BALTIC SEA ENVIRONMENT PROCEEDINGS

No. 25

SEMINAR ON WASTEWATER TREATMENT IN URBAN AREAS

7—9 September 1986
Visby, Sweden

BALTIC MARINE ENVIRONMENT PROTECTION COMMISSION
– HELSINKI COMMISSION –

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REDUCTION OF NITROGEN *

*) The state of advanced biological wastewater treatment in the FRG, presented by Dr. I. Sekoulov, was not available for printing

PREFACE

The Seventh Meeting of the Helsinki Commission, 11-14 February 1986, approved a Swedish invitation to a seminar on Wastewater Treatment in Urban Areas to be helt in Visby 7-9 September 1986. The seminar was organized jointly by the National Environmental Protection Board (SNV) and the Swedish Water and Waste Water Works Association (VAV). Some 40 people took part in the seminar and the following countries were represented: Denmark, Finland, the Federal Republic of Germany, the Polish People's Republic, Sweden and the Union of Soviet Socialist Republics.

Director General Valfrid Paulsson, SNV, opened the meeting and presented the background to the seminar and stressed the importance of measures against pollution from urban areas. The Executive Secretary of the Helsinki Commission, Professor Harald Velner, concluded the seminar by expressing his acknowledgement to the organizers of the seminar and to the host municipality, Gotland, and he said that the seminar had been a corner-stone for future activities.

All participants were very positive to the seminar and found it an excellent forum for the generation of good new ideas. These in turn may be used as fuel for the projects under the Helsinki Commission. It was strongly stressed that a continuation of the seminars is of utmost importance.

The authors are considered to be responsible for the contents of their papers. The Helsinki Commission is not responsible for any statements made or opinions expressed in this publication.

URBAN RUNOFF - SWEDISH EXPERIENCE

Mr. Jan Falk
National Environmental Protection Board
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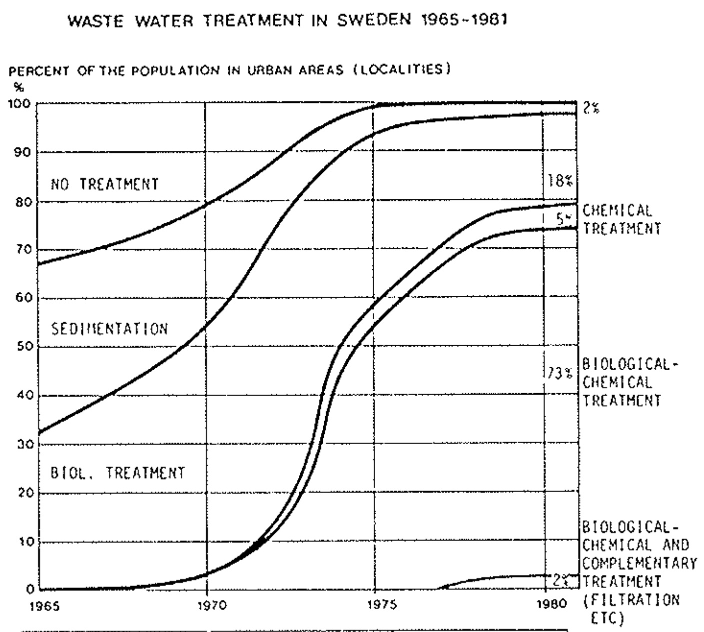
INTRODUCTION

During the past 20 years hard effort has been devoted to the protection of rivers, lakes and the sea from pollution. This effort has mainly been focused on the obvious sources of pollution i.e. the concentrated outlet of sewage. Currently 75 % of the urban population is served by advanced treatment plants, see Figure 1.



TYPE OF WASTE WATER TREATMENT	NUMBER OF TREATMENT PLANTS	NUMBER OF PERSONS SERVED
NO TREATMENT		7 000
SEDIMENTATION	117	140 000
BIOLOGICAL	317	1 258 000
CHEMICAL	166	312 000
BIO-CHEMICAL	654	5 020 000
BIO-CHEMICAL WITH FILTRATION	27	123 000
	1 281	6 865 000

Figure 1. Waste Water Treatment in Sweden 1965-1981. (Hultman and Moore, 1982).

Not until recently attention was paid to sewerage. The official policy was that separate storm sewers was the only acceptable system and discharge permits generally required separation of existing combined sewers. As all combined sewers were to be abandoned there was little concern about overflows.

The overall results of the anti-pollution measures so far are a sharp decrease in discharged amounts of oxidizable organic substances and phosphorus since the 1960's, Figure 2.

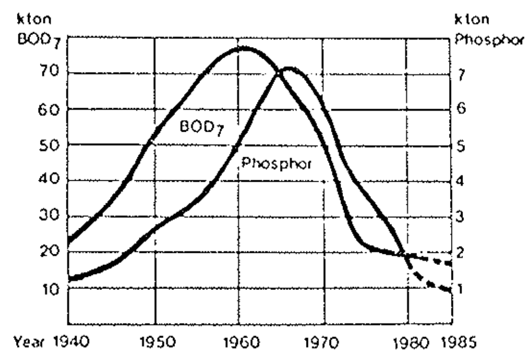


Figure 2. Discharges of BOD_7 and P in wastewater from urban areas 1940-85. (Water in Sweden, 1977.)

The relative importance of the management of storm water and combined sewer overflows thus increases with the improvement of treatment facilities. The sources are much more difficult to handle as the pollution occurs during single events having a statistically distributed effect on the receiving waters while the discharge of waste water is fairly stable concerning quantity as well as quality.

Sweden has today some 70 000 km of wastewater pipes, 47 % of which is for sanitary sewage collection, 39 % for storm water collection and 14 % for combined water. Annually another 1 700 km are constructed: 60 % for sewage water collection and 40 % for storm water collection.

In 1981 the total investment in sewerage and treatment plants amounted to 1 230 million SEK. The investment in sewers only amounted to 380 million SEK. The costs for operation and maintenance were estimated at 820 million SEK for treatment plants and 320 million SEK for the sewage network. The costs for operation and maintenance of the sewage network is estimated to be 650 million SEK by 1990. Today a sewage pipe in Stockholm is renewed on average once every 500 years while the assumed lifetime is less than 100 years.

POLICY

The policy of the environmental authorities has been that all combined sewers should be replaced by a sewer system with separate storm sewers. This was a very simple and very expensive plan for renewal. The costs for a replacement of combined sewers, not including house connections in Stockholm was estimated at 1 225 million SEK in 1983.

The 1970's research in the quality of urban storm runoff revealed that the runoff from highly urbanized areas was very polluted. The long accepted "truth" that a separated system is to be preferred from a pollution point of view thus was questioned.

Research in the 1970's also focused attention on the possibilities of a substantial reduction in storm water

runoff by using different methods to infiltrate the storm water.

These facts resulted in a policy change at the Swedish Environment Protection Board (SNV). In a letter to all Swedish municipalities SNV declared in December 1978 that impending requirements for separation of combined sewers could be revised provided the local authority presented a rehabilitation plan. General guidelines showing what a rehabilitation plan should include were published in 1978 (SNV, 1978). More elaborate guidelines were published in 1983 (SNV 1983 a, 1983 b).

The rehabilitation plan concept was launched by the SNV and the focus has been on the environmental aspects. As the existing sewer system however represents an immense value the development of rehabilitation plans are also in the interest of the water and sewage works. This has urged the Swedish Water and Wastewater Works Association to publish guidelines for the strategy of planning, maintenance, renewal and improvements of the water supply and sewerage networks (VAV, 1987). This strategy may be looked upon as a continuation of and compliment to the work carried out by SNV and where the economical aspects are more in focus.

The aim of storm water management is formulated by SNV (SNV, 1983 a) as:

> to manage storm water in a way that minimizes nuisances for buildings and environment and that minimizes the costs of investments, operation and maintenance.

This aim may be reached if the following means are regarded:

- the prevailing water budget conditions should be considered when planning an urban area

- storm water should be managed at the source when possible

- measures should be taken to prevent a deterioration of the quality of storm water

- the risks for surcharges and shock loading should be minimized by using all possible means of flow equalization

- heavily polluted storm water and combined sewer overflow should be purified before it is discharged in a receiving water.

A set of new tools are as of today ready for use, making it easier to achieve the aim set above, for example:

- Mathematical modelling of the urban runoff process - better decision making

- Swirl concentrators at combined sewer overflows - less pollution

- Renovation instead of rebuilding (see paper by Pär Sandin) - cost effective

- CCTV-inspections - malfunctions discovered

- Database for key information on the sewerage network - easier planning.

Most permits today for discharge of treated wastewater contains a paragraph which says that a rehabilitation plan for the sewage system should be devised. This plan has to be approved by the environmental authorities.

STORMWATER

During the 1970's some investigations were carried out to determine the quality of stormwater. This information together with results from our neigbouring countries have been summarized and generalized for planning purposes, see for example Malmqvist, 1983.

You must bear in mind that it is difficult to predict the quality of stormwater. The variation in average quality between a clean and a dirty catchment area may be of a factor ten. For one single catchment the variation in quality during different runoff events may be of a factor three. Very often you also have a variation during one specific runoff event, with the most polluted water entering the sewers in the beginning of the event, the so called first flush effect.

In spite of all these difficulties to predict the quality of stormwater a method was derived to estimate yearly volumes and pollution load via stormwater by means of simple hand calculation procedures (Falk 1986, 1987). The method is appropriate for areas with a separate stormwater system and gives as result the direct runoff due to precipitation. This means that water entering via connected drains and infiltration not is considered. The calculation method may also be used eventwise.

The stormwater runoff volume during the year considered may be calculated according to

$$Q_{year} = a \cdot A \cdot (Pr-b) \cdot 10^{-3} \quad m^3$$

where a = constant showing the portion of impermeable surfaces that is drained via the stormsewer network

a may be estimated according to

Land use	a
Single family houses	0.5-0.6
Multi family houses	0.6-0.7
Downtown areas	0.8-1.0

A = total area of impermeable surfaces in the catchment area (m^2). Varies from 10 to 100 % (single family houses sparsely distributed to downtown areas)

Pr = total amount of precipitation during the considered year (mm)

b = total loss of precipitation due to depression storage (mm).

b may for a year be estimated to 50 mm for steep areas and to 100 mm for flat areas.

The yearly outlet of pollutants may be derived by multiplying the volume calculated above with average pollution concentrations according to Table 1.

	COD mg/l	Oil mg/l	N_{tot} mg/l	P_{tot} mg/l	Pb µg/l	Zn µg/l	Cu µg/l
Single family houses	70	0.2	2.0	0.3	75	150	35
Multi family houses	100	0.4	2.0	0.3	150	200	50
Downtown areas	150	1.0	2.5	0.4	230	400	100
Traffic areas	200	2.0	2.0	0.3	230	250	50
Industrial areas	110	2.0	3.0	0.4	140	500	130

Table 1. Average concentration of pollutants in stormwater (Falk 1986, 1987).

The method should give an accuracy of ± 30-50 % as regards volumes. For pollution load calculations the accuracy of course is smaller. It is strongly advised to support the calculations by at least some measurements of quantity and quality on location.

The total amount of oil discharges via the stormwater networks for all urban areas in Sweden (4 900 km^2) may as an example be calculated for an average year. The following assumptions are made:

a = 0.6
A = 30 % of 4 900 km^2
Pr = 700 mm
b = 50 mm

$$Q_{year} = 0.6 \cdot 0.3 \cdot 4\,900 \cdot 10^6 \cdot (700-50) \cdot 10^{-3} = 573 \cdot 10^6 m^3$$

However only 80 % of the urban area is served by a separate stormwater system, which gives a corrected runoff volume of:

$$Q_{year} = 0.8 \cdot 573 \cdot 10^6 = 460 \cdot 10^{-6} m^3$$

Assume further that the average concentration is 0.4 mg/l. The yearly load F_{oil} then becomes

$$F_{oil} = 0.4 \cdot 460 \cdot 10^6 \cdot 10^{-3} = 185 \cdot 10^3 \text{ kg}$$

The calculations show that the total yearly load of oil via separate storm sewers is of the order-of-magnitute 200 tons.

COMBINED SEWER OVERFLOWS

During the 1980's some investigations on combined sewer overflows were performed (see for example Berndtsson et al, 1986). Figure 3 summarizes the results from those monitorings. In the figure the minimum and maximum levels of the concentration pertaining to each constituent are shown together with a class interval in which 50 % of the values occur.

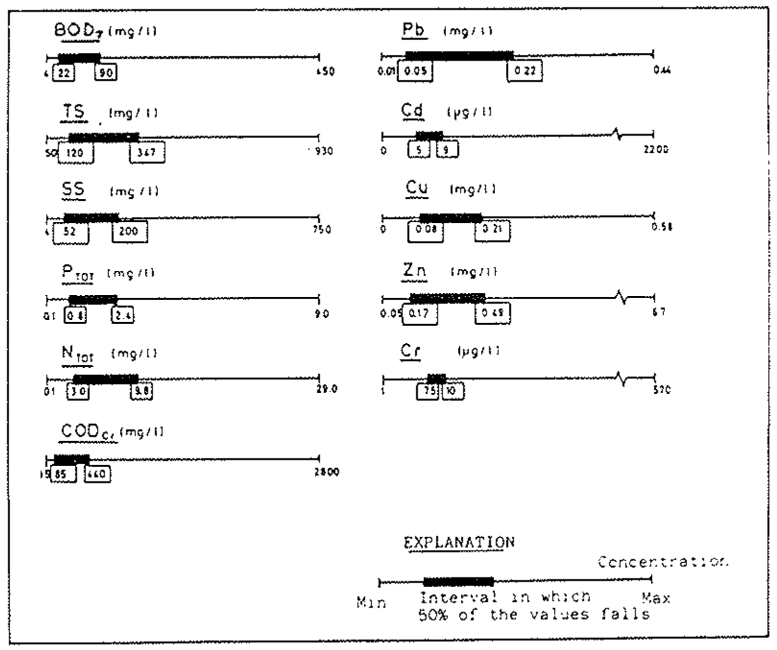


Figure 3. Combined sewer overflow discharge quality representative of Sweden (Berndtsson et al, 1986).

The values given in figure 3 may be used in simple calculations of pollution load due to overflows. However it must be noted that values indicated rest on a limited data base.

It is more difficult to derive a hand calculation method for combined sewer overflows (CSO) similar to the method above for stormwater. This depends on the fact that there is no simple way of estimating the CSO-volume. In this context you have to rest on the mathematical methods available.

The investigations carried out in Sweden show that yearly overflowing volumes vary from 0.1 % to 10 % of the volume going through the sewage treatment plant.

In this context a warning must be issued for using methods that rest on dilution when calculating pollution load due to CSO. In such a method the pollution load is calculated as the sum of the products volume and concentration for wastewater and stormwater at the overflow location. In flat areas especially a considerable sedimentation takes place during dry weather flow. The high discharge during overflows erode this material, which results in far larger pollution load than the calculation method shows. For some monitored CSO's the pollution load calculated by the dilution method was underestimated by two to five times when compared with what was measured.

CONCLUDING REMARKS

When managing stormwater from urban areas, and trying to minimize its pollutional impact, you should use all possibilities to meet the potential problems as close to source as can be done. Figure 4 shows how you can use source control measures, and if you are not able to take measures there, downstream control.

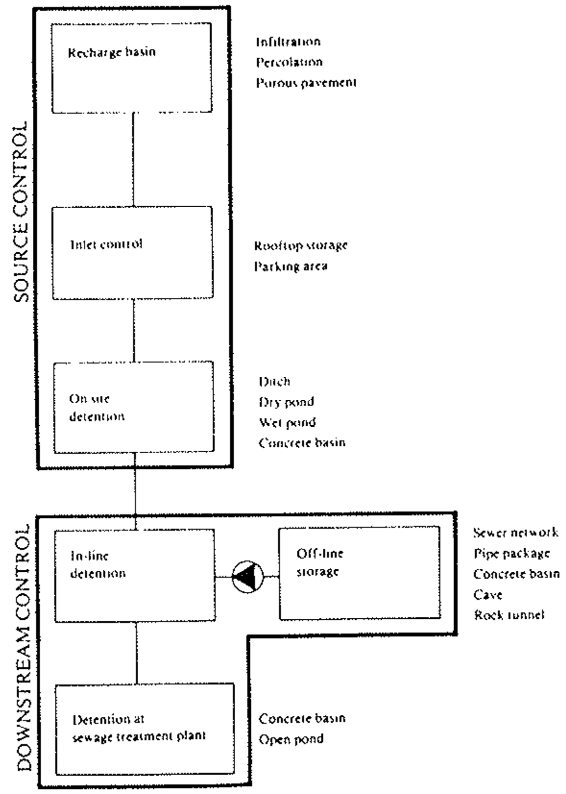


Figure 4. Scheme of how flow equalization basins can be systematized according to their technical configuration and their location in sewer system (Stahre, 1982).

It is not only in Europe we are using source control. Fujita (1984) describe an Experimental Sewer System (ESS) to cut down pollution in Tokyo. Figure 5 shows the symbol mark of ESS, saying clean water you dispose of in the ground and dirty water you convey to a treatment plant via sewers.

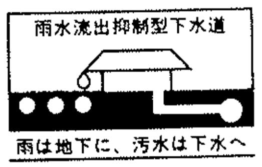


Figure 5. Symbol mark of E.S.S.

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SEWERAGE SYSTEMS: OVERFLOW PROBLEMS AND RENOVATION METHODS

Mr. Unto Tanttu/Plancenter Ltd/Finland

0 INTRODUCTION

Total investments in Finland (1984) spent on sewer systems were roughly FIM 590 million. A big share, about 14 % of this sum (FIM 82 million), was spent on rehabilitation of networks. But is this still enough? According to some evaluations the respective amount should be about FIM 500 million for rehabilitation only. So the question, how to keep the performance of sewer networks satisfactory in the future, is really important.

The overflow problem is one of the most serious problems caused by old and improperly working sewer systems. Anyhow, several other aspects of a poor condition of sewers are to be seen:

- excess hydraulic loading of treatment plants
- normal maintenance and operation (flushing, opening of clogs) increases and is more expensive
- unexpected renovation works and interruptions in operation cause e.g. troubles in traffic, odour problems in the environment, hygienic hazards etc.
- the performance of other underground networks (water pipes, district heating pipes etc.) may be threatened by earth crushings due to old sewers

In this paper a short description of these items is presented as well as a description of the sewer renovation methods used recently in Finland.

1 OVERFLOW OF SEWERS

The overflow problem is often seen to be in close connection with infiltration of ground water to sewers or with surface waters in combined systems. The bigger the excess water flow rate is, the bigger is the overflow straight to the recipient due to the insufficient capacity of the whole system (network and a treatment plant). Anyhow, there are also other aspects of overflow:

- water from the recipient (lake, river) may flow straight into the sewer and cause total mixing and circulation of surface waters with waste waters
- in practice the most visible effect of overflow is the flooding of basements; often it causes rather big costs and other difficulties in the operation of the whole sewerage system.

