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Nitrogen removal and heavy metals in leachate treatment using SBR technology

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ABSTRACT

Biological nitrogen removal by the use of Sequencing Batch Reactors (SBRs) is today an accepted and well proven model. The results of SBR performance on nitrogen removal have encouraged consultants, engineering companies and landfill operators to develop and build full scale SBR plants at a number of sites in Sweden. Two of these plants, Isätra and Norsa, have been studied closely. The Norsa plant treats leachate at a controlled water temperature, while the Isätra plant is exposed to temperature variation throughout the year. Both plants have very well proven nitrogen removal capacities, although winter conditions have an adverse impact on their performance. Typical nitrification efficiency is close to 100%, while the total nitrogen removal is about 90–95% under stable operation conditions. A good relationship between the nitrogen load and the nitrification rate has been observed at the Norsa SBR plant. The heavy metal content in the leachate is very low thanks to anaerobic precipitation inside the landfill into metal sulphides. The heavy metal content in the biological sludge is consequently also very low.

1. Introduction

Leachate wastewater from sanitary landfills has for a long time been considered as environmentally hazardous, especially as the deposit of solid waste was initially more or less uncontrolled, with little attention being paid to the separation of different refuse types, Aucott [1]. Separate treatment of leachate has been in evidence at least since the 1970s, amid a growing insight that “conventional” treatment methods used for municipal wastewater were inadequate, Bozkurt (Serti) [2] and Morling [3]. A large number of SBR plants are being built and operated worldwide to treat leachate from sanitary landfills. Madu [4] presents a summary of some of the plants in operation—the majority of these are plants built and operated in the UK. The first applications on leachate using SBRs go back to the 1970s. The first experimental plant using an SBR for leachate treatment in Sweden was operated for 18 months in 1988 and 1989 on the Swedish west coast. A number of studies were made of bench scale and full scale plants dedicated to treating leachate, built in the 1980s; Irvine et al. [5]. The use of Sequencing Batch Reactors (SBRs) soon became established based on the relatively small footprint that such a treatment would require, and also the fact that the amount of leachate is normally rather limited. A typical daily flow from a mid-sized landfill may range from 50 to 120 m^3/d. This means that the “step” from a pilot scale operation (very often based on an SBR unit) to a full scale plant for a leachate treatment reactor tends to be small. SBR development during the 1970s for municipal and industrial applications focused mainly on small plants. Thus, the experience from similar applications encouraged consultants and engineering companies to use this technology for leachate treatment. Leachate composition is by convention closely related to the material found in the landfill, but also to the age of the landfill, Bozkurt (Serti) [2] and Morling [3]. A potentially contentious opinion of leachate characteristics is that the content of heavy metals may be seen as a threat. This matter is true only for a very “young” leachate when the landfill is in the “acidic” stage and at the very end when the landfill turns aerobic again, Bozkurt (Serti) [2]. By far the most potentially hazardous agent in the leachate is ammonia nitrogen that sometimes is found in high concentrations. Zhou et al. [6] report on ammonia levels of 505–1200 mg NH_4–N/l in their lab scale tests; Klimiuk and Kulikowska [7] report on levels about 360 mg/l and Neczaj et al. [8] reports on ammonia nitrogen levels of 800 mg NH_4–N/l. Spangi et al. [9] found in their two and half year study on nitration operation modes that ammonia levels were up to 1540 mg NH_4–N/l.

2. Objectives

The objective of this paper is to study nitrogen and organic matter removal at two full scale leachate treatment plants (Isätra and Norsa) based on SBR technology. In addition the heavy metal content in leachate and biological sludge is addressed in order to assess the importance of heavy metal content in leachate. The results with respect to nitrogen conversion and its temperature dependence during biological treatment are compared with the initial pilot plant studies performed in Sweden some 20 years ago, Johansson et al. [10]. As this study represented the first SBR plant (in the

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Table 1
Summary of basic conditions and influent leachate composition for the three plants, Bösarp, Isätra and Norsa.

Variable	Bösarp test plant		Isätra SBR plant		Norsa SBR plant	
Operation period	1988–1989 Pilot plant 1	1988–1989 Pilot plant 2	2002–2004	2007–2008	2005–2006	2007–2008
Number of observations	12	12	29	8	33	10
Reactor size	500 l	70 m^3	250 m^3	250 m^3	300 m^3	300 m^3
Temperature range, °C	0.1–20	0.1–20	0.5–20	0.5–20	15–20	15–20
Daily flow variation, m^3/d	23–75 l/d	3–14	86	78/80	60/160	84/68
Average daily flow, m^3/d	50 l/d	7	86	79	85	75
COD, mg/l	4,720	4,720	452	164[a]	n.a.	[a]
BOD_7, mg/l	3,730	3,730	84	n.a.	16–32	[a]
Total N, mg/l	350–450	410	98	147	122	180
Cl^-, mg/l	7,000	<10,000	400/500	270/500	2,100–>3,000	2,500–>3,000
Hydraulic retention time, d	6.6–11	5–23	2.9	3.1–3.2	1.9–5	3.6–4.4

[a] For 2007 and 2008 TOC is used instead of COD and BOD.

