, which is then evacuated as overflow. Consequently, only a reduced ammonium load reaches the main flow. In this phase, activated sludge is also discharged continuously as part of the overflow. This

Table 2 Cycle in combination of sludge-liquor storage and treatment

Operating condition of basin	Related treatment phase
Basin is empty	Retained sludge, stand-by
Basin is being filled	Treatment in impounding operation
Basin is filled, further influent	Treatment in continuous operation
Basin is filled, no further influent	Treatment in batch operation Settling phase
Basin is being emptied	Sludge retainment

effluent is limited however, because the outlet is designed in the form of an overflow hopper. Unlike the exemplary case of an “ideally mixed basin”, in reality, the bottom layers of the basin might show a slightly higher activated-sludge concentration than those at the surface. At the same time, the overflow favours a continuous floating sludge evacuation.

A settling phase is foreseen before basin emptying starts, to make sure that the activated sludge sinks to the ground and the activated sludge for the next cycle can be retained in the system. Following this, the basin is emptied in compliance with quantity management requirements, with only the retained sludge remaining. Whilst the basin is fully emptied, aeration can be reduced to the level necessary to keep the nitrifiers active.

Preliminary tests are required to determine the dimensioning of the described system. To secure fault-free operation even during the continuous phases, increase ($\mu * X$) and discharge ($D * X$) of the nitrifying bacteria (X) in the basin must be balanced so that the following applies based on a simple flow fermenter:

$$\mathrm{d}X/\mathrm{d}t = \mu * X - D * X = 0.$$

The dilution rate D ($= Q/V$) is based on the hydraulic load resulting from quantity management. Depending on the effectiveness of the discharge system, a certain sludge retention can be achieved so that the average biomass concentration in the discharge (X') is below that in the basin (X):

$$X' = f * X$$

with reduction factor f ($f < 1$). As a result, the following must apply:

$$\mathrm{d}X/\mathrm{d}t = \mu * X - f * D * X = 0.$$

In the event that the maximum growth rate μ of the nitrifying bacteria which can be achieved in the respective system is superior to the product of reduction factor and washing-out rate ($f * D$), a balanced condition will occur between increase and discharge. At the same time, conclusions can be drawn from the corresponding preliminary tests in respect to the specific nitrification rate, whereby a pre-calculation can be made about the system’s throughput ratio, which can be achieved.

Testing the process on a semi-technical scale

During a 5-month test phase, the *Store and Treat* process was tested in a semi-technical test facility provided at the Hamburg-Köhlbrandhöft WWTP. In this test, two parallel-operation basins with a usable volume of 8 m^3 each were used as “storage basins”. The scale used in comparison with industrial-scale application in Hamburg was 1:500. Accordingly, the sludge liquor supply was limited to max. 0.3 m^3/h and/or 7.2 m^3/d. Aeration was effected using disk-type membrane aeration devices installed at the reactor bottom. While reactor 1 received compressed-air gas supply, reactor 2 was supplied with pure oxygen. Mixing was effected separately from aeration, by means of built-in stirrers. The basic design of the test reactors is given in Figure 1.

Apart from aeration, no other auxiliary materials were added for treatment. The pH value was maintained at a level guaranteeing optimal nitrification results, exclusively based on the acid capacity of the sludge liquor. In this way up to 50% of the ammonium load supply can be oxidised before the pH value – deteriorating owing to the fully utilised acid capacity – limits further nitrification. Depending on the amount of sludge liquor supplied, the temperature level in the system ranged between 25 and 35°C.

The volumetric conversion rate determined in the test based on reactor 2 is given in Figure 2. Following a start-up phase of roughly 2 weeks the reactors had already achieved a nitrification rate of ca 2.5 kg NH_4-N/d and/or 0.3 kg NH_4-N/(m^3*d). With the sludge liquor supply being increased, the oxidised ammonium load also increased. On the average, it was 3.2 kg NH_4-N/d and/or 0.4 kg NH_4-N/(m^3*d).

In total, approximately 40% of the ammonium load was nitrified in the basins in the semi-technical test. The ammonium content of the sludge liquor could be reduced from an average 1,250 mg/l NH_4-N in the influent to roughly 750 mg/l in the effluent, and nitrification ended with the nitrite. Nitrate was hardly found in the reactors, and if so in minor concentrations only. This is mainly due to the fact that nitrite oxidation is repressed by hydroxylamine, an interim product of nitrification (Siegel and Harms, 1998).

The activated sludge concentration in the test basins varied between 0.5 and 1 g DS/l, in the retained sludge (the basin being empty) between 2 and 2.5 g/l. In this context it must be taken into consideration that the varying DS-content of the sludge liquor influent also influenced concentration in the reactors. In laboratory tests, an organic share of ca 80% has been determined for activated sludge. The specific nitrification rate $r_{N,TS}$ ranged between 0.4 and 1 kg NH_4-N/(kg DS*d), which means that it was 10 times that achieved in the main flow.