According to the guidelines of water authorities the pollutants of the bypasses are added to the effluent pollutants, when the overall performance of the whole treatment system is evaluated. Usually there is the question of controlled and measured bypasses at the treatment plant. But still uncontrolled overflows occur in any place within the network to some extent, and so far good means to evaluate or measure the amounts of these overflows have not been found.

One step to improve the situation is to carry out a so called excess water survey in the network. This means flow measurements during nights for a rather short period, and the target is to find the parts of the network with the highest infiltration rate (see later 1.3). However, this does not yet tell anything about the actual overflow amounts of network, this kind of survey only gives basic information about the condition. Anyhow, this measure has been found to be the start to the development. At the moment water courts, who give the permits of sewerage discharges, normally enjoin the sewerage works to carry out the excess water survey as one of the conditions of the permit.

1.1
Reasons for overflow problems

The basic reason for the overflows is the infiltration of excess waters straight into the main pipelines. This can be due to a broken or damaged pipe wall, roots, improper fittings etc. All these are consequences of poor pipe materials, improperly done mountings, earth movings etc. Exact figures of the shares are not available.

Concerning pipe materials Finland is currently one of the most prominent countries in using PE and PVC as sewer pipe material. Roughly 75 % of the total pipe length has been constructed by using these materials. Anyway, no exact correlation between the new materials used and good tightness has been found. Frost, improper installation, earth moving etc. have caused infiltration problems in rather new plastic lines whilst many cases have shown old, concrete pipes to be in a good condition.

Very often the leakage inflows to sewers have occurred through manholes, especially through covers, uppermost joints and pipe joints. The importance of this matter has grown e.g. so, that the Associations of both Finnish Cities and Municipalities have published recently a guideline booklet: "Renovation of sewer manholes".

Problems have also been caused by old house sewers, by declined manholes, whose bottoms have been improperly designed, and by drains connected to sewers.

1.2
The sewerage rehabilitation program

One of the most used procedures in Finland is presented in Annex 1. The main phases of the procedure are:

- basic data collection
- evaluation of the overall situation, if there is an excess water problem

- systematic inspections of sewer manholes
- division of the network into suitable subareas and execution of the flow measurements
- identification of critical areas and lines
- detailed inspection of critical lines by TV-camera or visual inspections
- classification of the renovation measures which are feasible and economical in the case
- implementation of the renovation measures
- supervision of operation afterwards

To some extent specialized mathematic modelling and hydraulic analysis have also been used. The biggest problem connected with this procedure is the lack of the proper basic data.

1.3
Flow measurements

The methods used in flow measurements have been classified as follows:

- V-notch weirs and venturi flumes
- cross area/velocity methods
- measuring by pumping
- trace liquids and temperature measurements
- visual observations
- measuring the water level fluctuation in the suction tank of pumping stations
- flow analyses according to pump operation times

Mostly flow measurements in Finland have been carried out by consultants, anyhow in close co-operation with the client. The most popular methods have been moveable V-notch weirs and cross area/velocity methods. Venturi flumes are not used. The other above mentioned means are rather rarely used or are used as an additional method to some of the main methods.

Plancenter Ltd has developed a moveable V-notch weir system, which is used very widely in Finland at the moment. The schematic idea of the equipment is presented in Annex 2. The system enables flow rate measurements in sewer networks without entering the manhole. The equipment unit consists of needed amount of V-tubes, installation devices and the level detector.

The V-tube can be installed by means of a telescoping pole and fixed into the sewer pipe with its inflatable rubber sealing. The V-tubes cover the range of pipe diameters from 200 mm to 400 mm. The head of water inside the V-tube is measured with the specially designed digital level detector. The flow rate can be seen directly on the screen.

When measuring flow rates in several subareas one team of two men can operate with about 20 V-tubes. The V-tubes are installed in the daytime and the readings are taken after midnight when the consumption of water is lowest. This takes place with one level detector by the team going from point to point round the network a few times.

Flow rates are usually measured in various weather conditions. This makes it possible to find the amount and main reasons of excess water for each subarea.

1.4
Example: prevention of an overflow problem in the city of Porvoo

In the city of Porvoo the main problem was overflow structures located close to the river. When the water level in the river rose, it caused an overflow from the river to the sewer system. This caused sudden peak flows later at pumping stations and at the treatment plant as well as unintentional bypasses which were not under control. Raising of the weir level permanently was not possible because of basement floodings. So this problem was solved by constructing an adjustable overflow mechanism, presented in Annex 3. But still there was the problem with flooding of basements, if the flood occured simultaneously in the sewer system and in the river. Pumping of all peak flows to the treatment plant was not possible due to insufficient capacity of pumps, pipe lines and the treatment plant. The solution was an extra submersible pump, which pumps the peak flows straight into the river during problematic times. Even this seems to be an "unenvironmental" solution in a way, but it has at least two very important advantages compared with the previous situation:

- flooding problems of basements are prevented
- all overflows straight to the river are now under control

Of course, the target in the future is to cut away all these overflows by the rehabilitation program of the whole network.

2
RENOVATION MEASURES

2.1
Surface water arrangements

Two items are needed for the inflow problem: the hole in the sewer and excess water. The simplest way to decrease excess water amounts in the sewer is to prevent flowing of these waters into the pipeline. This can often be done very easily e.g. by leading surface waters in another direction. This type of renovation measure has often been found the most economical and effective way of minimizing the disadvantages due to leakage inflows.

2.2
Reconstruction

Though usually being an expensive method, reconstruction is the type of renovation used very often. The good result is sure, the capacity of the reconstructed line is easy to fix beforehand, and the whole working process is based on conventional, earlier known engineering.

2.3
Pipe sliplining

Two types of sliplining methods have been used:

- continuous sliplining (Annex 4); PE-material is used, first projects over ten years ago in Helsinki
- snap-together sliplining (Annex 5); linings made of short PVC-parts

Continuous sliplining is done with together welded PE-pipe, the diameter of which ranges from 40 mm to 1 600 mm. Without any special problems can a 100 - 200 m long pipe be inserted in one piece.

Snap-together sliplining is done with short (0,5 - 3 m) PVC-parts diameter ranging from 110 mm to 400 mm. If the 0,5 m -parts are used the work can be done from a manhole.

The prices of sliplining methods have varied between 10 - 60 % usually 30 - 40 % compared with those of total reconstruction.

2.4
Insituprocess (Insituform)

Coating the pipe line with English Insituform method is done by the Finnish contractor. The process is shortly described (see Annex 6):

The terylene stocking is filled in the workshop with polyester-liquid. The liquid amount is calculated exactly beforehand. On site the stocking is inserted into an inversion tube. The end of the lining is turned inside-out and attached to the end of the inversion tube. Cold water is pumped into the inversion tube, forcing the material inside-out and into the damaged pipeline. The polyester now lies against the pipe wall. Once the lining is fully extended, the cold water within the pipe is re-circulated through a boiler. This heat process cures and hardens the thermal-setting resin.

The process is mainly used in dense city areas (Helsinki, Turku) and in industry. For the present about 20 km is the total length of the repaired lines. The oldest objects are over 5 years. The experience is that the repaired lines have been absolutely tight and have stayed in good condition.

Current costs of insituform repairing are about: DN 250 mm pipe 1 000 FIM/m and DN 500 mm pipe 2 000 FIM/m. These sums include all costs, that means, the contractor carries out all works needed in the process, e.g. finding the connections by TV-inspection, cutting the connections, flushings, water supply etc. The time needed for one project is about one day.

2.5 Pipeline Insertion Machine (P.I.M.-method)

The newest method used in Finland is an English P.I.M.-method (ALH Systems Limited). The first projects were carried out in 1985 and for the present only about 2 km is run by this method.

The idea of the system is to both pull and push the torpedo-shaped, hammer action pipe breaker through the existing pipe, break it up and pull a sleeve pipe of appropriate length and diameter into the void behind it (Annex 7). The purpose of the sleeve pipe is to protect the new polyethylene pipe section, which is then pulled through the sleeve, from damage by metal fragments from the broken pipe.

The unit costs are a little bit higher than those in Insituform. Mostly the cases are economical, if there is a need to enlarge the pipe diameter.

2.6 Renovation of manholes

Several ways of manhole renovation have been used, as e.g.:

- to use the smaller diameter plastic manhole inside the old one and repair the bottom channels
- to change the uppermost rings and isolate the chamber
- to cast the manhole inside by using a special casting mould
- to install new plastic pipes through the manhole
- to coat inner walls by shotcrete
- to prevent the moving of rings due to frost by installing a two-layer plastic film outside the wall

Pre-fabricated, polyester-made elements are not used in Finland. Normally the costs of the above mentioned methods have varied from 1 000 FIM/piece to same thousands of FIM/piece.

RENOVATION OF THE STOCKHOLM SEWERAGE SYSTEM

Mr. Pär Sandin, Chief Engineer
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Sweden

Within a few years Stockholm will let all its treated wastewater into the Saltsjön. The Saltsjön is the inner part of the Stockholm Archipelago, which is one of the finest recreation areas in Sweden and where many Stockholmians spend a great deal of their leisure time. That is one reason why it is so important that all wastewater is treated before it reaches the recipient. A sewerage system in bad condition means that the risk of not allowed/unplanned overflows is increased.

In order to prevent overflows we drafted "Plan 83" which tells us how our sewerage system shall be constructed in the future and what measures has to be made in the system.

Renovations of the existing pipes is one method to get a well functioning sewer system. Today we have made about 50 different objects at a total length of 6 000 m. Why do we renovate sewers and why are we attempting to develop methods for piperenovations?

Firstly: Renovation of a sewer involves far less desruptions to traffic.

Secondly: The cost of conventional pipe laying has increased considerably during recent years. The cost of a pipe-laying project in the centre of Stockholm is currently about SEK 10 000 per metre of pipe trench. It is therefore natural for us to try to use the hole that is already in the ground, i.e. the existing pipe. Renovation may often prove less expensive than conventional re-laying. At best, a renovation may be half the cost of re-laying.

Thirdly: By trying new methods in the field, in sewers in use, we will give the different methods a chance to develop and become even better.

In order to try and develop new techniques and materials in connection with pipe renovation, Stockholm Water and Wastewater Works, in collaboration with the National Swedish Board for Technical Development (STU), has initiated a project for the acquisition of techniques in connection with the renovation of sewers. In order to furnish the project with the views of other Swedish municipalities, we have set up a reference group. Included in this group are representatives from a number of municipalities and the Swedish Water and Wastewater Association.

The scheme on which the practical work is to be done is an approximately 700 m long sewer in Beckombergavägen in the west of Stockholm. Also included are a number of approximately 15 metres long house connections that are to be renovated. On these attempts will be made to develop methods so that the house connections can be connected to the main sewer without excavation.

I should now like to make a brief summary of some methods that we use and that are currently being developed on the Swedish market.

Relining

This means that a pipe with a smaller diameter than that of the existing sewer is laid inside the existing pipe.

The space between the new and the old pipes can be filled with cement mortar in order to achieve greater strength.

The material most used for new pipes is PE, other materials can also be used.

The method means, however, that access pits have to be excavated and that the connection of, for instance house connections have to be dug up. Providing that the existing sewer does not have too many connections, and that the reduction in area, which may be quite considerable, is acceptable, this is a very good method.

Progress is, however, being made. Today there are new methods for the renovation of sewers which, although not fully developed, are completely usable.

Muscle relining

A tool, referred to as a muscle, is pulled through the existing sewer by means of a chain winch. At the same time, specially manufactured fibre glass, reinforced polyester pipes (GRP-pipes), are drawn into the sewer behind the muscle, which can be opened out by hydraulic means thereby cracking the existing pipe at the same time as the new pipe is pulled through the line. In this way it is possible for a new pipe of approximately the same cross-sectional area to replace the old one without having to excavate. It is also possible to feed in pipes with a greater diameter than the old ones, and thereby increase the capacity of the sewer. I said "without having to excavate", but I should perhaps modify this. House connections will of course have to be exposed for connection, but the muscle and GRP-pipes are manufactured in sufficently long sections to permit them to be inserted into ordinary manholes.

We have tried this method on 5 schemes in Stockholm over a total line length of about 400 m.

Pipe cracking

Produces basically the same results as the muscle. The method involves the use of a self-propelling hydraulic hammer that butts its way through the existing sewer, at the same time cracking and widening it. At the same time, a PE-pipe is slid through the existing pipe. This method can also be used to replace the old pipe with a new one of a larger diameter. In this case too, house connections, have to be dug up for connection. Since the tool is so large that it cannot be lowered into the manhole, access pits have to be excavated.

Both these methods are in the process of development. Among other things, attempts are being made to find some way of making house connections without having to excavate. In connection with trials with the muscle, we have experimented with so-called mini-excavators in order to make as small excavation pits as possible. It has proved to be quite difficult to do this since we have both sewers, water supply and gas lines in the same pipe trenches. However, attempts to excavate with a so-called sunk wells have proved to be successful and have resulted in considerably narrower top widths for the pits that have had to be excavated. This of course means less traffic disruption and lower reinstatement costs.

Elastic linings

There are at present two types of elastic linings available on the Swedish market. A third method, which is a completely Swedish solution, is in the process of being developed.

All the methods involve the insertion of a soft so-called stocking into the existing sewer where it is allowed to harden, after which the sewer is put back into service.

Insituform

Consists of terylene felt that has been impregnated with polyester or epoxy. The stocking arrives at the site inside our and is already impregnated. The stocking is twisted into the sewer via a manhole by means of water. The stocking is pressed and moulded against the internal walls of the existing sewer by the water pressure. When the entire stocking is in place, the water is heated to a temperature of about 75°C for a period of about five hours, during which time the material hardens.

The material thickness is normally 6-12 mm in the case of concrete sewers of $\leq$ 400 mm diameter.

Copeflex

Consists of a fibre glass fabric that is impregnated with epoxy. By the time the stocking arrives at the site, an inflatable rubber balloon has already been pulled inside it. The stocking is impregnated on site. After impregnation, it is pulled by a winch into the sewer via a manhole. The rubber balloon is inflated with compressed air and presses the fibre glass stocking against the pipe wall. After 5-10 hours, depending on the external temperature, the material has hardened, the air is let out and the balloon removed. The material is normally about 3 mm thick in the case of concrete sewers of $\leq$ 400 mm.

Inpipe system

Consists of a fibre glass plaited stocking impregnated with epoxy. The stocking is forced into the sewer from a manhole by means of compressed air. The air pressure moulds the stocking flat against the pipe walls and the material is hardened by pulling a UV lamp through the sewer. The design allowes changes in the diameter of the existing pipe. The system is in the process of being developed and is at present only available for diameters of $\leq$ 200 mm, although it is planned to cover diameters of 100-400 mm.

As a complement to these methods there are various types of remote- and TV-controlled devices. With certain types of apparatus it is possible to open house connections from within the sewer, and with others to cut off protruding lateral connections etc. Everything in fact to avoid having to excavate.

Attempts are also being made to make watertight connections between, for example, house connections and mains without the need of excavation. Practical testing and development of this kind of apparatus and methods will be included in the acquisition of techniques that I referred to earlier.

Aqua rings

For sealing the joints on lines with diameters large enough to permit the access of personnel, internal sealing of the joints can be achieved with the aid of rubber sleeves attached in place with stainless steel straps.

Panels

In large manually accessable sewers, panels can be used. There are two types of panels: fibre-glass reinforced cement mortar panels and fibre-glass reinforced polyester panels. After the panels have been fitted in place, the

space between the panels and the existing pipe walls is filled with cement mortar. The panels can be assembled either in complete sections or in parts that are fitted together inside the sewer. The polyester panels offer the advantage of being lighter, which means that larger parts can be made.

Small diameter pipe-jacking

Since renovation is not always suitable, for example if the existing sewer has settled so much that its hydraulic capacity is quite simply insufficient, the line has to be re-layed.

And as pipeline work in build-up areas is difficult and causes all kinds of traffic problems, the development of techniques which also permit small diameter pipe jacking is welcome. As a result of this development, small diameter pipe jacking will prove to be a good alternative to renovation or re-laying.

Today there are two methods of small diameter pipe jacking available in Sweden.

The Lundby method, which is a Swedish solution, was introduced a few years ago. The method means hydraulic forcing of pipes with a diameter of 400 mm through the ground. This method has for the most part been used in clay soils.

Last year we used this method to carry out a pipe jacking scheme. During the work the soil proved to be more coarsly grained than expected. Together with the contractor we decided to supplement the steering-pipe with equipment for flushing water at high pressure and in this way try to erode the soil.

The steering pipe was equipped with a number of nozzles for high pressure flushing at a water pressure of 800 bars, which is very high. We were now able to erode soil very easily into the pipe for removal. It was possible to continuously check the pipe jacking progress and to carry it out with the same degree of precision as when jacking in clay soil. This was done by matching the water pressure in the flushing nozzles with the pressure in the pipe jacking equipment.

This year another method for jacking small diameter pipes will be introduced in Sweden. The equipment, known as the Soltau system from West Germany, can operate in both friction soils and clay soils. The soil is transported into the pipe to the pressure pit by means of an earth screw. Steering and precision is said to be of the same order as that of the Lundby method. The Soltau system also has equipment for jacking house connections down to a diameter of 150 mm, which presents new possibilities for the connecting of properties, without having to carry out extensive excavation work.

MANAGEMENT OF SEWER OVERFLOW STRUCTURE IN THE FRG

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Due to the geological morphology of the south and west of Germany, combined sewer systems are used to drain sewage and rain water in urban areas.

In this system, industrial and domestic sewage as well as rain water flowing off areas with sealed surfaces are discharged into one pipe. Size and structure of this sewer system are designed to fulfil the criterium, that the total amount of water, stemming from rain events of an intensity not to be exceeded more than once a year, can be drained without flooding any part of the area considered.

In the past, construction costs were reduced by building overflow structures at suitable sites; these structures discharge a volume of water exceeding five times the amount of water produced during dry weather (Fig. 1) in a most direktly way in the outlet channel. In the sewage treatment plant, only two fifths of this remaining water volume was treated mechanically and biologically. Three fifths were discharged into the natural waters after mechanical treatment only.