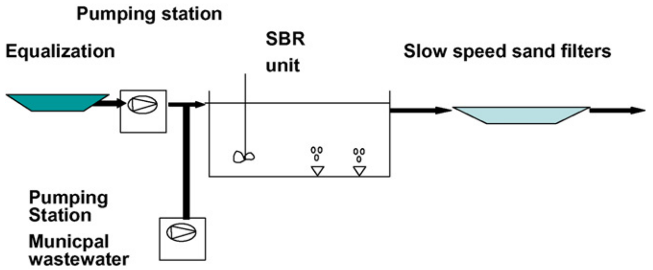

Fig. 1. Simple flow sheet of Norsa SBR plant for leachate treatment.

following labelled Bösarp) specifically aimed at nitrogen removal in Sweden in 1988 and 1989 it is deemed relevant to compare results and draw conclusions. Of crucial interest for the test operation was the water temperature impact on the treatment performance. The results are also compared with data found in literature with respect to nitrogen conversion. The main focus in the study is on nitrification rather than denitrification, as the nitrifying bacteria are the most sensitive ones in relation to toxic conditions in the untreated leachate. A second objective of the study is to address the matter of the heavy metal content in leachate and the biological sludge.

3. Experimental

3.1. Design data for the plants

The plant configuration differs between the plants. However, the main element in all the plants is the SBR unit. A simplified flow sheet of the Norsa SBR plant is shown in Fig. 1. The design data for the three plants are presented in Table 1. The two sanitary landfills at Isätra and Norsa are both relatively old ones. They both were taken into operation in the early 1970s. The conditions inside the landfill can in both cases be characterised as methanogenic, with true anaerobic conditions. The Bösarp plant was at the time of the experiments a combination of an old landfill and parts that were relatively young. This fact is reflected in the high content of BOD_7, and also the ratio between COD and BOD_7 that was quite low, less than 1.4:1.

In all cases two different observation periods are presented. For the Bösarp test plant two test reactors were used: one 500 l unit and a 70 m^3 lagoon that was converted into an SBR unit. In the Isätra and Norsa plants circular shaped reactors are used. The Isätra plant is a new construction, while in the case of Norsa an old sludge thickener with suitable dimensions was converted. The Norsa plant operates with a small addition of sewage from the adjacent municipal WWTP, benefiting from the sewage composition, as described by Zhou et al. [6].

The Bösarp plants were operated with a cycle varying from 8 to 24 h mainly according to the prevailing water temperature; ranging from about 0.5–21 °C. Table 2 shows the different operation cycles at the three plants.

The table demonstrates that the operation cycle is configured to a variety of process modes. This is one of the characteristics of the SBR process: within a given basic process design it is possible to adjust the cycle composition in accordance with the prevailing load and performance conditions. This has been done extensively at the Norsa plant as will be discussed below.

3.2. Sampling and analysis

The pollution data presented have been analysed in accordance with the Swedish Standards (SS) that generally complies with the corresponding European Standards (EN). All sampling has been

Table 2
Summary of different operation modes at the three plants, Bösarp, Isätra and Norsa.

Variable	Bösarp test plant		Isätra SBR plant		Norsa SBR plant	
Plant model	Pilot plant 1	Pilot plant 2	Full scale	Full scale	Full scale	Full scale
Total cycle length	24 h	12 h	12 h	8 h	10 h	8 h 10 min
Fill time	10 min	5 h 30 min		32 min	2 h	2 h
Idle after fill	1 h 50 min	Not used	Not used	Not used	Not used	Not used
Static fill					15 min	15 min
Fill/Mix		1 h 25 min	Not used	Not used	Not used	Not used
Fill/Aerate		4 h 5 min	4 h 50 min	Not used	1 h 45 min	1 h 45 min
Mix	2 h	Not used	Not used	Not used	Not used	Not used
Aerated react	12 h	3 h 30 min	Not used	3 h	4 h	1 h 30 min
Mixed react	6 h	1 h 20 min	3 h 20 min	1 h 40 min	2 h	1 h 50 min
Second aeration react, h	Not used	Not used	Not used	Not used	Not used	Not used
Second mixed react	Not used	Not used	Not used	Not used	Not used	Not used
Settle	1 h 45 min	1 h 20 min	2 h 35 min	1 h 52 min	1 h	2 h 5 min
Decant	15 min	15 min	<70 min	20 min	1 h	45 min
Idle	Not used	15 min	<40 min	36 min	Not used	Not used

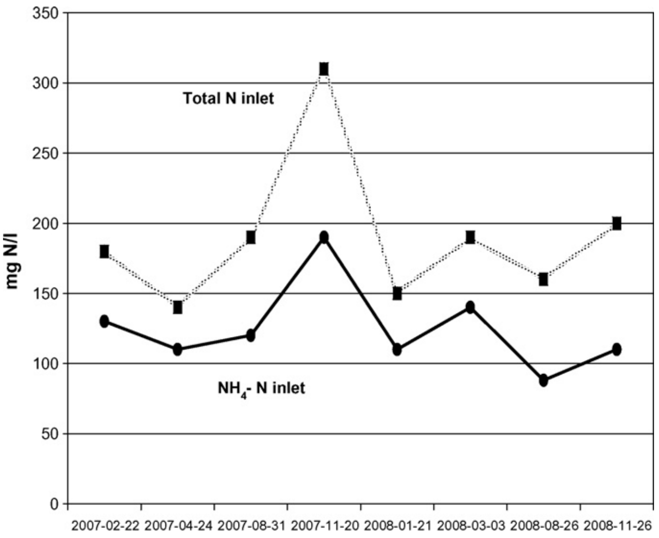

Fig. 2. Norsa SBR plant Total nitrogen and ammonia nitrogen, inlet leachate 2007 and 2008, eight observations.

performed on site by the plant staff and predominantly as grab samples. The reasons for the sampling method are the intermittent discharge along with small amounts of treated water and the assumed process stability during a 24 h period.