Owing to the H^+ ions released during ammonium oxidation, the pH dependency of the nitrification, combined with the acid capacity consumption, led to a self-controlled nitrification speed and pH value. As a result of the simple reactor design and the nitrifier's high growth rate the test was marked by flexibility and resistance to changes in the sludge liquor composition, and to disturbances.

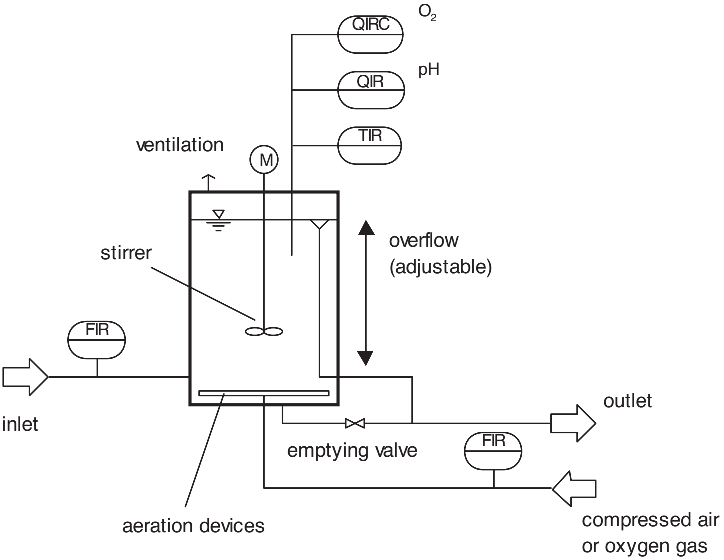

Figure 1 Basic test reactor set-up

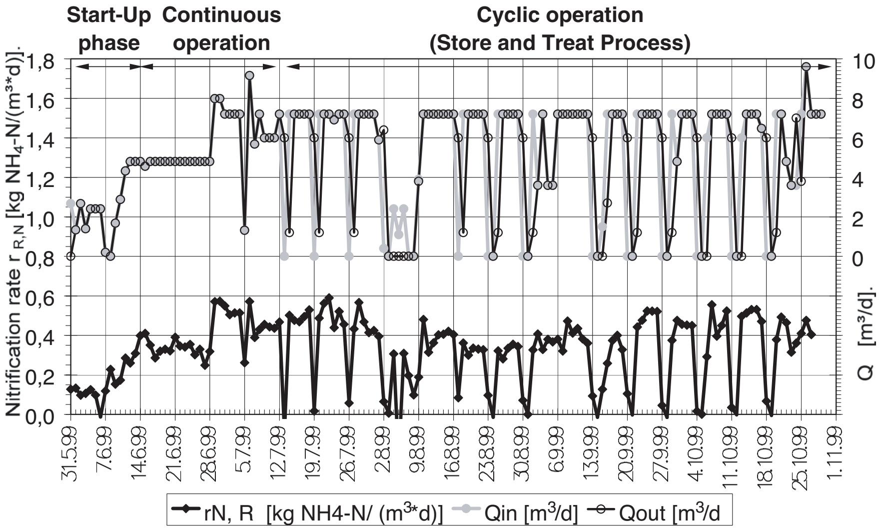

Figure 2 Nitrification rate of test reactor 2

Application at Hamburg's combined WWTPs

In view of the positive test results achieved in semi-technical test application, the *Store and Treat* process is also foreseen for industrial-scale application in Hamburg starting from 2002. As a condition, one of the two sludge liquor basins is currently being provided with the equipment required for such treatment. The required investment is mainly limited to the aeration system, a suitable outlet construction and measuring facilities for the main process parameters such as oxygen concentration, temperature and pH value. At approximately €300,000, the estimated subsequent equipment cost involved for the Hamburg plant is only one third of the cost of basin construction.

After commissioning the specific treatment costs (including investment and capital cost) will presumably amount to approximately €0.30/kg N. The expenditure involved for additional partial-flow treatment would then be fully offset by the expected savings in aeration energy in the main flow.

Application at WWTPs with intermittent sludge dewatering

At many plants, sludge dewatering is only effected on weekdays and during regular working hours. As a consequence, process sewage only occurs intermittently. Owing to the fact that without additional measures the high nitrogen loads would even affect sewage treatment plant operations, combined day and week storage basins are often used for sludge liquor. These have a balancing effect on the sludge-liquor quantity before it enters the biological phase, both throughout the day and the week. In most cases the basins are designed to a capacity of more than double the daily quantity ($V_{store} \geq 2\, Q_d$).