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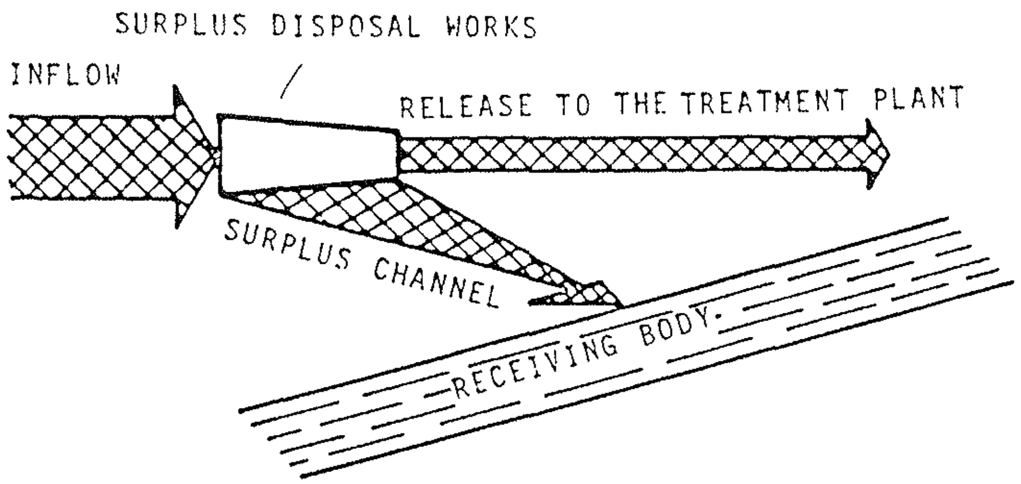

Fig. 1. Flow sheet of a surplus disposal works

These technical standards were considered sufficient until 1962. Since then, the regulations for the drainage of combined sewage and rain water have been tightened, as it became obvious that the rainwater and sewage water overflow carried a pollutant load harmful to natural waters.

Thus, regulations were formulated to define a relation between the volume of surplus water (sewage and storm water), mean low level flow of the natural water body and domestic and industrial sewage water volume, which would prevent any disadvantageous influence on natural water quality caused by combined systems (Fig. 2).

Extensive investigations on water flowing out of combined sewer overflow structures after rain events showed, that especially at the beginning of the overflow the pollution level is high, due to a rinsing effect.

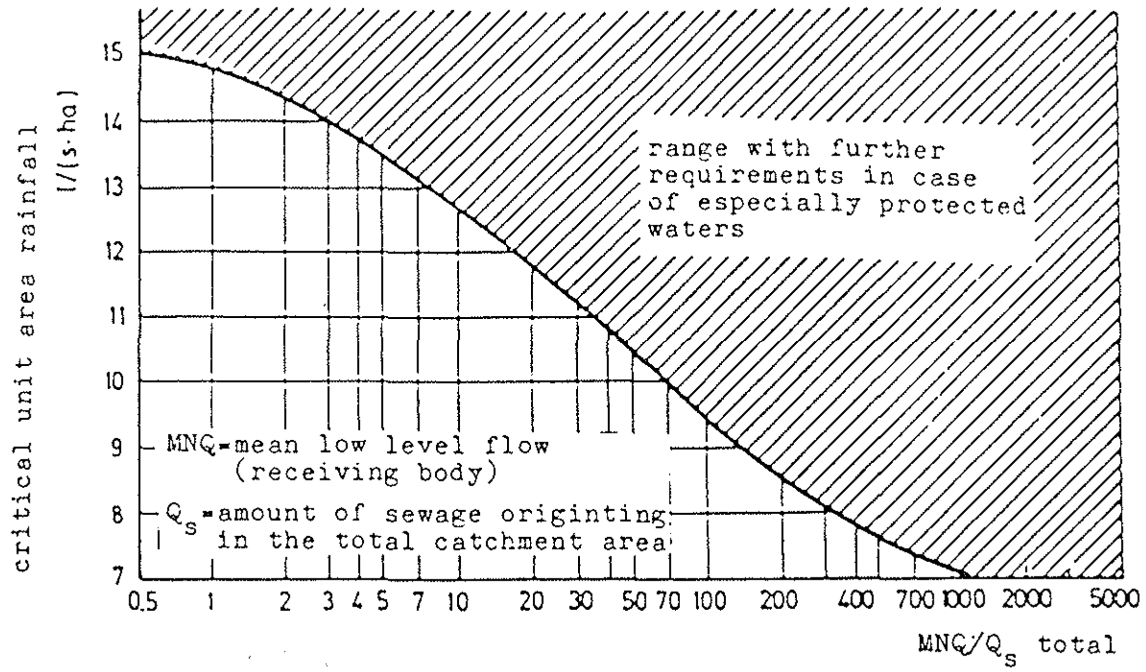

Fig. 2. Calculating of the critical unit area rainfall

Thus, technical regulations based on these results provide that the especially polluted first flush at the beginning of a rainfall is prevented to enter the natural waters and is treated in a sewage treatment plant together with the domestic and industrial sewage waters (Fig. 3) before finally being discharged. These technical regulations, published by the ATV in 1977 under the title "Design and structure of storm water overflow treatment in combined sewer systems" aim at using a system in which 90 % of the biologically degradable and sedimentable substances are discharged into and purified in a sewage treatment plant.

Usually, this is attained by constructing storm water overflow tanks in which an overflow starts only if and when a critical unit area rainfall of 15 l/s·ha is exceeded. The critical unit area rainfall refers to the sealed surfaces in the area linked to the drainage system. In most cases tanks are designed to take in the first, heavily polluted flush at the beginning of a rainfall; they are either integrated directly into the sewer system (Fig. 4) or by a shunt-like construction, linked to the main sewer system by special emtying systems (Fig. 5).

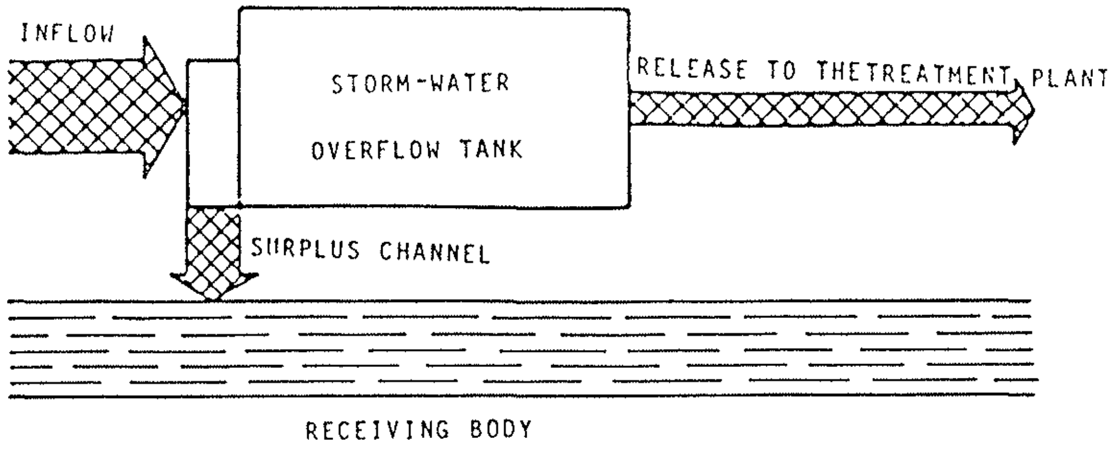

Fig. 3. Flow sheet of a storm-water overflow tank

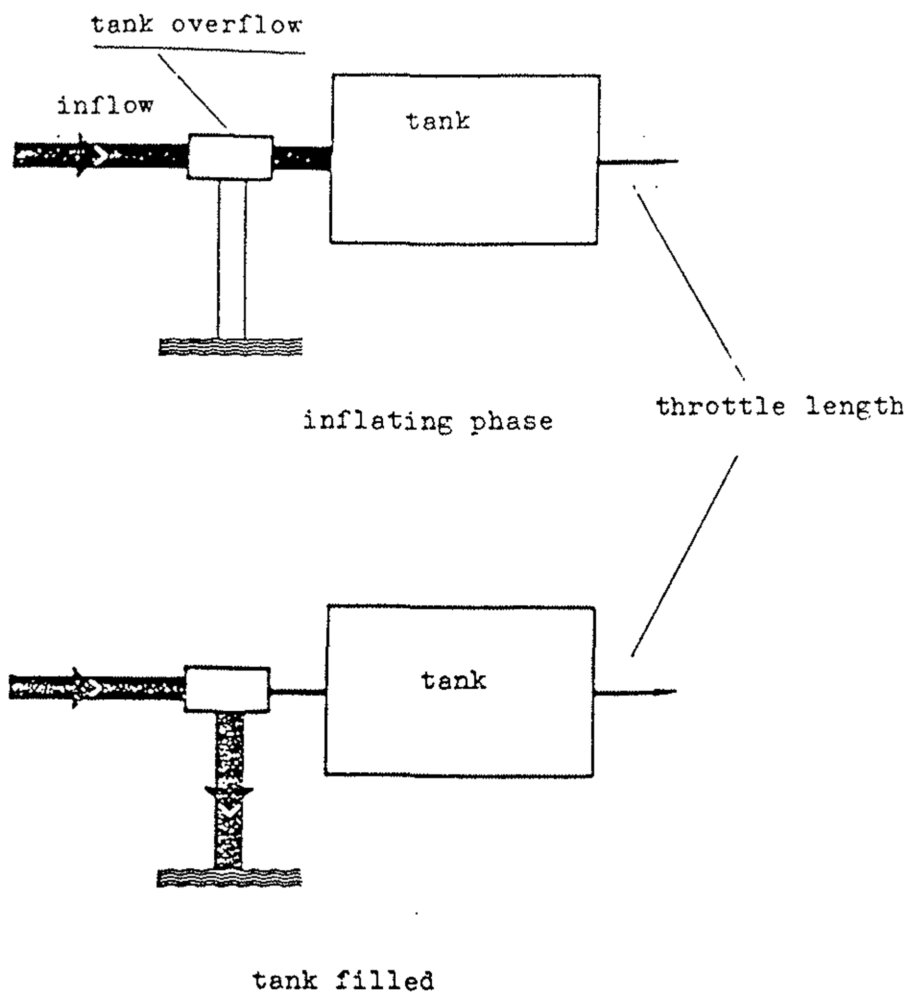

Fig. 4. Storm-water tank designed to retain the first amount of discharged storm-water (directly integrated)

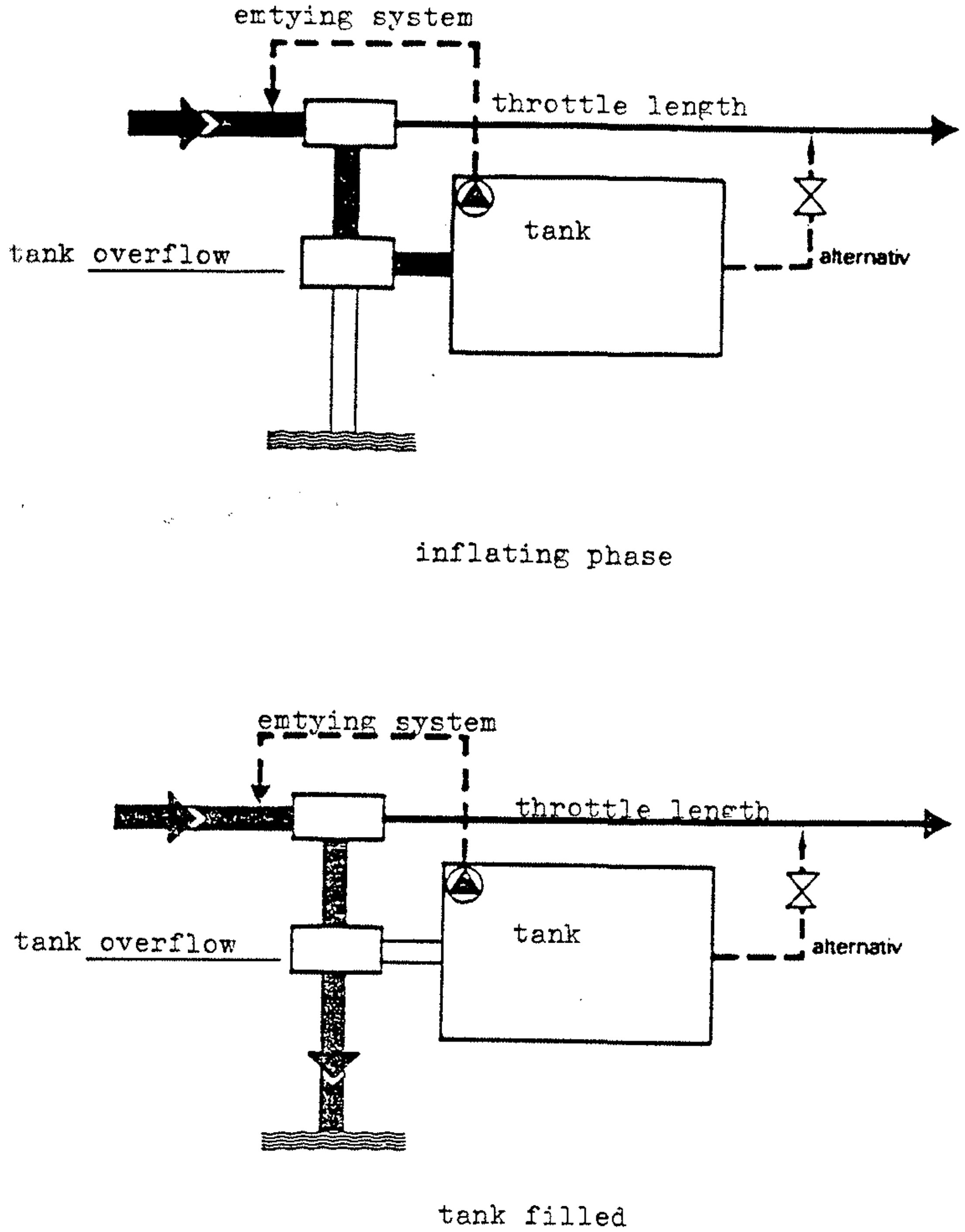

fig.5 STORM-WATER TANK DESIGNED TO RETAIN THE FIRST AMOUNT OF DISCHARGED STORM-WATER (shunt-like construction)

For the design of serial overflow tanks guaranteeing the drainage of larger areas, computer programs basing on pollutant load models were developed.

Thus, it is guaranteed that rainwater treatment and sewage treatment are regarded as one unit with respect to their influence on the natural waters.

In most of the federal states, compliance with these technical regulations, leads to an exemption of the tax for discharge of rainwater into the sewer system introduced in 1981. Due to this tax break regulation, in the southern and western parts of Germany most investments for water quality protection concern the construction of storm water overflow tanks designed to adapt existing combined sewer systems to the commonly accepted technical standards.

Around the Baltic Sea, sewer systems exist in the central areas of the cities of Lübeck, Schleswig and Flensburg. The remaining communities with more than 2000 inhabitants possess separate sewer systems. For those cities operating a combined sewer system, concepts exist for either construction of storm water overflow tanks or separation of rain and sewage waters. Progress of these projects depends on the technical and financial circumstances.

In small communities with less than 2000 inhabitants, combined sewer systems prevail. Requirements concerning rain water treatment are fulfilled by constructing sewage lagoons. In the West German part of the Baltic Sea area, the sewage water of 90 % of all inhabitants are discharged into central sewer systems and dealt with in biological treatment plants.

Where separate sewer systems are in use, rainwater is discharged into the natural waters directly. Purification steps, such as rainwater treatment basins, are required only in case especially protected waters. As in the case of the storm water overflow tanks, size and structure of rainwater treatment basins are based on a critical unit area rainfall of 15 l/s•ha, which takes care of 90 % of all storm water flow off events. The size of the basins is based on an max.hydraulic surface load of $9m^3/m^2 \cdot h$.

Pollution of natural waters is similar when either combined sewer systems with rainwater treatment or separate sewers without treatment of rainwater are applied. Thus, both drainage methods are considered equally suitable.

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CONCENTRATION LIMITS FROM A TECHNICAL STANDPOINT

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The discharge of hazardous substances in an industrial waste water can cause a number of negative effects in the sewers and in the treatment plants.

The most important of these effects are

- o Corrosion of sewers, pumping stations and treatment plants. Risk for explosion and fire.
- o Disturbances in the physical, biological and chemical treatment processes.
- o Disturbances in the stabilization and dewatering of sludge and increase of toxic components of the sludge leading to reduced usability in agriculture.
- o Detrimental impact on the ecosystem of the receiving streams and lakes.
- o Disturbances of the working environment for the operation staff, health risks, nuisance and inconvenience.

Swedish requirements governing the discharge of hazardous substances from industries into municipal sewerage systems have been put together in a list of limit values published by the Swedish Water and Sewage Works Association, VAV.

The list specifies the maximum concentrations that can be accepted at the connection point between the industrial plant and municipal network with regard to the effect on the sewers, and at the inlet to the treatment plant with regard to the treatment processes.

The technical reasons for selecting the limit values will be presented in the following.

Corrosion in the sewer system

A large part of the sewer system consists of concrete tubes, which can be damaged by acid water. The pH of the water should therefore not be lower than 6.5.

Some inorganic chemicals are also detrimental to concrete. Sulphate (and thiosulphate) ions react with the cement in the concrete and form compounds with a high specific volume (ettringite). This causes swelling and cracking of the concrete. The critical limit is considered to be 300 mg/l SO_4 and above concentrations of 1 000 mg/l the reaction is more pronounced. In gravity sewers H_2S in the water can go into the air and then dissolve in the humidity of the inner surface, where it is oxidized to sulfuric acid that attacks the concrete.

Some salts can cause the calcium in the concrete to dissolve. Magnesium concentrations above 300 mg/l and ammonium concentrations above 30 mg/l can cause concrete corrosion and must be avoided.

A system with plastic tubes is more resistant to corrosion, but temperatures above 45^{o} should be avoided.

Risks for explosion and health risks

Discharge of organic solvents should be limited as they may cause explosions in sewers and pumping stations and cause temporary and chronic injuries in the operating personel.

Examples of such solvents are

	Explosion risks	Health risks	Limit value g/m3
Hydrocarbons (alifatic) and esthers			
gasoline	x	x	< 10
kerosene	x	x	10
"white spirit"	x	x	10
buthyl acetate etc	x	x	50
Hydrocarbons (aromatic)			
bensene		x	should not occur
toluene		x	total value 10
xylene		x	
Chlorinated hydrocarbons			
choloroform		x	should not occur
carbon tetrachloride		x	" -
trichloroethylene		x	" -

The limit values for solvents have been set both with regard to the risks in the sewerage system and with regard to the effect on the treatment process.

Effects of industrial wastes on sewage treatment

Discharge of industrial wastes can result in many different types of disturbances of the treatment processes and make the sludge less suitable for agricultural applications.

The discharge of large amounts of organic substance during a short time may overload a biological treatment, especially the aeration system if it is not designed for high loads during a few hours per day.

A large discharge of industrial wastes can result in an unbalanced of organic compounds e.g. carbohydrates. This can lead to growth of filamentous bacteria and sludge bulking.

It is well known that certain inorganic compounds, e.g. heavy metals, disturb the biological treatment. The concentration of heavy metals from metal finishing industries must therefore be limited.

When assessing the impact of a certain discharge, however, consideration should be given both to the concentration and to the quantities and ways of discharge e.g. flow equalization.