4. Results and discussion

4.1. Nitrogen conversion

The nitrogen levels in the untreated leachate vary between the different plants. The Bösarp plant showed the highest nitrogen concentrations of up to 500 mg N/l, Table 1. The substantially higher nitrogen concentration at Bösarp, compared with the other two may be attributed to deposits from a regional slaughterhouse that is rich in nitrogen. The nitrogen levels in Norsa changed during the operation period 2000–2008. During the first year of operation the average total nitrogen concentration was about 120 mg N/l while the concentrations in 2007 and 2008 were substantially higher, or as a mean value about 180 mg/l. This pattern may indicate that the observation by Butler et al. [11] may be correct: as a landfill becomes older the nitrogen discharge will increase. The ratio between total N and ammonia N also has changed in recent years. Fig. 2 illustrates the inlet total N and NH_4–N variations during 2007 and 2008. The Norsa SBR plant performance in 2007 and 2008 shows quite different patterns with respect to nitrification: in the first months of 2007 a substantial disturbance of the nitrification occurred that remained for at least two months. The reasons for this disturbance have been suggested by the process engineer to be related to insufficient aeration in relation to the actual amounts of nitrogen and also a suspicion that hydrogen sulphate may have also affected the nitrification. When the nitrification was recovered in May, the shift from an "assimilative" nitrogen removal into a full nitrification was quick, as demonstrated in Fig. 3. In 2008 the nitrification was actually complete throughout the year, save for a short minor disturbance in September 2008. The disturbance in 2007 is most probably not related to the water temperature, as the presence of the heat exchanger guaranteed a minimum water temperature of about 15 °C.

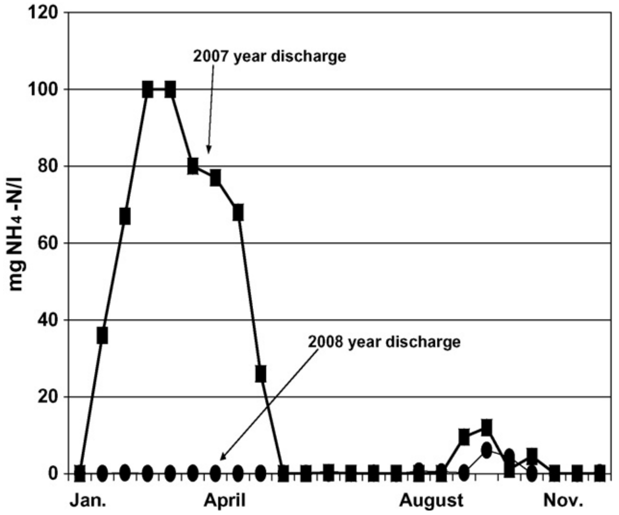

Fig. 3. Discharge of NH_4–N from Norsa SBR plant 2007 and 2008, 48 observations.

On the other hand the temperature influence on nitrification at the other two plants is more evident: the minimum winter temperature is about 0.5 °C. The nitrogen conversion pattern including the nitrification pattern at the Bösarp SBR test plant during start-up in springtime 1988 is shown in Fig. 4. A more detailed discussion on the nitrogen performance at the plant is given by Johansson et al. [10]. The temporary "build up" of nitrite prior to a complete nitrification indicates the possibility of establishing the annamox process on high strength leachate, Spangi et al. [9] and Gaul et al. [12]. Similar results as found in Bösarp on a temporary build up of nitrites were obtained by Kulikowska and Klimiuk [13]. However, the nitrification gradually became complete and resulted in a decline of nitrites after less than 20 days. The operation of the Bösarp plant demonstrated–as expected–a clear temperature influence on the nitrification capacity. As the temperature dropped the daily load on the SBR unit was lowered. Yet a drop in efficiency was observed in October 1988, as the ammonia nitrogen in the treated leachate started to increase. It is noticeable that the nitrification capacity was never washed out from the reactor, thanks to a further decrease of the load in wintertime. For the 70 m^3 SBR unit the nitrification performance was maintained by lowering the inlet flow during the winter. This action was successful, as the nitrification at the beginning of March was more or less complete. During the last months of the experiments this large reactor responded very well with respect to nitrogen removal. Step by step the daily flow into the reactor was increased from 3.6 to 14 m^3/d. The changes in