In application of the *Store and Treat* process such basins can easily be used for additional biological sludge-liquor treatment. The basin function is not affected thereby. The function principle is given in Figure 3.

The sludge-liquor flow occurring is fully supplied to the basin ($Q_{in} = Q_d$), the effluent quantity however, maintained at a constant level throughout the week ($Q_{out} \approx 5/7\, Q_d$). Accordingly, an increase in the basin fill level is noted initially over the day, and a decrease later on. Each morning, from the sludge-liquor quantity supplied on the previous day, only the portion retained for the weekly balance remains in the basin ($V_{stored} \approx 2/7\, Q_d$). Throughout the week it is noted that the stored quantity increases from Monday through Friday. In the event that the basin is equipped for biological treatment, the contents can be

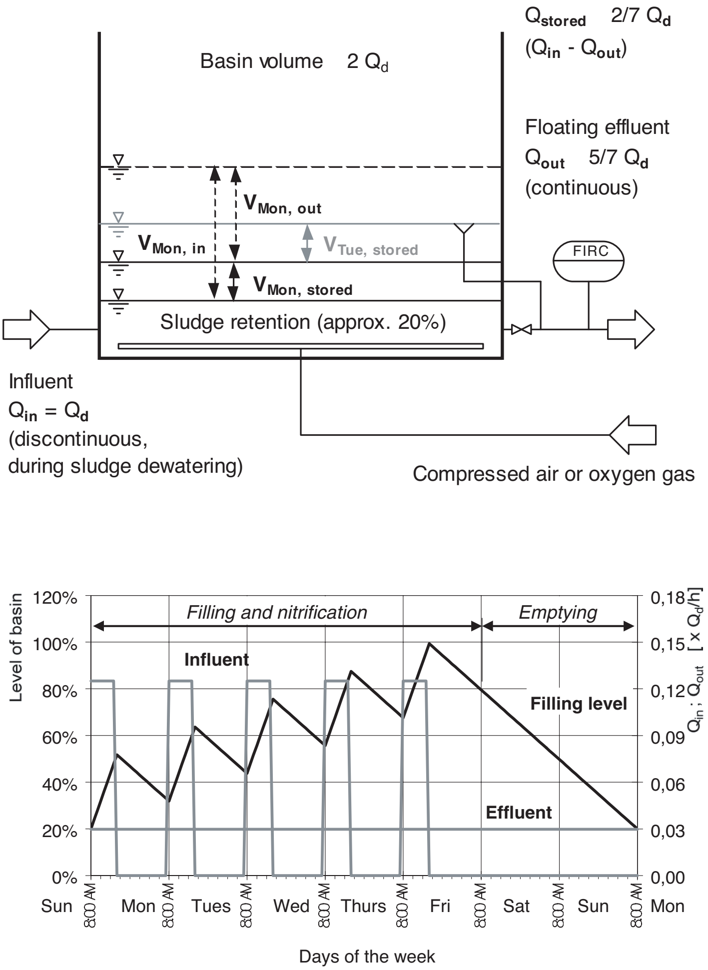

Figure 3 Possibility of application in a combined day and week basin
Top: Function principle
Bottom: Calculated basin hydrograph curve (example) with:
Q_{in} (non-continuous, Mo through Fri),
from 8–16 hours each day = 0.125 Q_d/h
Q_{out} (continuous, Mo through Sun) = 1/24 * 5/7 Q_d/h = 0.03 Q_d/h
$V_{store} = 2.4\ Q_d$, sludge retention when basin is empty: 20%

aerated starting from a fill level of approximately 40 to 50% so that a nitrification of the ammonium is achieved (from Monday until Saturday morning, as given in Figure 3). On weekends the basin is emptied again (aeration switched off and no stirring) with a continuous effluent, with only such sludge retention remaining as is needed for treatment.

Within the framework of a Hamburg-Harburg Technical University thesis the described concept was tested in the summer of 2001 on a sewage treatment plant serving 20,000 inhabitants (Burmeister, 2001).

Conclusion

Storing and treating sludge liquor in one and the same basin makes good economic sense in terms of sludge-liquor management. Whilst peak load times can be countered effectively through sludge-liquor storage, the integrated treatment leads to a decrease in the effluent load on the average. Thereby, the additional partial-flow treatment can be effected at a cost based on kg of oxidised nitrogen, which, under favourable conditions, can be fully offset by energy savings in the main flow. This is possible as auxiliary material dosage is no longer required, through utilisation of the existing storage basin as a “reactor” and a simple procedural concept. Last but not least, the treatment integrated into the sludge-liquor basin also has a positive effect on quantity management because the basin-emptying process is facilitated through the load reduction already effected.

This process is particularly advantageous for plants with previous or simultaneous denitrification as the nitrified partial flow reaches activation at a point where a sufficient number of easily degradable carbon compounds is left for effective de-nitrification.

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