The limit values have been set after an extensive survey of the litterature. The values for some of the more important metals are given below.

	Limit value g/m3	
Chromium	2,0	the sum must not exceed 5 g/m3
Copper	1,0	
Lead	1,0	
Nickel	1,0	
Zink	2,0	

In an earlier issue of the list of limit values two different values for certain metals were given. The lower value was set with respect to the risk for high metal concentrations in the sludge from the treatment plant.

Problems with too high metal concentrations have however been uncommon so the lower limit values with respect to the sludge have been omitted. The values have been replaced with guidance values for monthly means at the inlet to the treatment plant.

	Guidance value g/m3. Monthly mean
Zink	0,5
Copper	0,25
Lead	0,05
Chromium	0,03
Nickel	0,03
Cobalt	0,003
Cadmium	0,003
Mercury	0,001

Organic substances have been divided into three groups with regard to their capacity for decomposition in municipal treatment plants, toxicity and risk of biological accumulation in biological sludge and in the natural environment (water recipient and soil). These groups comprise:

I	Treatable
II	Treatable to a limited extent
III	Non treatable

Treatable substances (Group I), i.e. easily decomposed and with a low level of toxicity, can be discharged to the municipal sewage system provided their concentration in the wastewater is so low that no danger can be anticipated. However, as was mentioned earlier, one limiting factor may be the capacity of the treatment plant in that the substances in question both increase the specific BOD load and thereby affect the treatment efficiency and also require oxygen when they are decomposed, which may mean that the aerators cannot supply all the oxygen that is needed. Other factors can also be of a limiting nature, e.g. the volatility or odour of the substances or the risk of explosion.

The substances that are **treatable to a limited extent** (Group II), i.e. which are decomposed slowly and/or are toxic, are grouped into three sub-groups where the substances in Sub-group a) are least harmful and those in Sub-group c) most harmful. The factor determining in which of the sub-groups a-c the substance is placed is its toxicity and volatility. If the substance is not accumulated in the natural environment it can be discharged to a limited extent provided it cannot be expected to cause any damage.

Non-treatable substances (Group III) are such that cannot be decomposed in the treatment plant and which can be accumulated in biological sludge and in the natural environment. These substances should not be discharged to the municipal sewage system.

Substances belonging to group I are e.g.

ethanol
urea

Substances belonging to group II

many aldehydes and ketones
many alcohols and esthers
turpentine, petroleum spirits, mineral oil etc

Substances belonging to group III (should not be discharged)

chlorinated hydrocarbons
many aromatic compounds

The limit values vary considerably for the different compounds and the reader is referred to the list of limit values.

It is not possible to list all substances that might be discharged from industries. The fact that a substance is not included in the list does not mean that is can be discharged freely into the sewer.

Even if many of the limit values apply to the concentration in the inlet of the treatment plant, the requirements should also normally apply at the connection point between the industrial plant. The assumption cannot be made that a dilution always will occur in the sewers. Exemption from this requirement necessitates a closer examination of the dilution conditions.

LIMIT VALUES IN SPECIAL AGREEMENTS BETWEEN FACTORIES AND SEWAGE WORKS

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Finland

1 BACKGROUND

The operation of sewage works is controlled in Finland by the water and health authorities. These authorities set special quality demands for the effluent from sewage treatment plants into the recipient. Also other wastes from treatment plants, mainly sludges, have special regulations and operational target values.

Sewage works have to achieve the aim goals and limit values set. In order to fulfill the regulations, sewage works impose such limit values on factory wastewaters that there will be no problems at the treatment plants. Sewage works can act in two ways:

- require the factory to operate in such a way that the limit values are not exceeded
- the factory pays a certain sum of money to the sewage works, which takes care of the whole problem.

It can be said in general, that it is not possible to get rid of harmfull substances by payment to the sewage works if the substances cause treatment problems or problems in sludge disposal.

If the factory produces wastewater that contains a higher organic load, more suspended solids or a higher nutrient load than normal sanitary wastewater, the problem is most often solved by paying an extra fee to the sewage works.

2 LIMIT VALUES IN SPECIAL AGREEMENTS

In general the requirements are fairly similar in all of Finland. Naturally there are also differences, but these are due to earlier permits with less strict goal levels. Most often the regulations concern the following:

- operational limitations
- wastewater control
- pre-treatment control
- duty to inform water authorities
- sludge disposal
- amount of heavy metals

2.1 Examples

2.1.1 Acids and Alkalies

Acids and alkalies can be discharged if the pH-value is between

6 - 11 (Helsinki)
6 - 10 (other parts of Finland)

2.1.2 Organic Solvents

Group 1

Very hazardous, not soluble in water (diethylether, petrolether)

- discharge prohibited

Group 2

Hazardous, not soluble in water (toluene, xylene, cyclohexane)

- discharge mainly prohibited
- if it is not possible reasonably to remove these from the wastewaters, their total amount may not exceed 3 mg/l

Group 3

Non-flammable, not soluble in water (dichlormethane, chloroform, carbon tetrachloride)

- discharge prohibited

Group 4

Flammable, soluble in water (alcohols)

- mainly no limits

2.1.3 Poisons, First Class

Discharge is prohibited in general. The only exceptions are weak solutions as follows:

Cyanides, limit value 0,5 mg/l

Formaldehyde, limit value 50 mg/l

Phenols, limit value 10 mg/l

Discharge of unused reagents, for instance, is not permitted even after dilution with water.

2.1.4 Heavy Metals

Because of the general trend in Finland that all sewage works dispose of their sludges for useful purposes, there are also recommendations for sludge disposal. The following limit values for heavy metals are imposed when sludge is used for agricultural purposes:

Substance		Max. concentration mg/kg TS
Cadmium	(Cd)	30
Cobalt	(Co)	100
Chromium	(Cr)	1000
Copper	(Cu)	3000
Mercury	(Hg)	25
Manganese	(Mn)	3000
Lead	(Pb)	1200
Nickel	(Ni)	500
Zinc	(Zn)	5000

Maximum amount of cadmium is 100 g/hectare every five years.

The following table gives the concentration limits and maximum loads for heavy metals set down in agreements between plating plants and the Helsinki City Water and Sewage Works:

Substance	Concentration mg/l	Load g/d
Zn	5...10	300...500
Cr	1...3	100...300
Ni	1...2	50...100
Cu	1...3	100...300
Pb	1...3	100...200
Cd	0,01	0,5...1
Hg	0,01	0,5...1

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THE CONDITIONS FOR INDUSTRIAL EFFLUENT DISCHARGES TO THE MUNICIPAL SEWERAGE SYSTEM

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The industrial waste waters of an urban area are jointly treated with municipal sewage waters. The operation of the municipal sewage treatment plant depends substantially on the quality and quantity of industrial waste water conducted to the treatment plant for joint treatment and drainage. In order to guarantee the normal run of the plant a number of normative documents have been worked out /1, 2/ regulating the discharge of industrial effluents to the municipal sewer network. Detailed requirements for individual industrial enterprises have been elaborated on the grounds of these documents by the local bodies of Water Supply and Sewage Management. The local requirements are coordinated with the institutions for the regulation of water utilisation and water conservation under the USSR Ministry of Land Reclamation and Water Conservation and the Ministry of Fisheries and are confirmed by local municipal authorities. Control over the implementation of obligations is exercised by Water Supply and Sewerage Management authorities.

The discharges of industrial effluents to municipal sewer network have to meet both general and specific requirements. The general requirements are viewed below.

1. Industrial effluents may be discharged to municipal sewer network in case if they do not affect the operation of the sewer system or its separate structures; provide the safety of their operation and after joint treatment with municipal - domestic sewage satisfy the requirements and standards of "The rules for protection of surface waters from pollution by sewage waters".

2. It is prohibited to discharge to municipal sewerage system industrial waste waters containing substances, which could obstruct the pipes, wells, screens or deposit on pipe walls, wells and screens (cinder, lime, gypsum, metallic chip, etc); substances impairing the materials of pipes and elements of sewerage installation; harmful substances which could hinder the biological treatment process of waste waters; harmful bacterial contaminants; insoluble oil, resin, fuel oil; biologically heavily oxidizable substances; biologically "hard" SAA (surface-active agents); suspended and volatile solids the concentration of which exceeds 500 mg/l; substances for which limiting permissible concentrations (LPC) have not been established in the water bodies used for drinking - domestic, recreational and fishing purposes.

3. It is prohibited to discharge to the municipal sewerage system of acids, combustible impurities, toxic and soluble gaseous substances (in particular solvents: petrol, diethyl ether, benzene etc) which may constitute in the sewer network and installations toxic gases (hydrogen sulphide, carbon bisulphide, carbon monooxide, hydrocyanic acid, vapours of heavily volatile aromatic hydrocarbons and others).

4. It is prohibited to discharge into municipal sewerage system sewage waters the composition of which could rise the amount of pollutants of the receiving waterbody above the permissible amounts; industrial waste waters with the temperature above 40°C pH being below 6.5 or over 9, COD 2.5 times higher than BOD_5 or 1.5 times higher of the BOD_{tot}, concentrated mother and still liquor.

The permissible concentrations of pollutants in industrial waste waters are calculated by the bodies of Water Supply and Sewerage Management according to the following scheme.

1. The amount of pollutants in the treated effluents discharged to the waterbody is determined according to "The rules for protection of surface waters from pollution by sewage waters" and approved by water conservation bodies of the USSR Ministry of Land Reclamation and Water Conservation and the Ministry of Fisheries.

2. The maximum content of pollutants in municipal sewage waters subject to treatment are determined with regard to the treatment efficiency. If municipal sewage water is treated by biological methods the maximum permissible concentration of pollutants must not exceed concentration limits announced for biological treatment of waste waters.

3. The concentration of pollutants in industrial effluents is determined with regard to the dilution degree of industrial and municipal waters and so as not to exceed the concentration of mixed waters allowed to enter the municipal treatment unit. In cases if the enterprise has its own treatment plant for removal of specific pollutants (petroleum hydrocarbons, heavy metals, etc) the degree of treatment of industrial wastes is determined on the account of the possibilities of these plants.

The industrial enterprises are obliged to control regularly the quantities and qualitative content of industrial waste waters discharged to the municipal sewerage system. The content of waste waters is analysed in the laboratory and the quantity of discharged waste water measured in the control well. Industrial waste

water, as a rule, should be conveyed to the municipal sewerage system by separate outlets connected with control wells located outside the territory of the enterprise.

Returns about the volume, quantitative content, the regime of waste water discharge to the municipal sewerage system are to be delivered systematically to the bodies of Water Supply and Sewerage Management.

The calculated concentrations of pollutants in industrial effluents from Tallinn are brought as an example. The municipal discharges from Tallinn amounts to 370 000 m^3 per day and are converted by deep sea outlets to the Tallinn Bay to the depth of 25 m. The dilution degree at a distance of 250 m, the radius of the protection zone for fishery,is 65. The dilution degree considering the LPC for fishery, the permissible concentration of several pollutants in treated effluents are presented in Table 1.

Table 1. Permissible concentrations of pollutants in treated effluents discharged from Tallinn.

Pollutant	LPC mg/l for fishery	Background concentration in Tallinn Bay	LPC after treatment, mg/l
Chromium	0.001	-	0.065
Copper	0.005	-	0.325
Iron	0.05	-	3.250
Zinc	0.05	0.02	1.970
Nickel	0.01	-	0.650
Cadmium	0.01	0.0004	0.610
Lead	0.01	0.006	0.270
Mercury	0.001	0.0001	0.059
Arsenic	0.01	-	0.650
Phosphorus TOT P	0.1	0.027	4.770

The calculated concentration of pollutants in municipal sewage waters conveyed to treatment is determined with regard to the treatment efficiency of the plant. When biological treatment is used it is necessary to compare the obtained figures with normative concentrations of pollutants announced for biological purification. The smallest values are the limiting ones.

Table 2 presents the calculation results of concentration of pollutants in industrial effluents allowed to discharge to municipal sewerage system.

Table 2. Permissible concentrations of pollutants in industrial effluents allowed to discharge to the sewerage system of Tallinn.

Pollutant	Treatment efficiency of the plant %	Calculated concentration in municipal sewerage systems mg/l	LPC for biological treatment mg/l	LPC in industrial effluents at dilution degree 2:2 mg/l
Chromium	80	8	2.5	5.59
Chromium	80	0.325	0.1	0.22
Copper	80	1.625	0.5	1.10
Iron	80	16.250	5.0	11.00
Zinc	70	6.560	1.0	2.20
Nickel	50	1.300	0.5	1.10
Cadmium	60	1.525	0.1	0.22
Lead	50	0.540	0.1	0.22
Mercury	60	0.118	0.005	0.01
Arsenic	50	1.300	0.1	0.22
Phosphorus	50	9.54	-	21.00

As seen from Table 2 the calculated concentrations of pollutants in municipal discharges are substantially higher of the limiting permissible concentrations announced for biological treatment. The determination of the permissible concentration for industrial enterprises is based on the limiting permissible concentrations of waters allowed to enter biological treatment facilities. As the permissible concentrations of pollutants for industrial waters are in correlation with municipal and industrial effluent ratio, which are different for separate towns no uniform standards have been set within the Soviet Union.

The calculated concentrations of pollutants, however, cannot always be met by enterprises discharging their effluents to the municipal sewerage system. To these belong the enterprises with electroplating workshops, which are the main sources of heavy metal pollution.

At the sewage treatment plant of the electroplating workshop special measurements were carried out by means of an automatic system "San-2" worked out at the Baltic Branch of the Institute of Applied Geophysics. The system enables to monitor simultanousely 7 parameters at a time interval from one to 60 minutes. During the 26 day experiment the measurements of pH were made with the frequency of 5 minutes. The aim of experiment was to determine the optimal frequency for monitoring quantitative parameters of treated effluents having a relationship with pH. The comparison of measurement results with the technical operation cycle of the workshop and the local sewage treatment plant have revealed that the optimal frequency of measurements is an hour. The results of averaged measurements are presented in Table 3.

The average value of pH calculated on the basis of the table data was 7.16. The 136 measurements showed lower and one measurement higher values than the permissible ones. This is an indication of the unsatisfactory operation of the local sewage treatment plant and the workshop has to pay a fine to the Water Supply and Sewerage Management. The operation of the sewage treatment plant has been repaired and the pH of effluents is permanently between 6.5 and 9.0.

Table 3. The dynamics of acidity of treated effluents from electroplating workshops.

X_i[pH]	0-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3 5-4.0	4.0-4.5	4.5-5.0
mi	2	11	4	7	6	10	8
Pi*	0.003	0.0017	0.006	0.011	0.009	0.016	0.013

5.0-5.5	5.5-6.0	6.0-6.5	6.5-7.0	7.0-7.5	7.5-8.0	8.0-8.5	8.5-9.0	9.0-9.5
9	10	11	12	13	14	15	16	17
26	29	35	61	227	147	48	6	1
0.041	0.046	0.056	0.098	0.363	0.235	0.076	0.009	0.001

$$\sum_{i=1}^{16} m_i = 626 \qquad \sum_{i=1}^{16} P_i{*} = 1$$

The permissible concentration of heavy metals in effluents treated at local treatment plants may be determined from Table 4, if measurement are not carried out.

Table 4. The metal removal efficiency by various treatment methods.

Treatment method	Treatment efficiency %	Residual concentration of heavy metals in treated effluents mg/l at initial concentration of 50 mg/l
Reagent treatment	80-95	2.5 - 10
Adsorption by carbon	90-98	1 - 5
Ion exchange	80-92	4 - 10
Reversed osmosis	65-95	2.5 - 17.5
Electrodialyse	60-80	10 - 20
Distillation	90-98	1 - 5

As seen from Table 4 the concentration of heavy metals in treated effluents at an initial concentration of 50 mg/l varies from 1 to 20 mg/l, depending on the treatment method used. The calculated concentrations presented in Table 4 are higher of those shown in Table 2. The authorities issuing permits for industrial effluent discharges may raise the calculated concentrations 2-3 times, but it must be taken into consideration that the averaged concentrations of municipal and industrial effluents should not exceed normative values.

Table 5 presents the permissible concentrations of heavy metals for effluents treated at local sewerage treatment plants.

Table 5. Permissible concentrations of heavy metals in industrial effluents discharged to the municipal sewerage system after local treatment.

Pollutant	LPC for untreated effluents discharged to municipal sewerage system mg/l	LPC for effluents treated at local treatment plants mg/l
Chromium	5.29	16.50
Chromium	0.22	0.66
Copper	1.10	3.30
Iron	11.0	33.00
Zinc	2.20	6.60
Nickel	1.10	3.30
Cadmium	0.22	0.66
Lead	0.22	0.66
Mercury	0.01	0.03
Arsenic	0.22	0.66

An identical system for issuing of permits for industrial effluents to be conveyed to the municipal sewerage system exists in the whole Soviet Union. Specific requirements for discharges of industrial waste waters to municipal sewerage system are different and depend on discharge conditions of treated municipal waste waters to the water-body and also from the relationship between the industrial and municipal effluents.

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TRACING AND SUPERVISION OF POLLUTANT SOURCES

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Abstract

Wastewater treatment works are mainly built to take care of wastewater from households. The processes are designed to remove organic materials, suspended solids and, at least in Sweden, phosphorus. These substances are so called treatable pollutants. Nontreatable pollutants, for example heavy metals, nondegradable organic substances, toxic materials and so forth, are not to be discharged into the sewer system. The main object for an industrial supervisory group are to keep nontreatable polutants on as a low level as possible in the wastewater that are to be treated in the wastewater plant.

The problem of what to do with the produced sludge has been intensively discussed in Sweden recently. We in the "business" have during a long length of time tried to produce a sludge that are well fitted to be spread on arable land.

For that purpose the tracing and supervision of industry discharges are essential. We think we have succided rather well during the last decade and the discharges of nontreatable pollutants from industries are now on a relatively low level. But neither we nor the farmers organisations are completly satisfied with the quality of the sludge.

Industry supervision are still important but the use of hazardous materials in households and elsewhere in the community are more and more becoming a substancial source of nontreatable pollutants that still end up in the sludge or are discharged into the recipient. For example the cadmium content in the sludge are now on a level that approaches the background level which are found in excrement from humans.

Introduction

During the seventies great efforts have been made, from among others the waste water treatment works in Sweden, to control industrial outlets of nontreatable pollutants to the sewer systems. These efforts have been rather succesful as regards to the pollutants that have been measured, that is some heavy metals, PCB and DDT.

The aim has been to keep the concentration of the mentioned substances in the sludge under a certain level set by the authorities. Almost all treatment plants have today a sludge that meet now existing demands.

There are today in Sweden discussions about lowering the limit concentrations for heavy metal as regards to land spreading. The major part of the produced sludge is in Sweden spread on arable land.

The main efforts in controlling outlets of nontreatable pollutants have been done in order to improve sludge quality. Nontreatable pollutants often have other detrimental effects on the running of a treatment plant, for example toxic effects.