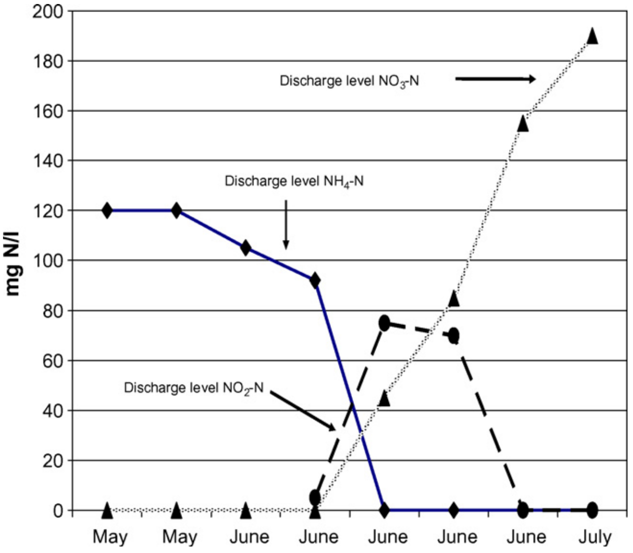

Fig. 4. Bösarp SBR test plant, nitrogen conversion patterns 1988, modified after Johansson et al. (1989).

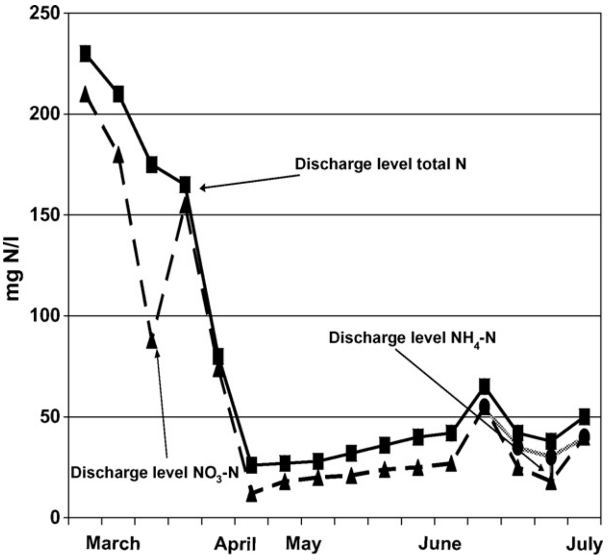

Fig. 5. Bösarp SBR 70 m^3 test plant, nitrogen discharge levels, 16 observations, modified after Johansson et al. (1989).

nitrogen discharge from the beginning of March until the end of the experiments in the first half of July is shown in Fig. 5. Only at the Bösarp plant it was identified a temporary increase of nitrites that occurred before the formation of nitrates. By comparing the two curves for NO_2 and NO_3 it may be concluded that the nitrite formation may have delayed the nitrate formation somewhat, but the slope of these two curves does not indicate that any substantial inhibition has occurred. For the two other plants no temporary nitrite build up has been identified. Probably this may be linked to the initial nitrogen concentration in the untreated leachate, as it is substantially lower in Isätra and Norsa compared with Bösarp.

A more complex pattern is revealed at the Isätra SBR plant. Earlier operational performances show that the nitrification capacity is exhausted by late winter, Morling [14]. The recovery of the nitrification capacity in springtime is relatively quick, and complete nitrification at the plant is found at the end of March every year, Figs. 6 and 7. Full year nitrogen conversions in the SBR unit are presented for years 2007 and 2008. The prevailing water temperature when the nitrification is established is between 5 and 8 °C. The interruption of the nitrification in June 2008 is quickly overcome in the reactor and complete nitrification remains until the end of the year. The denitrification has been "secured" by adding an external carbon source—in Isätra and Norsa methanol has been used. When a proper dosing has been applied the denitrification has been more or less complete. The limitations on total nitrogen removal at these two plants have been an incomplete nitrification or an insufficient addition of methanol. At the Bösarp pilot plant the organic carbon content was sufficient in the untreated leachate as shown in Table 1. The ratio BOD_7 : total N in the leachate was 9:1 during the test period. Fig. 8 illustrates the nitrogen discharge at the Norsa SBR plant during the first quarter of 2006. The nitrification was complete throughout the period, but due to a failure in the methanol dose the remaining NO_3–N concentration was higher than normal. Once the dosage was corrected the system responded quickly, and the total nitrogen removal went down. At the Bösarp test facility the pattern was somewhat different, as the organic carbon in that

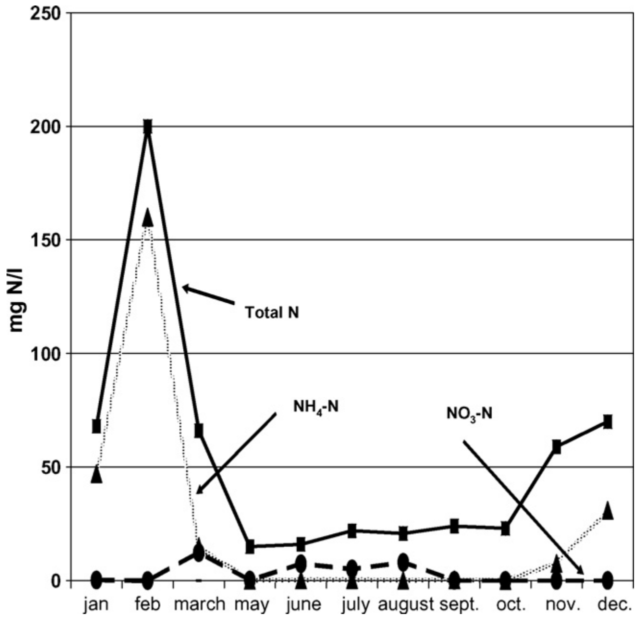

Fig. 6. Isätra SBR plant, nitrogen discharge levels during 2007, 11 observations.