I will in this paper deal with tracing and supervision of substances that can have a detrimental effect on the processes in the treatment plant or pollute the sludge. I will give examples of how we in the Stockholm region have tried to trace and control some important pollutants. But before I do that I will show the different routes by which a pollutant can enter a sewer system. Figure 1 gives a schematic picture of this.

Important sources of nontreatable pollutants are not just industries. Many substances have their main sources in corrosion, households, storm water etc. That goes for both inorganic and organic pollutants.

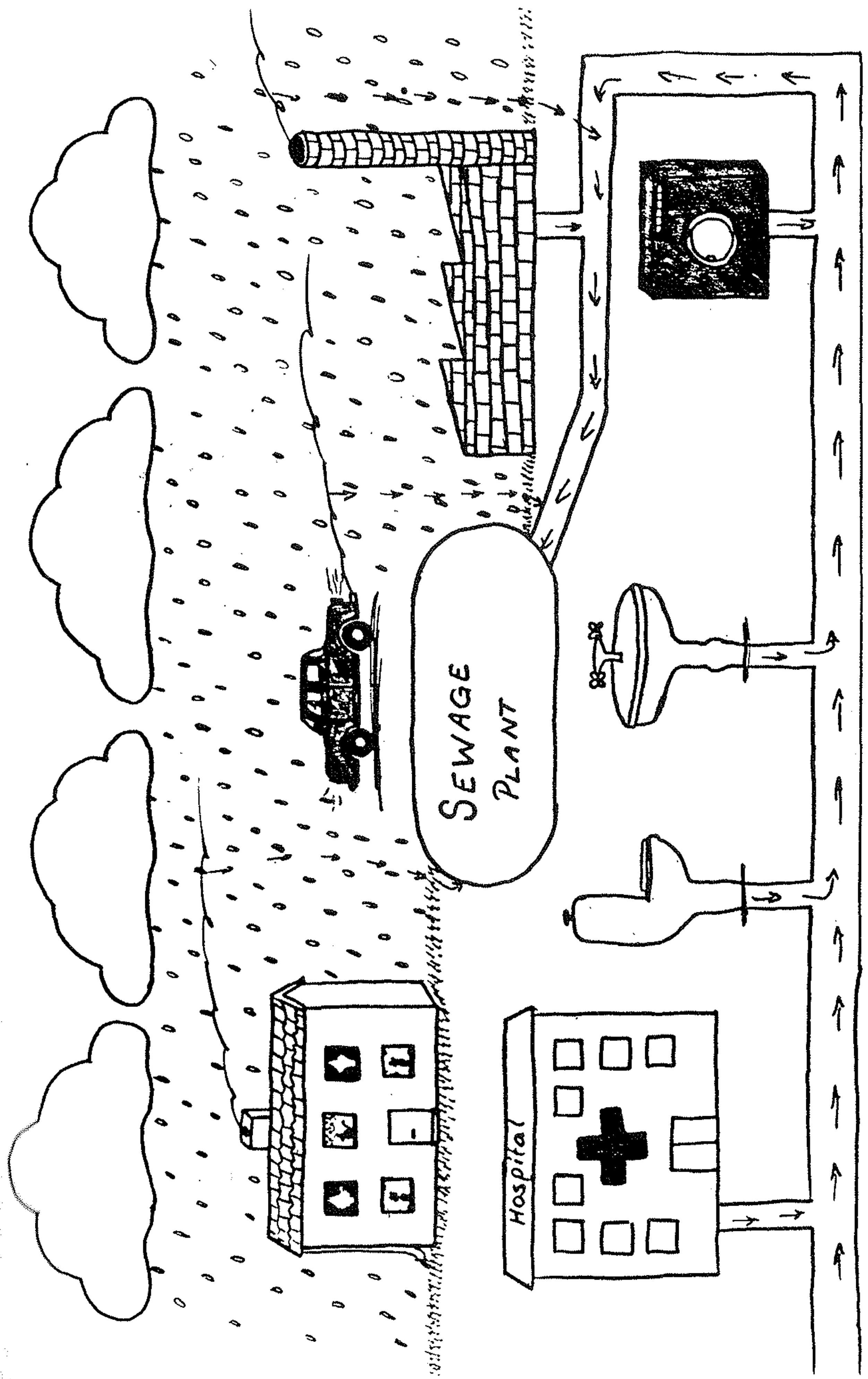


Figure 1 Pollution sources

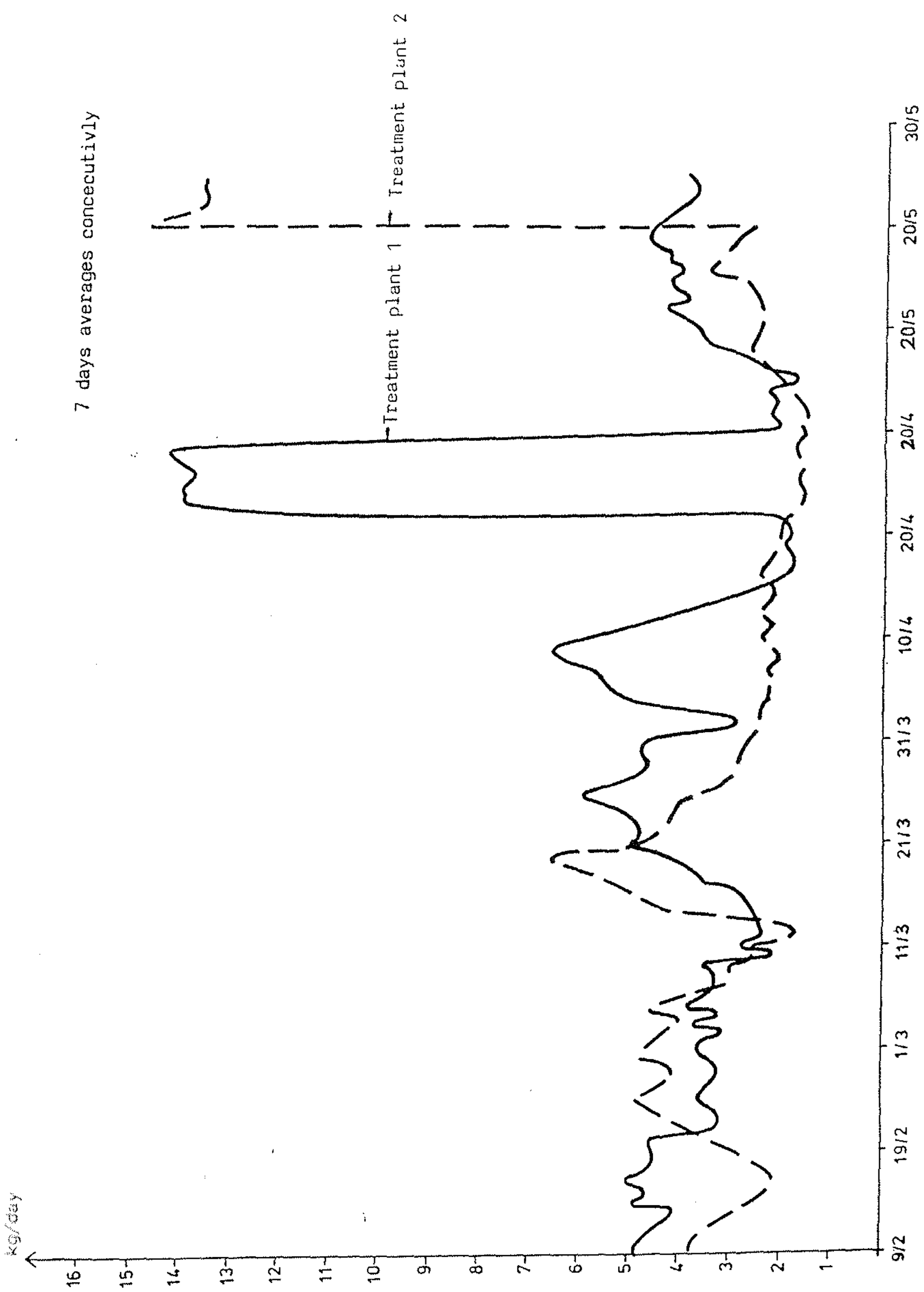
Tracing, general

The first step in controlling a pollutant is of course to try to track down the main sources. This can be done mainly in two ways namely, tracing in the sewerage or by direct contact with suspected sources for example industries with the knowledge of processes in different branches of industry as a background. Both ways are laborious, specialy in big cities with a great number of industries like the Stockholm area. One can calculate that there are perhaps up to 4.000 industry plants of different kinds and sizes in this region that can have outlets to the sewerage of some significance.

Tracing in the sewerage by taking out samples requires sofisticated and expensive equipment. In many cases it is necessary to use battery driven equipment, sampler and preferably flow meters. Because of the rather low capacity of the battery used one must charge this almost every day.

Running problems are common. Clogging occurs frequently when taking out samples from raw waste water. If one has multiple sampling points then it can be very difficult to make the samplers run simultanously with no clogging or other problems for a longer period. It is a tedious and frustrating work and the automatic sampler does not feel that automatic any more. One is almost forced to sit beside it and control it all the time. If equipment connected to the electric net can be used the situation is improved and the need for supervision is decreased. In pumping stations for example sampling is more easily operated and one has the oppurtunity to let the running time of the pumps influence the sampling rate, that is, one gets flow proportional sampling.

Tracing pollutants in a sewer system by just taking out grab samples manually is mainly feasible if one looks for a substance that is present all the time. For example a leaking oil tank can be traced in this way. Otherwise the only answer a grab sample gives is a qualitative confirmation that the observed substance exists in the sewer at that point at that time.



In big sewer systems with both households and industry connected the concentration and amount of a given pollutant are fluctuating a great deal. Figure 2 shows the fluctuation of the amount of chromium in the inlets of two wastewater treatment plants in Stockholm. The two lines represent consecutive seven days averages. As you can see the quota between the highest and lowest value is over 10. Therefore, it is not enough to take out samples during a short time, say a week if one would like to trace major sources or if one is examining the general flow of a pollutant. We have in Stockholm carried out examinations for periods of several months. This kind of examinations is very expensive in labor, equipment as well as analysis.

Another conclusion one can draw from examinations of that lenght is that a substantial part of the amount of heavy metals in the incoming water to the wastewater treatment plant is coming during few instances in high concentrations, so called dumpings. For cadmium, chromium and nickel between 20 and 40 percent of the total amount during 3 months was "dumped", that is these metals occurred in the inlet water in less than five instances and each instance was just a few hours.

Tracing by setting up an industry register of known industries is necessary in order to control nontreatable pollutant outlets. Often industry personnel does not know what is harmful to the waste water treatment plant. A dialog with the people in charge where the persons from the treatment plant explain their point of view is often a very effective control measure, specially in the case of small industries. I will later show a case where the innocence was monumental and almost unbelievable.

To find industries of interest to the personnel of the treatment plant can raise problems. We have learnd that the telephone book is an effective information source as regards to small industries. Perhaps small industries do not want to be so well known by, for example, tax authorities, but they must have a telephone in order to stay in business.

To keep an industry register up to date is a personal demanding task but it is a necessity. Registers of small industries more then five years old tend to be of no use.

After this introduction and general remarks I will go through some case studies.

Lead

We have in Stockholm during 1981 analysed the lead content in a storm water sewer during rain fall and at the same time in a pumping station with combined and separate sewer nets connected.

Results from this investigation show that the lead concentration in storm water is much higher than it is in waste water. Table 1 shows the result.

Table 1

	Content of lead mg/m^3	
waste water	dry weather	35
	rainy days	55
storm water		120

Though the amount of storm water through the pumping station corresponds to only 5% lead from storm water corresponds to roughly 15% of the total amount during both dry and wet weather. The influence of storm water in the waste water is confirmed by the higher concentration of lead durig rainy days. The main source for lead in storm water is no doubt the use of lead containin petrol in automobiles. Another source is probably refuse combustion.

In Sweden restrictions concerning the lead content in petrol have been stricter and stricter since the middle of the seventies. The effect of these restrictions are clearly seen in the decrease of the lead content in the digested sludge from the treatment plants.

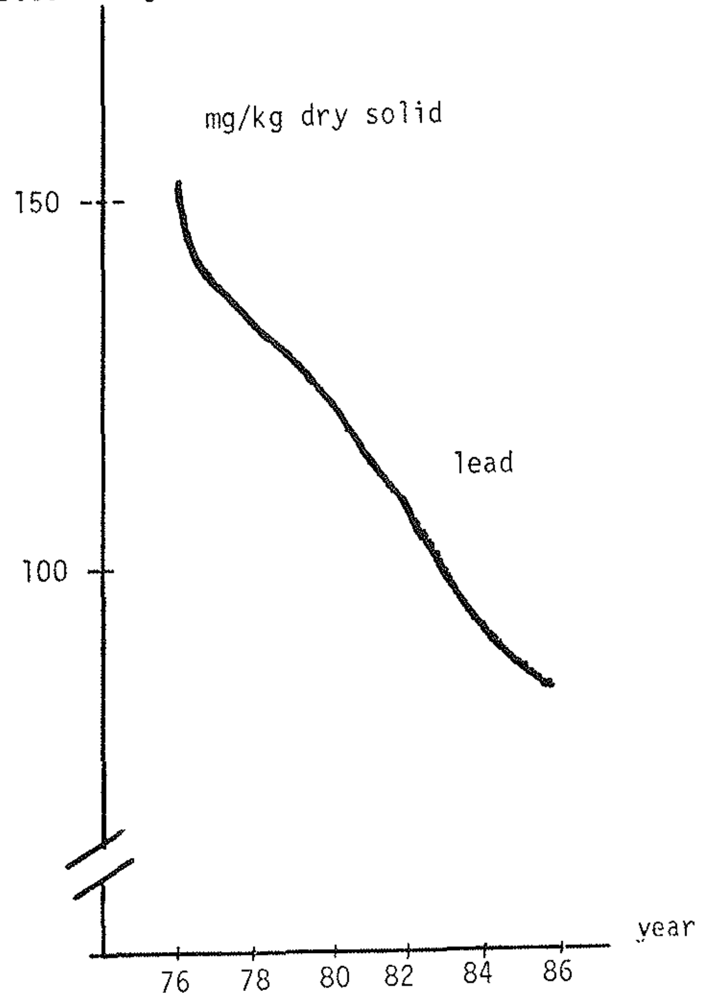


Figure 3 Concentration of lead in digested sludge. Käppala sewage treatment plant.

Figure 3 shows this decrease for Käppala treatment plant. As I see it there is no other single more importent factor that has affected lead content in sludge than lead in petrol. Industry discharges are, I believe, roughly the same between the middle seventies and middle eighties.

At least that goes for the Stockholm area. Few industries in this area have lead in their waste water. As far as I know no one of those has made any big changes in their handling of lead.

Our estimations concerning lead outlets to the sewer system in Stockholm area are that the three possible origins for a pollutant industry, household and storm water contributes with one third each. Controlling the lead outlets to the sewer system can only be done to a significant degree by controlling the use of lead in society as a whole. The use of lead in petrol is most probably stopped in the near future. Lead from refuse combustion will also be reduced in the near future by the better air cleaning devices that are being implemented.

Industry outlets to the wastewater plant can be and will be reduced by a better separation of waste water streams containing treatable and nontreatable pollutants within the industry plants.

Streams with nontreatable pollutants should not be lead to the treatment plant.

Cadmium

Also the content of cadmium has been decreasing substantially in digested sludge in the Stockholm region during the past decade. Figure 4 shows this fact for Käppala waste water treatment plant.

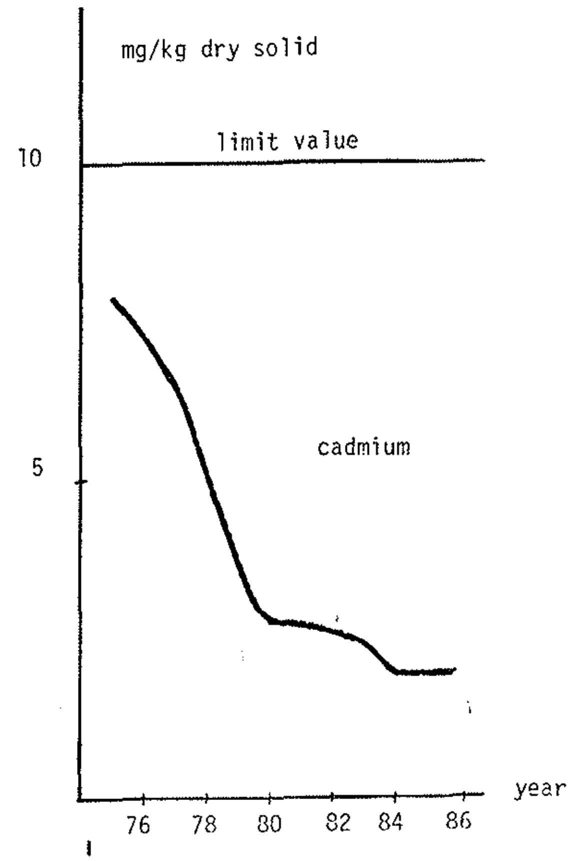


Figure 4 Concentration of cadmium in digested sludge, Käppala sewage treatment plant.

In the beginning of the seventies several metal finishing industries used cadmium. Most of them stopped using cadmium in the middle and in the end of the seventies. During this period the cadmium concentration dropped from top valuas of over 30 mg/kg dry solid in digested sludge from some of the Stockholm treatment plants to just under 10. During the eighties the decrease continued and the concentration in sludge from Käppala as one can see in figur 4 is now around 2,5 mg/kg dry solid.

The decrease during the eighties can not be explained by industry efforts, but by efforts made from society as a whole. The only point source in Käppala sewage system that I know of is refuse dump sites. There are five dump sites connected to the Käppala system in use today. Their cadmium outlets contributes roughly to 10% of the total amount of cadmium in the inlet water.

A substantial source for cadmium in the inlet waters of Stockholms all treatment plants is refuse combustion. This source was probably even bigger before the prohibition to use cadmium in certain application was introduced in the beginning of the eighties. But the authorities have not yet taken care of one item that still is being burnt and contains a big amount of cadmium. That item is batteries. The authorities have not a complete control over the use of mercury and cadmium containing batteries in Sweden. The matter has been discussed during the last ten yares and some battery collection activities on a free base have been tried. I estimate that between 20 and 30% of the amount of cadmium are brought to the treatment plants with storm water and a major source of that cadmium is refuse combustion. If the authorities can not control the batteries better air cleaning at the refuse combustion plants are the only hope to eliminate this source and further lower the cadmium content in digested sludge.

The cadmium concentration in sludge is, however now near the background level that one would find in human excrements with no direct influence of other sources. In one examination the concentration in digested human excrements was found to be 1,5 - 1,7 mg/kg dry solid.

Petroleum products

One continuous source of petroleum products are easy to point out in a city. Car washes and garages are important contributors of these products to the sewer. In the Stockholm region their are roughly 200 petrol stations with car wash or some other kind of service and at least 1.000 garages. Tracing these different kinds of service stations is easiest done by looking in telephone books.

Earlier the garages had to pay an authorized collector to get rid of their spent motoroil. This lead to some illegal activities where part of the spent oil was dumped in the sewer. Now spent motor oil is paid for and this problem has stopped. Some spill still occur in the garages and service stations which are flushed out in the sewer during cleaning up operations. Still the main source of petroleum product outlet from this kind of plants is car washing with degreasing agents. The waste water from car washing and other activities whithin servicestations is normally led to the public sewers through some kind of oil separator.

A condition for the separator to work is that the degreasing agent does not create a stable emulsion with the grease and oil that are washed away from the cars. We have in Sweden a regulation that imply a longest separation time of two hours. After that time the concentration of petroleum products in the waste water should be under 100 mg/l. This means that the oil separator should have a retention time at highest flow of at least two hours.

We have in Stockholm made a thorough survey of the servicestations and bigger garages as regards to their oil separators. We compared the accual dimension of the oil separator with the highest load measured in m^3/h. In this survey we found that out of about 170 plants roughly half of them had underdimensioned separators. We insisted that the underdimensioned separators either were replaced with bigger ones or that the activity at the service station was altered in order to lower the flow to a suitable level.

During a period of three to four years measures at the service stations were taken. Now all of the examined plants have acceptabe installations as regards to their sewer systems. The outlet water from the oil separators have also been examined during the last years by sampling and analysing the oil content. The results are promising. With oil separators big enough, good care and with the right degreasing agents, the quality of the purified water is acceptable. The concentration of petroleum products often is around 10 to 20 mg/l which I think is a good result. The investigation of the outlet waters often were conducted without the owner of the service station knowing it in advance.

The normal investment for a new oil separator of ordinary size was around 100.000 SEK.

The mercury incident

I would like to finish this survey by reporting "the mercury incident" which started in the autumn 1984 and finished in the summer 1985.

We recognized in the autumn 1984 that something was going on when the mercury concentration in the digested sludge from one of Stockholms treatment plants slowly increased. By the end of that year the concentration had doubled. This means an increase with about 60 kg/year of mercury. In the beginning of 1985 the situation began to be critical. The concentration was reaching the limit value for arable land spreading. The tracing of the mercury source began. This was done in two ways. Figur 5 shoes a schematic picture of the sewer system connected to the treatment plant. Tracing by taking out samples was carried out in this system from the plant and down into the system.

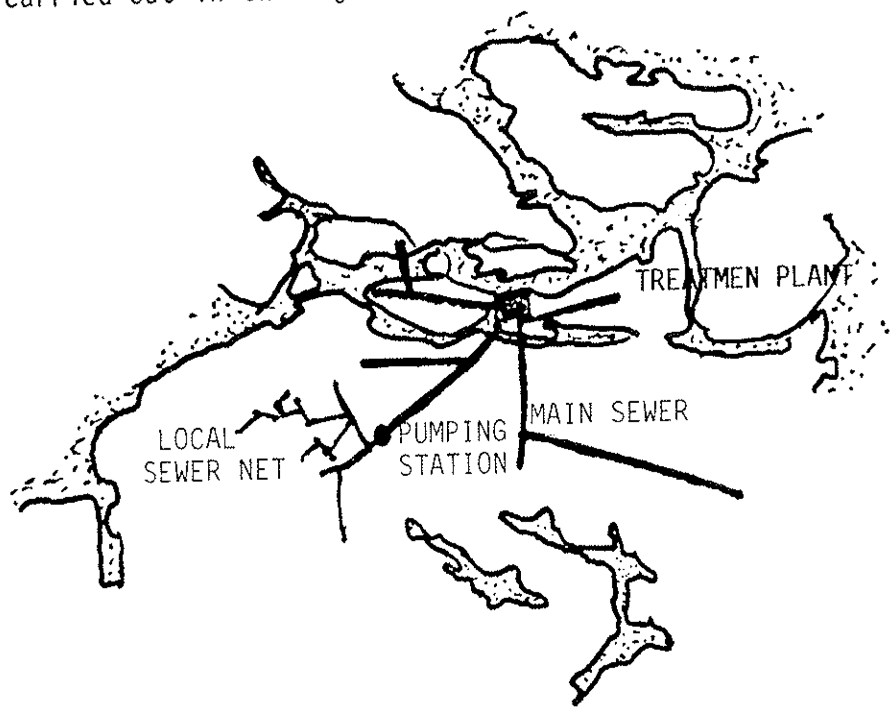


Figure 5 Schematic map of Stockholm

We discovered from the analyses of taken samples that the "extra" mercury occured intermittent. This made the tracing even harder. It was sometimes more than a week between each instance. In each cross point we therefore had to be persistant and go on taking samples for weeks. During a couple of months we had succeded in getting nearer and nearer the source further and further out into the system. Simultanously with the investigations in the sewer system we used our knowledge of known and suspected mercury sources. Among other things we used a register of firms which had reported mercury as hazardous waste. We called several firms asking them how they dealt with their mercury waste. One of these firms told us that one for us unknown firm purified metalic mercury wastes. This firm was located in the same area which we had pointed out in our sewer system tracing.

We could at this point just contact the suspected firm, six months after the beginning of the intensified investigation, and get our suspicions confirmed.

It was a small firm with just a couple of employees. Among other activities they purified metalic mercury for instrumental and medical use. The amount per year was about 1.000 kg.

The purification process was made batch wise. A certain amount of mercury was filtered through a filter paper and was then mixed with a mixture of sulphuric acid and nitric acid. Mercury is soluble to some degree in nitric acid but not in sulphuric acid. The spent acid mixture was dumped into the sewer whithout even neutralisation which the manager confessed without any hesitation. I don´t think he had realy understood the concequences of his behaviour. He was very surprised when we told him the rather drastic consequenses, that is, jeopardizing Stockholms whole sludge handling. Millions of swedish crowns was at stake if the sludge spreading was forced to be stopped.

This incident puts the spot lights on two things. First the problem of tracing a pollution source and the costs involved and secondly the impact a small firm can create by handling hazardous wastes improperly. The tracing costs was estimated to roughly 100.000 SEK. Part of this cost the firm was forced to pay.

Final remarks

I have in this paper tried to show that pollution control is not only an industrial issue. For some pollutants industrial outlets are the major source, but I think that for many nontreatable pollutants, this is not the case. As far as industry outlets are concerned I would like to say that we have the situation under control. We have the tools to stop most of the more significant outlets or at least we could have them decreased to an acceptable level. It will take some time and a lot of work but with the help of the environmental protection authorities it is possible.

There are some point sources I see as a problem. One of them is dump sites, old ones or running ones. All of them leak. The drainage from dump sites contains not only organic substances to a degree that justifies them to be treated in public treatment plants. But the drainage also contains, among other poisons heavy metals. The concentration is very low but the enormous amount of drainage makes the amount in kg/year large. Other solutions for this kind of waste waters are perhaps necessary.

Other outlets or inputs into our systems that we have no or little influence over are waste waters from households and storm water. The only thing we can do is to try to trace the sources and point them out to the authorities concerned.

This I have tried to do in this paper. I have as an example showed the impact which the cadmium prohibition and the decrease of lead in petrol has had on the concentrations of these substances in digested sludge.

We have at least in Sweden one source of heavy metals within our plants. The demand on phosphorous reduction force us to use precipitation chemicals. Even if we use a chemical of very high quality, which we do, the amount we use of this chemical makes the contribution from this source of some heavy metals substantial.

The only way to have a digested sludge and a recipient of good quality is to control societies use of poisons and I mean society as a whole.

PROBLEMS WITH TEXTILE WASTEWATER DISCHARGE

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ABSTRACT

The general character of textile industry wastewaters is briefly discussed. General guidelines and practice in Finland when discharging textile industry wastewaters to municipal sewer systems is described. A survey revealed that most municipalities experience some problems due to textile industry wastewaters. Pretreatment is not always practiced and in some cases pretreatment is not operated efficiently.

INTRODUCTION

Textile industry covers a vide range of industrial activities. An individual factory can be a source of severe environmental problems or almost harmless to the environment. Some are producing tens of thousand cubicmeters of wastewater which can be toxic or otherwise very harmful while some have only sanitary wastewaters. This makes it very difficult to deal with the textile industry as one field giving certain type of wastewater problems to be solved in a routine manner. On the contrary each factory is to some extent an individual case and very often great effort should be paid on thorough investigations to chracterize the wastewater and its treatment possibilities. This can be done by studying water balance of the process, chemicals used and level of housekeeping and management of waters. Some laboratory or pilot scale experiments could give valuable information for decision making in solving wastewater problems.

Combining textile industry wastewaters with municipal wastewaters is a very common solution especially in the case of small factories. Combined treatment is in general environmentally and economically the best solution. Very often pretreatment is needed and operational problems at the treatment plant may occure.

In Finland there are no special conditions established to join textile wastewaters to municipal sewers but general conditions for combining industrial and municipal wastewaters are followed. In a number of cases some special conditions have been added to the agreement between the municipality and textile factory. /1/

CHARACTER OF TEXTILE WASTEWATERS

Textile industry wastewaters can be described beeing very colourful, having fairly high suspended and dissolved solids content, reasonable concentration of biodegradable matter and nutrients. Concentration of oil, ammonia, metals, phenols, sulfates and chlorides as well as excessive alkalinity can cause problems in wastewater treatment. Wastewater is at least occasionally toxic, pH may vary dramatically and temperature can be quite high /2/.

Textile industry can be divided based on raw materials into three different fields /3/, Figure 1. Textile factories have often several different departments of figure 1 but some factories have only one of the activities (e.g. finnishing, knitting, etc.)

There are plenty of different chemicals and raw materials in use in textile industry. During the process new combinations can be formed. All this makes it very difficult to characterize the wastewater based on used raw materials. There has been some attempts to characterize the wastewater more in details regarding tensides, carriers and some finnishing chemicals /4/, but analytical problems were difficult to solve. Therefore very reliable and useful results were not reached. In the Scandinavian study /4/ it was concluded that normally textile wastewaters should not be harmful for activated sludge process. In practice there are many cases where textile industry wastewaters have caused operational problems and decreased the treatment efficiency of activated sludge process in combined treatment /1/. The reason for this may be high pH variations which occur during accidental spils or unproper operation of pretreatment facilities and unfavourable dilution situation.

COMBINED TREATMENT

General guidelines used in Finland for discharging industrial wastewaters to the municipal sewer system tries to protect both network and the treatment process, sludge handling as well as operators and resipient from harmful effects /5/. It is not practical to give exact values for all compounds which can be found in wastewaters to fulfil the above set general guidelines. Therefore the principle is that wastewaters which are similar to normal municipal wastewater (BOD_7 250-450 mg/l, total P 10-20 mg/l, total N 35-70 mg/l and SS 200-400 mg/l) can be discharged to the municipal system without pretreatment. A number of inorganic and organic compounds as well as pH and temperature are given guideline values at the point of discharge to the sewer or at the treatment plant. Table 1 outlines some of these values.

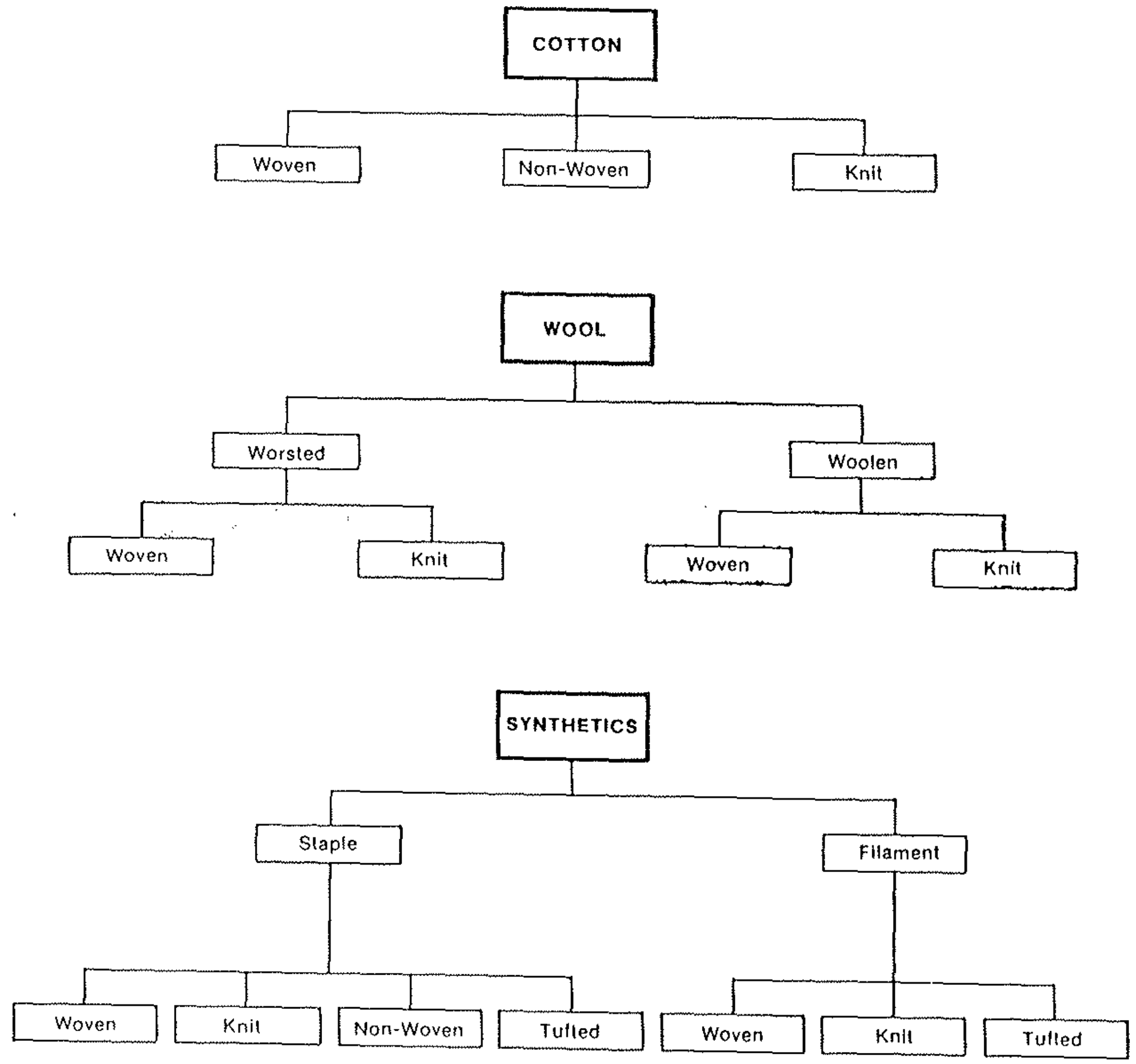

Figure 1 TEXTILE INDUSTRY CATEGORIZATION BY FIBER PROCESSED

Table 1 General guidelines in Finland for discharging industrial wastewaters to municipal sewer (some examples)

A. Fysical - chemical factors

pH 6-10 at the point of connection
temperature max 35°C in the point of connection

B. Inorganic compounds

Compound	Limit in mg/l	Comments
Cd	0,01 x) 0,005 x)	at treatment plant
total Cr	2,0 x) 0,5 x)	- " -
Cr (VI)	0,5	- " -
Pb	1,0 x) 0,2 x)	- " -
Ni	1,0 x) 0,1 x)	- " -
$SO_4 + S_2O_3 + SO_3$	400	at connection point
NH_3, NH_4	50	- " -
Cl	2500	- " -
CN	0,5	- " -

C. Organic compounds

Mineral oils	50	at treatment plant
Phenol + cresol	50	- " -
Tensides	25	- " -
CS_2	10	at connection point

x) Higher limit is set from process point of view and lower limit from the sludge utilization point of view.

Toxics like pesticides, PCB, etc. cannot be discharged to the municipal sewer.

These values should be kept as guidelines and exceptions can be made after careful consideration based on relevant information.

The variation of flow and pH in textile wastewaters can be so high that only these factors make the pretreatment very important. The quality of textile wastewaters must be well examined before combining it with the municipal sewer. The most economical and appropriate actions must be taken to ensure that textile wastewaters do not give harmful effects to the municipal system. In the case of new factory it is difficult to know exactly the quality of wastewater in advance but it should be possible to get good enough estimates. Production process and water balance can be arranged with minor modifications and improvements in instrumentation so that remarkable savings in water consumption can be reached /4/. This is very important because it reduces the wastewater charges and makes the pretreatment cheaper. Re-use of process water after treatment inside the factory may be a very economical solution in some cases but there have been some technical drawbacks like increased bioactivity that may limit the possibilities of this concept /6/. In the case of Finland re-use has not gained very strong interest since water is well available and there is always a fear to get problems in the quality of products if the factory is too closed /7/.

The selection of pretreatment process depends on the factory itself, the wastewater treatment process which the municipality is using and the loading from the factory compared to the load of the municipality.

In a recent study a questionnaire was sent to some 50 municipalities in Finland. The questions were dealing with combined treatment. The municipalities were selected so that in all of them some industries were discharging wastewater to the municipal sewer. In eight municipalities altogether fourteen textile factories were connected to the municipal sewer /1/. Seven factories involved dying process, four were laundries and three other type of factories. In all cases some type of problems were noticed by municipality in their wastewater system. Seven factories did not have any pretreatment. Only in one case the textile industry wastewaters were specially taken into consideration during the design of the treatment plant of the municipality. In that case there were no pretreatment. Flow variations and foam formation have caused problems in this case but treatment process has been working satisfactorily.

Table 2 Some results of Finnish Survey 1986 /1/

Process	Pretreatment	Proportion of total flow %	Problems
Dying	4	12	colourful, effluent
Dying	1,3,4	20	pH, others
Dying + others	1,4	14	several
Fibre processing	0	30	foaming etc.
Wool production	2,6	6	minor problems
Laundry	0	1	"
Laundry	0	1	"
Laundry	0	32	several
Laundry	1	30	several
Dying + others	0	20	x)
Dying + others	0	5	x)
Dying + others	0	6	x)
Dying + others	1	45	several, very severe

Pretreatment: 1. neutralization, 2. quality equalization, 3. oil and grease removal, 4. flow equalization, 5. settling, 6. screening

x) Connected to one municipal wastewater treatment plant which has experienced number of problems. Part of these problems are due to other fields of industries connected to the same plant.

It looks quite obvious that if the proportion of textile industry wastewaters is high the problems faced in combined treatment are more severe than in the case where the proportion of industrial wastes is low. Anyhow in the case where textile industry wastewaters had been taken seriously into account already during the design the problems faced in operation have not been at all severe though the proportion of textile industry wastewaters is high.