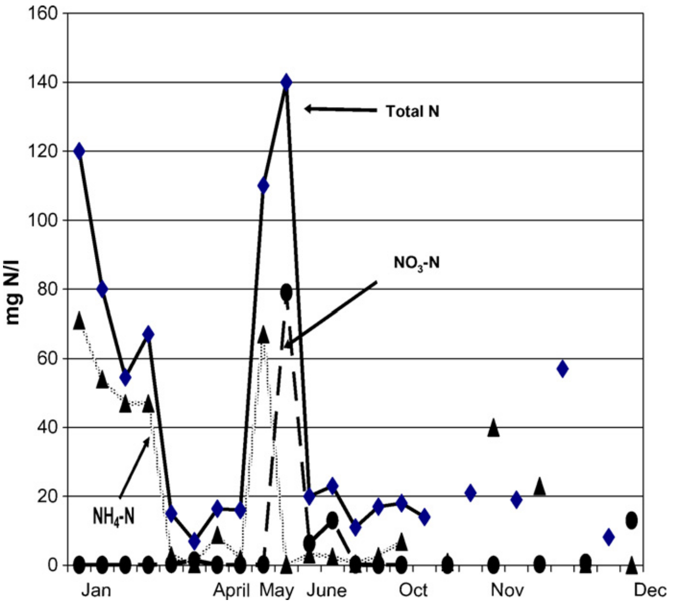

Fig. 7. Isätra SBR plant, nitrogen discharge levels during 2008, 19 observations.

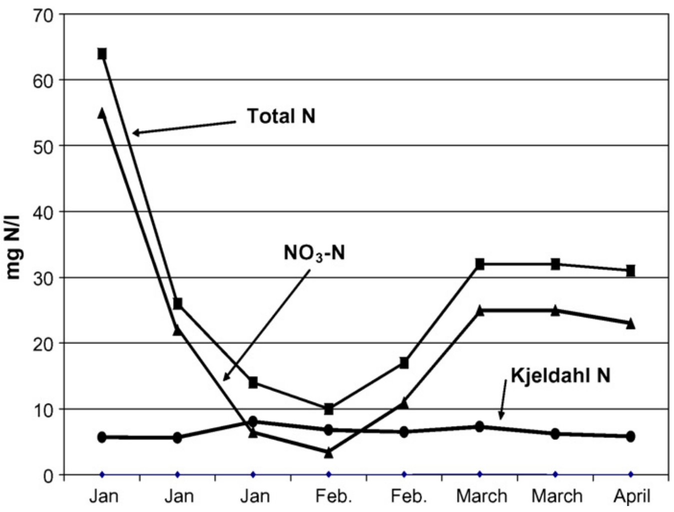

Fig. 8. Norsa SBR plant, nitrogen discharge levels during first quarter 2006, eight observations.

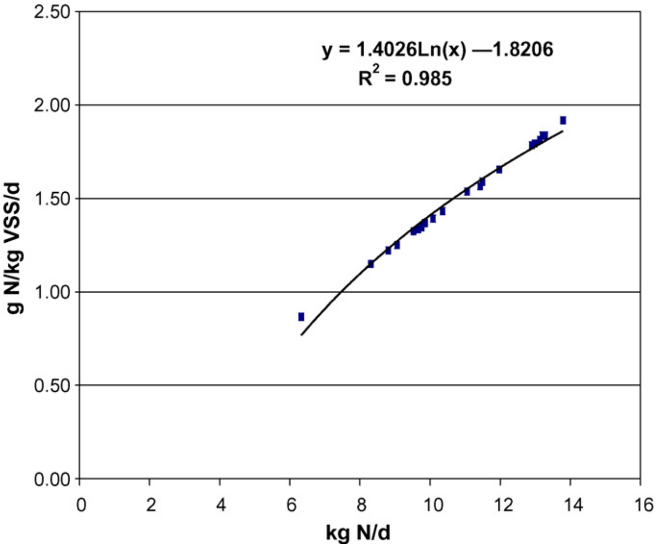

Fig. 9. Norsa SBR plant, specific nitrification rates in relation to nitrogen load.

case had a more complex composition; possibly the organic acids were the dominating part in the BOD content. However, as illustrated in Fig. 5 the denitrification was rapidly established during the late winter and early spring seasons. As from the end of April until the end of the test period in July the discharge of total nitrogen was low. The total nitrogen removal over the plant during this period was about 95%.