Pretreatment facilities are not operated in very high efficiency. For example pH has been found to vary very much though neutralization has been one of the pretreatment processes.

The development of peoples fashions has also influenced the wastewater treatment. Two laundries have been washing new jeans which have been over dyed and the aim of the washing is to remove the excess dye. In these cases the proportion of textile wastewater has been quite high and therefore for instance effluent from the wastewater treatment plant has still been colourful. Cotton fibres which are removed during the washing have also caused some problems during the wastewater treatment. Slight toxicity indications have been found as well but the reasons for these have not been clear. One reason may have been the pH variations.

CONCLUSIONS

Combined treatment gives environmentally good and economically justified solution to solve the wastewater disposal problems of textile industry. The character of industrial wastewater must be taken into account on an individual basis in the case of each factory. Textile industry wastewaters can differ very much from one factory to another even if the production processes are close to each others. Pretreatment should be employed to avoid harmful effects of industrial wastes. Neutralization and flow equalization are the most important pretreatment methods but case by case other processes should be involved according to the need. Internal measures to reduce wastewater flow and loading are very important steps which each factory should seriously consider before joining to a municipal sewer.

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REDUCTION OF NITROGEN

Finnish state of the art

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ABSTRACT

In Finland nitrogen has been considered of importance as a limiting growth factor in some coastal areas and heavily polluted lakes. For the present, however, the usefulness of nitrogen removal in municipal wastewater treatment has not been clear enough and requirements concerning removal of total nitrogen have not been set. The need for nitrogen removal depends mainly on the local conditions. On the coastal regions, nitrogen removal should be started first in the biggest of those municipalities which are loading the Gulf of Finland and the Archipelago Sea. The city of Helsinki has to be prepared for nitrogen removal before the end of the next decade.

The adverse effects of ammonia are apparent in many inland water courses. In recent years reduction of ammonia nitrogen in wastewater treatment has been required in some cases, mainly in order to prevent oxygen depletion caused by nitrification in receiving waters. Other important reasons for ammonia reduction have been the adverse effects of ammonia in water supply and the toxic effects of molecular ammonia on fish.

In practice, ammonia removal has been performed by nitrification in connection with the activated sludge process. The choice of process combinations and design values have always been based on pilot plant or full scale experiments. In order to reach a sludge retention time long enough during the cold season, the design values of sludge load have been 0.06-0.08 kg BOD_7/kg MLSS·d in combined carbon oxidation and nitrification processes. At new nitrification plants, denitrification has been used for diminishing the operation costs.

1. INTRODUCTION

The degree of municipal wastewater treatment has been improved step by step. In Finland, phosphorus removal was taken into practice during the 1970's, when it was found necessary to prevent eutrofication of the receiving water bodies, both inland waters and sea areas. Nitrification has been required in some cases during the 1980's, in order to prevent oxygen depletion in receiving inland watercourses, to prevent the adverse effects of ammonia nitrogen in water supply or to prevent the toxic effects of molecular ammonia on fish. Efficient nitrification is, in addition to that, an indicator of the high degree of biological decomposition in wastewater treatment. The number of nitrification plants is increasing.

At present, the question of nitrogen removal is actual. No requirements concerning removal of total nitrogen have, so far been set, because the need for nitrogen removal compared to the technical difficulties and costs of an efficient removal has not been clear enough. However, it seems that nitrogen removal should be commenced during the 1990's at some of the biggest treatment plants, especially on the coastal area of the Gulf of Finland.

2. MUNICIPAL WASTEWATER TREATMENT

2.1 Treatment methods

Sewerage systems designed to serve more than 200 inhabitants covered 3.5 million inhabitants which means 72 per cent of the total population of Finland, at the beginning of 1985 (Table 1).

In terms of wastewater flow and number of inhabitants, only 1 per cent of the total amount of municipal wastewater was discharged without centralized treatment. The share of mechanical-biological treatment (mainly stabilization ponds and land filtration) was 1 per cent, the share of mechanical-chemical treatment (direct precipitation) was 14 per cent

Table 1. Municipal wastewater treatment in sewage works designed to serve more than 200 inhabitants 1.1.1985.

Method	Number of treatm. plants	People served 1000 inh.	%
No treatment	-	33	0.9
Direct precipitation	56	479	13.6
Simultaneous prec.	395	2 662	75.4
Pre or post prec.	40	252	7.1
Other methods	88	106	3.0
Total	579	3 532	100.0

and the share of mechanical-biological-chemical treatment (mainly simultaneous precipitation) was 84 per cent.

At present, there are about 400 simultaneous precipitation plants, and about 40 pre or post precipitation plants, treating 82 per cent of the total amount of municipal wastewater. Almost all of these plants use activated sludge method. The proportion of simultaneous precipitation is increasing, even if most plants which use primary sedimentation operate with partial pre-precipitation.

Ferrous sulphate is the main chemical used for phosphorus removal in simultaneous precipitation. In direct and post-precipitation, the share of lime has decreased and the share of aluminium and ferric salts has increased.

2.2 Treatment requirements

Requirements for wastewater treatment are almost always expressed as maximum allowable concentrations of BOD_7 and phosphorus in the effluent, and as the minimum allowable percentage reduction of these parameters (Table 2). The requirements refer to average results during a specified time period (3, 6 or 12 months), including possible by-passes and process disturbances. BOD_7 values in the new permit conditions refer to determinations that preclude

nitrification with allylthiourea (ATU) additive. In most cases the use of allylthiourea means about 10 mg/l lower values.

Table 2. Typical new requirements for municipal wastewater treatment in Finland.

Treatment method	BOD_{7ATU} mg/l	BOD_{7ATU} %	Phosphorus mg/l	Phosphorus %
Direct precipitation	60-70	60-70	1.0	85-90
Simultaneous precipitation	15-20	85-90	0.5-1.5	80-90
Pre or post precipitation	15	90	0.5	90

When nitrification has been required, the maximum permitted concentration of ammonia nitrogen has been 4 mgN/l, with the requirement for 80-90 per cent reduction. The reduction calculation has to be based on total nitrogen concentration in influent and ammonia nitrogen concentration in effluent.

Exceptional requirements are mainly based on special needs or possibilities to protect the receiving water bodies. Sea areas have not had significantly different requirements compared with inland waters.

All discharge permits require an efficient plant operation regardless of numerical concentration or performance values.

The city of Helsinki is now planning a new central treatment plant for a person equivalent of roughly one million. According to the statement of the National Board of Waters the effluent concentration of the new plant should not exceed 15 mg/l of BOD_{7ATU} and 0.5 mg/l of phosphorus. In addition to that Helsinki should be ready to start nitrogen removal before the end of 1990's.

2.3 Treatment results

In 1984, the total efficiency of BOD_7 (without ATU additive) removal was 84 per cent, which corresponds approximately with 90 per cent reduction of BOD_{5ATU}. The removal efficiencies of phosphorus and nitrogen were 87 and 34 per cent (Table 3).

Table 3. Municipal wastewater load to the receiving waters and treatment efficiencies including overflows in 1984.

	Total discharges to waters	Discharges to the inland waters	Direct discharges to the Baltic Sea
Wastewater flow, million m^3/a	571	300	271
People served, million inhabitants,	3.53	1.95	1.58
The shares of different treatment methods, per cent			
No treatment	1	1	1
Biological	1	2	0
Chemical	14	13	15
Biological-chemical	84	84	84
Waste load, t/a			
BOD_7	18 600	9 360	9 240
BOD_{5ATU} (estimated)	10 000	4 800	5 200
Phosphorus	560	310	250
Nitrogen	13 800	6 910	6 890
Reduction, per cent			
BOD_7	84	86	81
BOD_{5ATU} (estimated)	90	92	88
Phosphorus	87	87	87
Nitrogen	34	38	29
Concentration mg/l			
BOD_7	33	31	34
BOD_{5ATU} (estimated)	18	16	19
Phosphorus	1.0	1.05	0.9
Nitrogen	24	23	25

3. NEED FOR NITROGEN REMOVAL

3.1 Effects of nitrogen

The nutrient load to the Baltic Sea has increased considerably as a result of human activities. At the same time effects of excessive eutrophication have been observed.

In the inland waters of Finland, besides eutrophication, ammonia nitrogen can seriously increase oxygen consumption because of nitrification. Also it may have harmful effects on water supply and fish.

On the basis of annual nitrogen and phosphorus cycles, concentrations, and N/P-ratio in the surface water it can be assumed, that phosphorus is the most limiting nutrient for the phytoplankton production in the Bothnian Sea and Bothnian Bay, whereas nitrogen might be the most important factor in the Gulf of Finland.

In the Bothnian Bay phosphate is exhausted in summer, but dissolved nitrogen concentration remains at a high level. In the Gulf of Finland, where the concentrations of total phosphorus and total nitrogen are high, dissolved nitrogen is exhausted already early in summer, and phosphate concentration in summer is also low. However, the upwelling of deep Baltic water in the Gulf of Finland occasionally increases the concentration of phosphate.

The total mass balances of phosphorus and nitrogen are hard to work out. Especially, the proportion of nitrogen fixation by blue-green algae, denitrification and sedimentation are very difficult to measure. Estimations and predictions may differ from each other greatly. In any case the discharge of municipal wastewater to the Baltic Sea plays a significant role as a source of phosphorus, even if some countries already have an efficient phosphorus removal, whereas its relative importance as a nitrogen source is smaller.

3.2 Nitrogen load

Tables 4 and 5 give the estimated amounts of phosphorus and nitrogen discharged to the surface waters in Finland in 1980. According to these figures, direct and indirect municipal wastewater load covered roughly 17 per cent of total phosphorus and 15 per cent of the total nitrogen discharged from Finland to the Baltic Sea. The estimations do not include the airborne nutrient loads which fall directly to the sea. Without any wastewater treatment the proportion of municipal phosphorus load would have been 50 per cent and the proportion of municipal nitrogen load 20 per cent.

Table 4. Phosphorus load to the surface waters (without airborne discharges) in Finland in 1980.

	To inland waters	Direct to the Baltic		Total to the Baltic x)	
	t/a	t/a	%	t/a	%
Municipalities xx)	410	390	10	700	17
Industry	430	340	8	650	16
Agriculture	1 400	-		1 050	26
Total by rivers		3 340	82		
Other load by rivers				1 700	41
Total		4 100	100	4 100	100

x) Consists of direct load to the Baltic and the estimated proportion of discharges into inland waters, which reaches the sea.

xx) The total removal efficiency of phosphorus in the municipal treatment plants was 80 per cent.

Table 5. Nitrogen load to the surface waters (without airborne discharges) in Finland in 1980.

	To inland waters	Direct to the Baltic		Total to the Baltic x)	
	t/a	t/a	%	t/a	%
Municipalities xx)	6 300	6 700	10	10 000	1
Industry	4 200	3 000	5	5 000	8
Agriculture	31 000			20 000	31
Total by rivers		55 000	85		
Other load by rivers				30 000	46
Total		65 000	100	65 000	100

x) Consists of direct load to the Baltic and the estimated proportion of discharges into inland waters, which reaches the sea.

xx) The total removal efficiency of nitrogen in the municipal treatment plants was 31 per cent.

3.3 Need for nitrogen removal

Compared with the phosphorus removal, which is always necessary, the need for nitrogen removal is not self-evident.

As far as nitrogen compounds are concerned the removal of ammonia nitrogen (nitrification) is the principal aim in municipal wastewater treatment by inland watercourses.

In sea the main harm caused by nitrogen is eutrophication. Also in those cases, where direct discharges are concerned the need for nitrogen removal depends mainly on the local conditions.

Taking into account the effects of nitrogen, the share of municipal wastewater as a nitrogen source and the technical and economical possibilities, it is evident that in Finland nitrogen removal should be started first in the biggest of those municipalities which are loading the Gulf of Finland and the Archipelago Sea.

Primarily this concerns the Helsinki-Espoo district (about 800 000 inhabitants) on the coast of the Gulf of Finland and the Turku district (about 200 000 inhabitants) on the coast of the Archipelago Sea.

By improving the nitrogen removal efficiency in the treatment plants of Helsinki and Espoo to a level of 70 per cent, the direct load of municipal nitrogen from Finland to the Gulf of Finland could drop from today's level of 4 000 tN/a to a level of 2 000 tN/a. This drop is 1.5-2 per cent of the total nitrogen load to the Gulf of Finland (Table 6).

If in addition to Helsinki and Espoo, the nitrogen removal efficiency in the Turku area were 70 per cent, the total amount of municipal nitrogen discharged directly to the Baltic Sea from Finland could drop from today's level of 7 000 tN/a to a level of 4 500 tN/a. In terms of yearly weighted average values for the whole country this corresponds with effluent concentration of 16 mg N/l and treatment efficiency of 55 per cent.

Table 6. Nutrient load to the Gulf of Finland in 1980-81 (Finnish-Soviet Working Group on the Protection of the Gulf of Finland, report no 3/1984).

	Phosphorus		Nitrogen	
	t/a	%	t/a	%
Direct municipal discharges from Finland[x)]	210	3.5	3 800	3.2
Direct industrial discharges from Finland	40	0.7	550	0.5
River discharges from Finland	620	10	12 000	10
Total discharges from USSR	4 700	78	80 000	67
Deposition from the atmosphere	400	7	24 000	20
Total	6 000	100	120 000	100

x) In 1984 the total removal efficiencies for phosphorus and nitrogen were 85 and 26 per cent and the corresponding loads 160 tP/a and 3 900 tN/a, respectively.

4. NITROGEN REMOVAL TECHNOLOGY

4.1 Methods

In order to achieve efficient nitrogen removal primarily combinations of nitrification and denitrification processes have to be considered.

In Finland there are so far no treatment plants especially designed for the removal of total nitrogen, even if partial denitrification has been performed mainly for saving operation costs of nitrification plants. In practice, only so called one-sludge systems with one or two tanks have been used in pilot and full scale plants. The DN-process has been the most common application.

Removal of ammonia nitrogen has been required in some cases. In practice, ammonia removal or oxidation has been performed by nitrification in connection with the activated sludge process and simultaneous precipitation of phosphorus. At present, there are several nitrifying plants.

The first nitrifying plants in Finland were comparatively small oxidation ditches. Efficient nitrification could be carried out with a sludge load approximately 0.05 kg BOD_7/kg MLSS.d even at process temperature lower than 5^oC, especially if it was possible to maintain the dissolved oxygen profile on a suitable level for denitrification and hence prevent an excessive alkalinity drop. In those cases, in addition to nitrification, about a 50 per cent reduction of total nitrogen could be reached as an annual average.

The first plants designed especially for an efficient nitrification were built in 1983 at Hyvinkää and Riihimäki. Both are oxidation ditches for person-equivalents of roughly 35 000 and 50 000, respectively. Primary sedimentation tanks are used for partial pre-precipitation together with simultaneous precipitation. Denitrification takes place in the same aeration ditch at Riihimäki and in a separate ditch at Hyvinkää.

4.2 Process design criteria

The basic process parameters are:

- wastewater quality, C/N-ratio etc.
- sludge age in the activated sludge process
- process temperature
- alkalinity and pH
- dissolved oxygen content in the process

According to the simplified equation for nitrification ($NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$), 4.6 g oxygen and 0.14 mol alkalinity is consumed to oxidize 1 g of ammonia nitrogen. This drop of alkalinity corresponds with a lime dosage of 5.3 g as $Ca(OH)_2$ or 7.1 g as $CaCO_3$. Denitrification brings back half of that alkalinity and also about half of the oxygen consumed in nitrification.

The average amount of wastewater in Finland is about 400 l/p.d and the usual influent quality as follows:

BOD_7	200 mg
Total phosphorus	8 mg
Total nitrogen	36 mg
Ammonia nitrogen	25 mg
Alkalinity	3 mmol/l

Taking into account the effect of pretreatment, biological decomposition of organic nitrogen compounds and nitrogen removal in connection with excess sludge an assumption can be made, that about 85 % or 30 mgN/l of the influent nitrogen will be nitrified. Thus, in a complete nitrification the oxygen consumption could be 120-150 mg/l, and the alkalinity loss could be 3.5-4.5 mmol/l. The increase of oxygen consumption is about 60 per cent.

Alkalinity may be consumed also by chemical precipitants. In Finland, Fe or Al salts are used for pre- or simultaneous precipitation. The usual dosages needed for phosphorus removal spend alkalinity by 0.6-1.2 mmol/l, which probably can slightly exceed the buffer capacity of carbon dioxide produced by biological decomposition. For maintaining the effluent alkalinity at a level 0.5-1 mmol/l, a lime dosage of 50-100 g $Ca(OH)_2/m^3$ or an efficient denitrification is needed.

As concerns nitrification, the most important factor in Finland is the low process temperature especially during snowmelt. The growth rate of nitrifying organisms is lower than the average growth rate of biomass and also more temperature-dependent. For that reason long sludge retention times are needed during the cold season. According to the design quidelines given by the National Board of Waters the minimum sludge retention time used in designing the process should be 25 days at a process temperature of 5°C, 15 days at 10°C and 10 days at 15°C. The design values of sludge load for combined carbon oxidation-nitrification processes have been 0.06-0.08 kg BOD_7/kg MLSS.d, which are adequate also for a partial denitrification. The volume of anoxic zone has been about 40 % of the total volume of aeration tanks.

4.3 Experiences

Several experiences, which have been gained during the last 15 years, have shown, that a complete nitrification is possible even at the lowest temperatures, if the following conditions are fulfilled:

- The sludge retention time must always be sufficiently long. The necessary time is dependent on the process temperature. At 10°C the retention time must be about 10-14 days, which requires a sludge load of about 0.08 kg BOD_7/kg MLSS.d.

- The fall of alkalinity below the value of 0.5-1 mmol/l must be avoided in order to maintain the pH-value at a suitable level.

- The content of dissolved oxygen should be at least 1-2 mg/l.

Furthermore, a successfull plant operation requires good final sedimentation. The settling properties of activated sludge may be rather poor which demands a great capacity of final settling but on the other hand a short detention time of sludge in the sedimentation basin. A usual value of the sludge volume index, SVI, has been 200 ml/g or more. Sludge volume load is mostly the basic design criteria for dimensioning of final settling tanks. In order to avoid dissolving of phosphate as a result of the long sludge retention time it is recommended to feed a part of precipitation chemicals to the input of final settling, when pre-or simultaneous precipitation is used. The usual dosages of Fe and Al precipitants have not been found to inhibit nitrification. When nitrification-denitrification processes have been used in very low loaded oxidation ditches the settling properties of activated sludge have been adequate.

The efficiencies of denitrification processes have been comparatively low, even if the necessity for raising alkalinity by lime has been avoided. The main reason for poor denitrification is probably the too low supply of easily degradable organic carbon for the denitrifying organisms. More knowledge about the effects of different process combinations is needed to improve the situation. The best efficiencies of nitrogen removal have been only 50-60 per cent as yearly averages when ordinary municipal wastewaters have been treated.