4.2. Nitrification rates

Nitrification rates in leachate treatment have been studied in the laboratory by Kulikowska and Klimiuk [7,13] and Görfelt [15] at a controlled temperature of about 20 °C. All have found high specific nitrification rates when treating leachate: levels are shown to be between 2.9 and 10 mg $N_{oxidised}$/g VSS/h. These figures are substantially higher than what may be derived from the performance figures in Bösarp, Isätra and Norsa. Some important factors must be pointed out in this context, in order to avoid misleading conclusions when comparing the bench scale results with the results from the three plants presented in this study:

1. The temperature variations at Bösarp and Isätra affect the operation conditions more or less continuously and not provide "ideal" conditions for nitrification.
2. The fact that the nitrification is complete at all the plants, particularly when the water temperature is above 14 °C, means that it is not possible to correctly calculate the true nitrification rate. It is more than likely that the nitrification rate is substantially higher than a calculated value. The "highest" values found at these three plants are 1.3–2.2 mg $N_{oxidised}$/g VSS/h. For the Isätra plant substantially lower nitrification rates are found, in the vicinity of 0.5–1.1 mg $N_{oxidised}$/g VSS/h. In this context it should be underlined that the Norsa plant is operated with a good control of the water temperature, by means of a heat exchanger.
3. At the Norsa plant it has been possible to establish a very good relationship between nitrogen loading and the nitrification rate, Fig. 9. The number of observations is sufficient to establish a reliable relation. It also should be noted that the increase in nitrification rate as a function of the actual nitrogen load has been demonstrated at other plants, see for instance Morling [17]. The explanation may be found to be logical: as long as the actual nitrogen loading of the system is lower than the corresponding maximum nitrification rate the nitrifiers will not work at their maximum capacity.
4. Another important factor for the nitrification rate is the ratio COD/nitrogen in the untreated water. The nitrification rate is inversely related to the ratio COD/nitrogen: at low ratios the nitrification rate is higher. This matter has been described by Choubert et al. [16] and Morling [17].

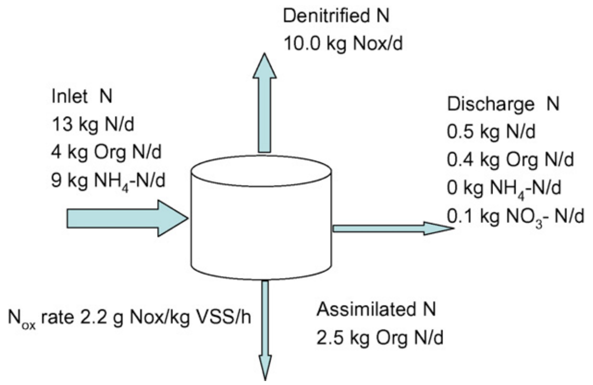

Fig. 10. Norsa SBR plant, nitrogen balance typical summer conditions, based on eight observations.

A balance over the SBR plant in Norsa with respect to nitrogen removal, based on summer 2008 values is shown in Fig. 10. During summertime the highest nitrification rates are normally found thanks to the prevailing water temperature. A similar balance for the SBR plant in Isätra is shown in Fig. 11. For the experimental plant in Bösarp a nitrogen balance has not been established, due to the varying conditions throughout the operation period. In this context it is important to underline that a material balance must be based on a sufficient number of observations in order to provide a reliable overall picture. The use of single observations from inlet and outlet figures may result in a misleading picture. Some assumptions must also be done in order to establish a material balance, as some of the variables are not measured:

1. Assimilation nitrogen removal is assumed to be 6–8% of the VSS content in the waste activated sludge;
2. Most of the denitrified nitrogen will be removed as nitrogen gas, only a minor part would be found as laughing gas (N_2O). This issue has been addressed by Park et al. [18] and the findings underlined that the operation mode of the SBR could influence the N_2O formation. According to their findings a SBR cycle start-

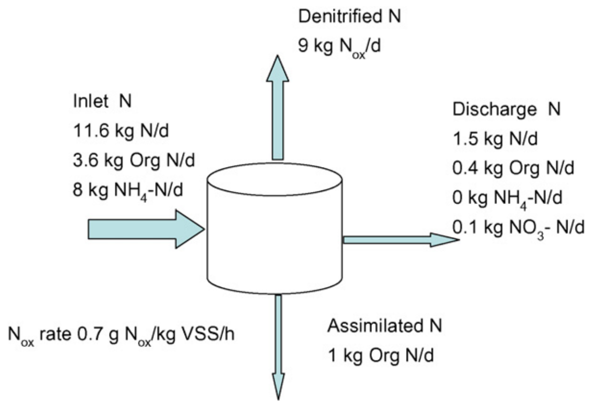

Fig. 11. Isätra SBR plant, nitrogen balance typical summer conditions, based on eight observations.

Table 3
Treatment performance at the three leachate SBR plants.

Plant Variable	Bösarp mg/l	Isätra mg/l	Norsa mg/l
COD in	2000–8000	Not used	Not used
COD out	<300	<300	Not used
BOD in	1000–6400	250	19–60
BOD out	6–20	5–29	3–22
Total N in	200–500	87–220	140–310
Total N out	45–63	7–24	9–(56)
Total N rem.	67.5–91%	82.9–96.5%	81.9–93.6%
NH_4–N in	185–480	77–190	88–190
NH_4–N out	5–25	<1.0	<1.0
NO_3–N out	0–15	0–10	0–16

ing with an aerated fill would be most beneficial way to limit the N_2O level.

4.3. *Organic matter removal*

COD removal was initially a concern for all the plants. The Bösarp plant showed a significant COD decrease as shown in Table 3. At the two other plants the COD decrease was substantially more modest. There are a number of reasons to explain this: high Cl^- content in the water influences the COD analysis result, and a part of what is analysed as COD are "non degradable" compounds, as underlined by Kulikowska and Klimiuk [13]. The conventional oxidation process included in the SBR system is not sufficient to oxidise these compounds. The high COD removal level in the Bösarp case is explained by the presence of easily degradable organic compounds, demonstrated by the high levels of BOD_7, and also by a low COD to BOD ratio in the Bösarp case <2:1.

4.4. *Sludge quality aspects*

At all three plants the sludge quality, expressed as SQI (sludge quality index) or SVI (sludge volume index) have been consistently at low levels (>100 mg/g). One important observation in this respect derived from the operation at the Norsa SBR plant was related to the SRT (solids retention time). When the SRT exceeded 40–45 days a typical formation of pinpoint sludge was observed. This problem has been overcome by a correction of the sludge wasting and limiting the SRT to about 30 days.

4.5. *Heavy metals*

The question of heavy metal content is a frequently addressed concern in leachate composition and thus, seen as a potential hazard, Aucott [1]. Heavy metal content in leachate is presented in LEACH 2000 database [19]. A comparison of some of the heavy metal in this database with the actual findings at the Isätra and Norsa plants would not be fair—in all more than 200 landfills included in the database are not identified with respect to their condition or their landfill age and these factors have a substantial effect on the heavy metal concentrations in the leachate. It is more relevant to compare four reported landfills in New Jersey, Aucott [1], with the actual concentrations found in Isätra and Norsa, Table 4. At Isätra and Norsa the following heavy metals are regularly controlled: Arsenic (As), Lead (Pb), Cadmium (Cd), Cobalt (Co), Copper (Cu), Chromium (Cr), Mercury (Hg), Nickel (Ni) and Zinc (Zn). In all the observations, except for Cobalt, the heavy metal concentrations are lower or substantially lower than the ruling standards for tap water in Sweden. The Co discharge level over a two-year period varied from 3.5 to 10 µg/land at an average level of 4.8 µg/l was found (based on 8 observations). The ruling limit for Co in tap water is presently 4.0 µg/l. A general observation with respect to the discharge metal levels and especially the limited removal level would be underlined. While the different inlet Me^+ ions are more or less totally soluble Me ions are found in the discharge as both soluble and assimilated in the suspended solid content. Nevertheless the part found assimilated to the discharge suspended solids may be incremental.

On the other hand the removal of heavy metals is rather limited in the SBR process. The efficiency of arsenic removal at the Norsa plant is illustrated in Fig. 12. The inlet concentrations of arsenic and lead at the Isätra plant are shown in Fig. 13. Similar results have been reported by Abu-Rukah [20] who studied leachate at a landfill site in Jordan. The Cd and Pb concentrations in the leachate were in the same magnitude as found in Isätra and Norsa; Cd 0.6 µg/l and Pb 2.5 µg/l. The main reason for the low heavy metal content in the leachate is that when the landfill is operated in the methanogenic phase the heavy metals are precipitated as sulphides and remain inside the landfill. Only when the landfill becomes aerobic will the metals be released. As a consequence the removed biological sludge from the SBR system will have low concentrations of heavy metals. Table 5 shows a comparison of some heavy metal levels in sludge from the Norsa SBR plant with the ruling recommendations for sludge reuse on agricultural areas. The levels are substantially lower than found in most sludge from municipal wastewater treatment plants in Sweden. It should be observed that the analysis was done at one single sample, and as such gives an indication rather than a substantial verification. Nevertheless the indication is interesting enough to question the conviction that the sludge from a leachate treatment facility by convention has excessive heavy metal content. From other applications, such as municipal wastewater treatment

Table 4
Comparison of heavy metal content in leachate, from three New Jersey land fills with Isätra and Norsa SBRs.

Plant/Variable	LEACH 2000 Database	Cape May Co., NJ	Cumberland Co, NJ	Pineland Park, NJ	US drinking water req	Isätra	Norsa	Swedish drinking water req.
Nos .of obs	>2000	8/16	27	11		16	16	
		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
As	441	55	7.4	n.a.	10	3.5	5.9	10
Cd	283	3	2	5.3	5	0.11	0.8	1
Pb	133	3	2.5	26	15	2.3	2.8	10
Hg	7.3	<0.1	<0.1		2	<0.10	<0.10	1
Cr	235	n.a.	15	37	100	12	12	50

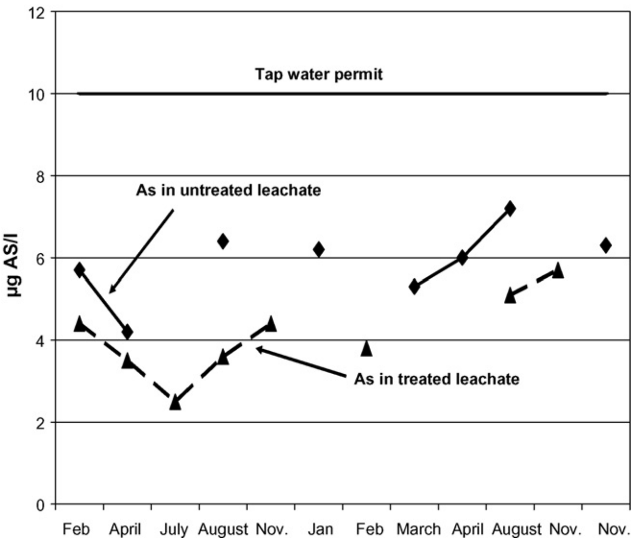

Fig. 12. Arsenic removal at Norsa SBR leachate treatment 2007 and 2008, 11 observations.

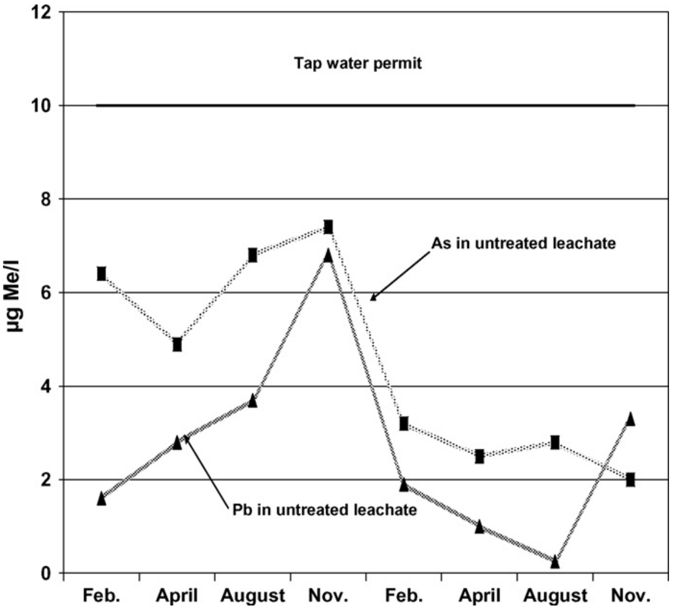

Fig. 13. As and Pb in untreated leachate at Isätra SBR plant, 2007 and 2008, eight observations.

it is well known that biological sludge will readily absorb some of the heavy metals. Very good uptake of chromium in the biological sludge at the Nowy Targ plant in Southern Poland has been found; where Cr reductions were found from about 14 mg Cr/l to <1.2 mg Cr/l, Morling [17]. Experimental studies by Jung et al. [21] underline that organic matter has an important absorption capacity with respect to heavy metals.

Table 5
Sludge from Norsa SBR plant, content of heavy metals compared with requirements for agricultural use (mg/kg TS), results from sample 2003.

	Sludge from landfill leachate treatment	Swedish EPA guidelines ref
Lead	5.1	<100
Cadmium	1.0	<2
Copper	99	<600
Chromium, tot	7.7	<100
Mercury	0.06	<2,5
Nickel	7.7	<100
Zinc	71	<800

Complex organics such as PCB and nonylphenol were also analysed in the bio sludge at the Norsa SBR plant: seven different PCB compounds regarded as potentially hazardous were analysed on three occasions. The concentrations of these PCB compounds were found to be low to very low. The analyses showed that the sum of these seven compounds was $<\Sigma 0.02$ mg/kg TS on all three occasions. The Swedish EPA guidelines for agricultural use stipulates $\Sigma\text{PCB} < 0.4$ mg/kg TS. The nonylphenol concentration was measured in the sludge on three occasions. The results found were the following: 12 mg/kg TS (2000-08-16); 3.6 mg/kg TS, (2001-05-04) and 3.1 mg/kg TS, (2002-04-19). Again these levels can be regarded as low, or even very low in comparison with the Swedish EPA criteria for nonylphenol; <50 mg/kg TS. Similar results have been shown at the Isätra plant. However, the number of observations is very few, and does not allow for any substantiated conclusions. Nevertheless the matter is of importance and further studies providing additional sampling would facilitate an analysis of the conditions at these sites.

5. Conclusions

The key factor for biological nitrogen removal in leachate from sanitary landfills–nitrification–has been studied at three Swedish plants. The first one, the Bösarp test plant, served as a forerunner for a number of full scale plants built in Sweden later on. The most important finding at this test plant was the ability to perform complete nitrification, and also substantial denitrification. The highest removal level found during the tests was about 91% (summertime results). It was found to be possible to adjust the operation mode to accommodate decreasing water temperature. This in turn has been of central importance in the design and elaboration of two full scale plants, the Isätra and Norsa SBR facilities. The results from these plants with respect to nitrification and the possibility of operating the plants under varying conditions confirms the initial findings from the late 1980s at the Bösarp plant: SBR is a viable technology for leachate treatment, as long as the main objective is to reduce nitrogen, and especially ammonia nitrogen. A very good relation between nitrogen loading and nitrification rate was found at the Norsa plant. The results from this plant also confirm the temperature influence on the nitrification rate. The maximum rate >2 g N_{ox}/kg VSS/h is still substantially lower than what has been found in small scale tests.

At both Isätra and Norsa plants very low heavy metal contents are found in the leachate. This pattern is also found at other sites operated with landfill in the methanogenic stage. It is thus, important to carefully define the operational conditions for landfill before any clear statement is made regarding the heavy metal content in the leachate. It cannot be claimed unconditionally that a discharge of leachate will include leakage of heavy metals at hazardous levels. The fact that the leachate has low levels of heavy metals, however, does not allow us to conclude that it is not hazardous, as other complex organic agents may be present. On the other hand the successful nitrification of ammonia nitrogen can be seen as a detoxification action, and as a fact is used as an indicator on the toxicity in wastewater.

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