Tables 7 and 8 present some recent results and process parameters of Hyvinkää and Riihimäki plants. The low loading has increased energy consumption especially at Hyvinkää.

Table 7a. Hyvinkää oxidation ditch.
Weighted average results in 1985-1986.

		1985			1985 + 1986					
		1.1.-31.12.			1.1.-31.3.			1.4.-30.6.		
Parameter		Inf	Pr	Eff	Inf	Pr	Eff	Inf	Pr	Eff
Alkalinity	mmol/l	2.8	3.3	0.7	3.6	4.2	0.9	2.5	3.0	0.8
pH		7.4	7.9	6.7	7.6	8.3	6.8	7.2	7.8	6.8
BOD_{7ATU}	mg/l	107	65	9	132	75	11	88	51	5
BOD_{7ATU}	red. %		39	92		43	91		42	94
P tot.	mgP/l	6.0	3.8	0.4	7.7	5.2	0.5	5.1	3.5	0.5
P tot.	red. %			94			93			90
P soluble	mgP/l			0.2			0.2			0.2
N tot	mgN/l	28	26	15	36	33	19	24	22	12
N	red. %			47			48			50
NH_4-N	mgN/l	21	19	0.7	28	26	1.6	17	15	0.1
NH_4-N	red. %			98			96			100
NO_3-N	mgN/l			13			16			10
Susp.solids	mg/l			8			10			9

Inf is influent
Pr is outlet of primary settling
Eff is effluent

Table 7b. Hyvinkää oxidation ditch.
Average process parameters in 1985-1986.

Parameter		1985 1.1.-31.12.	1985 + 1986 1.1.-31.3.	1.4.-30.6
BOD_{7ATU} load	kg/d	960	785	920
Electr.cons. total				
- per ww.flow	kWh/m^3	0.32	0.49	0.25
- per tot. BOD_7 rem.	kWh/kg	3.18	4.00	2.94
Electr.cons. in aeration				
- per tot. BOD_7 rem.	kWh/kg	1.50	1.76	1.47
- per biol. rem. BOD_7	kWh/kg	2.62	2.98	2.67
$FeSO_4 \cdot 7H_2O$ dose				
- before prim. sed.	g/m^3	128	154	100
- before final. sed.	g/m^3	21	26	18
- Fe/P molar ratio		2.7	2.4	2.5
$Ca(OH)_2$ dose				
- to aeration tank	g/m^3	15	15	15
- to sludge treatment	g/m^3	67	67	67
Detention in anoxic + oxic z.	h + h	11+16	14+21	8+12
D. oxygen in oxic zone	mg/l	1.9	1.8	1.8
Sludge recirculation	%	700	700	700
Sludge return	%	220	260	140
MLSS concentration	kg/m^3	1.9	2.2	2.4
Sludge load	kg BOD_7/kg MLSS.d	0.06	0.025	0.025
Sludge yield	kg MLSS/kg BOD_7	1.32	1.07	1.67
Sludge retention time	d	24	31	23
MLVSS/MLSS	%	54	56	52
Fe/MLSS	%	20	19	18
SVI	ml/g	87	107	78
Process temperature	°C	10.3	6.5	10.0

Table 8a. Riihimäki Carrousel plant.
Weighted average results 1.6.-31.7.1986.

Parameter		Inf	Pr	Eff
Alkalinity	mmol/l	3.9		1.4
pH		7.0	7.1	7.3
BOD_{7ATU}	mg/l	473	197	6
BOD_{7ATU}	red %		58	99
P tot.	mg P/l	14.5	4.0	0.3
P tot.	red %			98
P soluble	mg P/l			0.2
N tot.	mg/l	52	42	20
N red	%			61
NH_4-N	mg N/l	27	31	0.9
NH_4-N	red %			98
Susp.solids	mg/l			3

Table 8b. Riihimäki Carrousel plant.
Average process parameters 1.6.-31.7.1986.

BOD_{7ATU} load	kg/d	5 780
Electr. cons. in aeration per biol. rem. BOD_7	kWh/kg	1.2
$FeSO_4 \cdot 7H_2O$ dose	g/m^3	106
$Ca(OH)_2$ dose	g/m^3	62
Detention in anoxic + oxic z.	h+h	8+20
D. oxygen in oxic zone	mg/l	1.4
Sludge return	%	162
MLSS concentration	kg/m^3	2.0
Sludge load	kg BOD_7/kgMLSS.d	0.09
Sludge retention time	d	17
MLVSS/MLSS	%	65
SVI	ml/g	290
Process temperature	°C	16

MUNICIPAL WASTEWATER TREATMENT FOR EFFECTIVE REMOVAL OF ORGANIC MATTER AND NITROGEN

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The organic matter, as well as nitrogen and phosphorus, are nutrient substances. Their excess concentrations in water receiving bodies lead to eutrophication, moreover, the nitrogen content in water bodies is standardized according the sanitary-toxicological criterion of harmfulness: NH_4^+-N $\leq$ 0,39-2,0 mgl$^-$, NO_3-N $\leq$9,1-10 mgl$^-$.

The municipal wastewater contain, usually, organic matter estimated by BOD 150-200 mgl$^-$, and COD 300-400 mgl$^-$, the nitrogen compounds 50-60 mgl$^-$, and NH_4^+-N 20-25 mgl$^-$. NO_x-N are practically absent. Their presence indicated on discharge of industrial wastewater. The total phosphorus is present in the concentration of 15 mgl$^-$, PO_4^--P 5-8 mgl$^-$.

Activated sludge process has been most widely used in the USSR for municipal wastewater treatment. The activated sludge is biocenosis of heterotrophic and autotrophic microorganisms. They consume nutrient matters, transferring pollution of wastewater by means of enzyme systems in acceptable formes. C, N and P-containing matters are removed from wastewater by biological intake for cell synthesis. Moreover C-containing matters are removed by oxydation to CO_2 and H_2O. P-containing compounds under definite conditions associate with solid fraction of activated sludge and thus simultaneously removed from wastewater. The removal of nitrogen in addition to biosynthesis is carried out only in the denitrification process, when oxygen of NO_x-N is used for oxidation of organic matter and produced gaseous nitrogen escapes into the atmosphere.

Till recently, the basic purpose of such treatment was the removal of organic matter and suspended solids. The controling parameter of the biological system is organic load. The increasing of organic load increases the removal rate of organic matter and decreases treatment effectiveness.

In the USSR complete biological treatment has been most widely used: BOD of effluent is 15 mgl$^-$ (organic load 300 mg BODg$^-$d$^-$). Under this regime of work the organic matter removal is 90 % and more,nitrogen 40 %, as well as NH_4^+-N. The effluent contains of NH_4^+-N IO-15 mgl$^-$, of NO_x-N 2-4 mgl$^-$. In the activated sludge process, operating in the regime of long-time aeration (organic load 70 mg BOD g$^-$d$^-$) provide more effective nitrification: the concentration of NH_4^+-N decreases upto 1,5-2,0 mgl$^-$, the content of NO_x-N increases upto 15 mgl$^-$.

For reduction of nitrogen amount upto above mentioned standards it is suitable to use nitrification-denitrification method in the single sludge system, operating under alternating aerobic-anaerobic conditions.

In this case three simultaneous biological processes take place in one unit, namely oxidation of carbonaceous matter, nitrification and denitrification. In these processes the reserves of biological system are fully utilised. Treated wastewater provides a source of carbon for denitrification, oxygen of nitrites and nitrates is used for oxidation of organic matter; there is no need for an increase of alkalinity for nitrification, biomass production and electrical energy consumption are decreased, as compared with the conventional system. It is important, that the technology of the single sludge nitrification-denitrification is based on the use of the conventional activated sludge tanks and settling. Therefore, when necessary, the existing wastewater treatment

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plants can be transferred to the new operating regime without considerable capital investment.

The method of the single sludge nitrification-denitrification can be carried out according to one-stage and combined schemes (1, 2). The one-stage scheme contains denitrification tank, aeration-nitrification tank and clarifier. The recirculation of sludge is carried out from clarifier into denitrification tank and the whole amount of influent is also delivered there. In the combined scheme multiple alternation of aerobic-anaerobic conditions is used. This scheme includes denitrification tank, nitrification tank, postdenitrification tank, post-nitrification tank and clarifier. The main part of influent flow rate (70 %) is delivered to the denitrification tank, 30 % - to the postdenitrification tank. The dissolved oxygen concentration in the aerobic zones - is 2 mgl^-, in the anaerobic zones - is $\leq$ 0,5-0,8 mgl^-.

The use of one-stage and combined schemes in municipal wastewater treatment provides effluent with BOD 10-12,5 mgl^-, COD 40-50 mgl^-, NH_4^+-N upto 2 mgl^-, NO_x-N upto 8-10 mgl^- (one-stage scheme) and upto 6 mgl^- (combined scheme). The effect of total N removal is 75 %. These results are obtained under municipal wastewater treatment and characterized by the following values; BOD 125 mgl^-, COD 297 mgl^-, N-tot 72 mgl^-, NH_4^+-N 38 mgl^-, BOD/NH_4^+-N 3:1. Organic load is 100-200 mg BOD g^-d^-, MLSS 1-8,5 gl^-, sludge index 100 cm^3 g^-, the treatment time 4-16 hours, sludge age 3-30 days, recirculation of sludge 400 %, anaerobic/aerobic ratio 1:1. While treatment of wastewater with greater ratio of BOD/NH_4^+-N, relative anaerobic volumes must be decreased, and aerobic - increased.

The increasing MLSS reduces treatment time, however, because of possible disturbance in operating of clarifier, MLSS are to be not more than 2-3 gl^-.

For provided BOD of effluent upto 10 mgl^-, COD upto 40 mgl^-, on NH_4^+-N upto 2 mgl^-, NO_x-N upto 10 mgl^- with the effect of total N by 60 % intensive biological treatment systems with higher aerobic degree can be used (3). These systems are the activated sludge tank with flotated separation mixed liquor and open activated sludge tank with use of pure oxygen. Both systems operate under MLSS 4-8 gl^- and provide the abovementioned effluent effect with organic load 150 mg BOD g^-d^-, the treatment time is 2-4 hours.

In systems with higher aerobic degree activity of nitrifying microorganisms is intensified, and this result is high effective nitrification. Simultaneously with high effective nitrification partial denitrification takes place. The effect of denitrification makes up 40 % of the nitrification effect. This phenomen was mentioned in the article (4) and while investigations of the single-sludge systems. In the single-sludge system increasing of dissolved oxygen concentration in aerobic zones is not recommended, as in these conditions it is difficult to establish an anaerobic regime in the denitrification tank.

Thus, effective removal of nitrogen is possible at existing wastewater treatment plants under decreasing of load by 1,5-3 times and arranging aerobic and anaerobic zones in aeration tank. Production capacity of existing wastewater treatment plants is reduced.

The purpose of further investigation is intensification of process so that effective removal of nitrogen can be performed at existing wastewater treatment plants without reduction of their input capacity.

Construction of new wastewater treatment plants with the use of combined and one-stage schemes requires the increase of the cost by 11-32 % as compared with the conventional systems.

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EXPERIENCE WITH BIOLOGICAL DENITRIFICATION AT THE HIMMERFJÄRDEN PLANT

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Introduction

The Himmerfjärden Sewage Treatment Plant is situated in the southwestern region of Stockholm. The plant serves a population of 230 000 people. The treatment includes both mechanical, biological and chemical treatment. The treated water is discharged into the Himmer Bay (Himmerfjärden), which is a bay of the Baltic Sea. Since nitrogen is regarded as the limiting nutrient in the Baltic the discussion of nitrogen removal at plants in the coastal region has started in Sweden. At the Himmerfjärden Plant full-scale experiments with biological nitrogen removal have been carried out since 1984.

For phosphorus removal both aluminium sulfate and ferrous sulfate have been used during the test period. The removal efficiency in the primary sedimentation tanks was for suspended solids 60-75%, organic matter (COD) 50-60% and phosphorus 45-55%. The higher figures are for the addition of aluminium sulfate. The usual nitrogen reduction for the plant, without denitrification, is only 10-15%.

Experimental methods

The main aim of the experiments done at the plant was to improve the nitrogen reduction within the existing plant by usage and development of existing methods. These must be adapted to the local conditions i.e. a conventional built waste water treatment plant, low content of organic waste in the sewage and low temperatures during the winter time.

Two methods of biological nitrogen removal have been investigated, pre-denitrification and post-denitrification. For pre-denitrification anoxic zones have been built in front of the aerated zones in two aeration tanks.The first tank was rebuilt in 1984 with one small anoxic zone, mixed with two mechanical stirrers (figure 1a). With guidance of experiences of the first year, another tank was rebuilt and started in 1986. In this tank the anoxic zone is divided into three parts by wooden walls. Three mechanical stirrers were installed for the mixing (figure 1b). Nitrified sludge and water are recirculated to the anoxic zone.

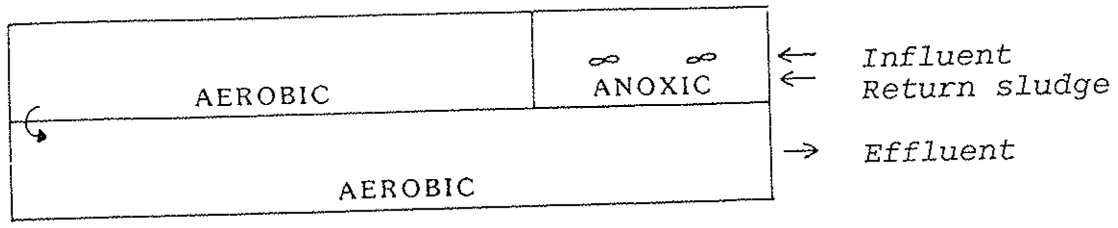

Figure 1a Pre-denitrification

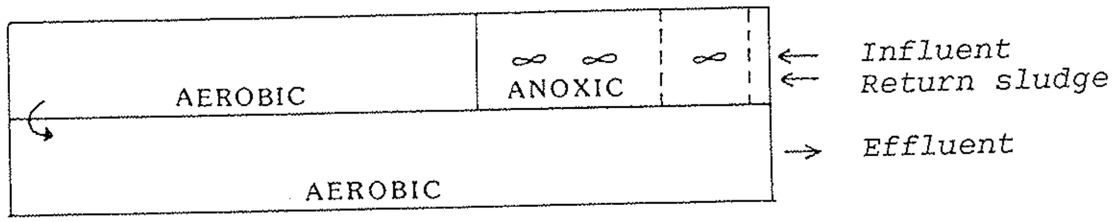

Figure 1b Pre-denitrification

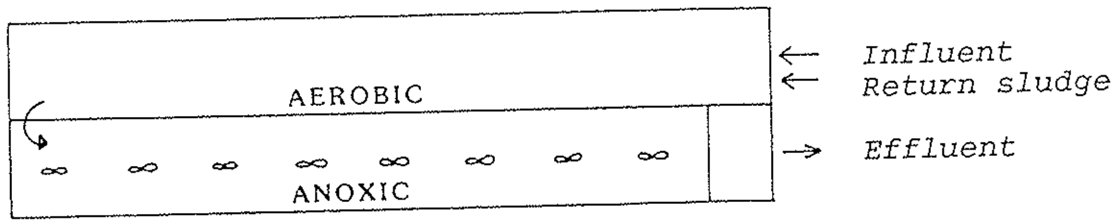

Figure 1c Post-denitrification

Post-denitrification was interesting to investigate because the plant has sedimentation tanks both for biological and chemical sludge. The intention was that the secondary sedimentation tanks should be reconstructed to anoxic tanks. The sedimentation tanks for the chemical step could then be used as sedimentation tanks for the biological sludge. Pilot-plant tests had showed interesting results and therefore one aeration tank was reconstructed for post-denitrification. In the second half of the tank the aeration system was replaced by eight mechanical stirrers. A small aerated zone was built just before the outlet to remove nitrogen gas (figure 1c).

Results

Post-denitrification

Almost complete nitrification was obtained during the experiment time. Average value of the nitrification efficiency was 98% (figure 2), calculated according to the formula:

$$NE = \frac{tot\text{-}Ni - NH4\text{-}Ne}{totNi}$$

NE = nitrification efficiency
tot-Ni = influent total N, mg/l
NH4-Ne = effluent NH_4-N, mg/l

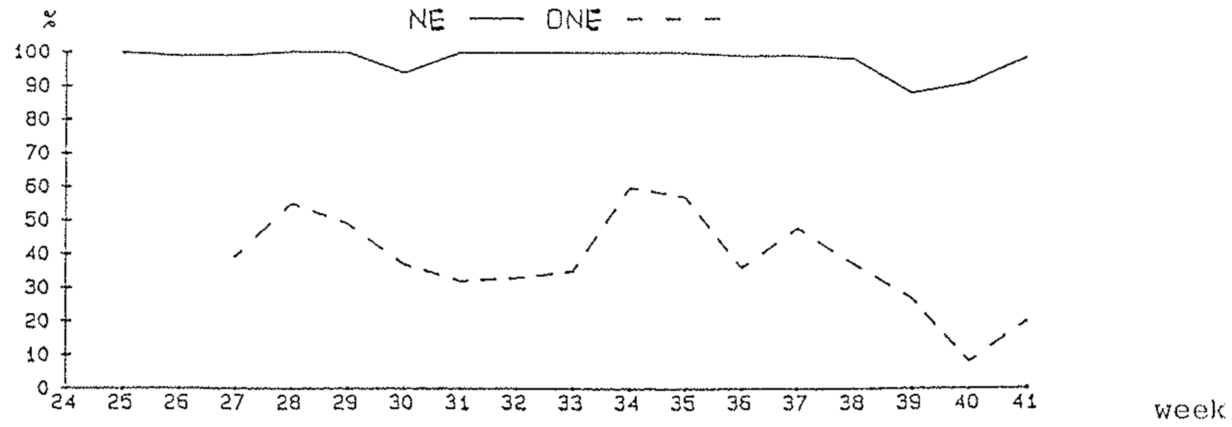

Figure 2 Nitrification and denitrification efficiency

The ammonia nitrogen concentration in the effluent was seldom higher than 0,2 mg/l. The decrease in nitrification efficiency during the weeks 39 and 40 was caused by a loss of mixed liquor suspended solids from a concentration of about 2700 mg/l to 1500 mg/l.

The reason for such a high nitrification efficiency (NE), was

- high average wastewater temperature, 16,6°C
- high hydraulic retention time, 5,3 h
- high sludge age, 50 days
- low sludge load, 0,25 kg COD/kg SS d

The nitrification rate was calculated according to the following formula:

$$kn = \frac{tot\text{-}Ni - NH4\text{-}Ne}{ts * VSS}$$

kn = nitrification rate
ts = hydraulic retention time in aeration tank
VSS = volatile suspended solids

The nitrification rate, calculated as mean values for a week, varied between 1,1 to 3,8 mg N/ g VSS h. The results are shown in figure 3.

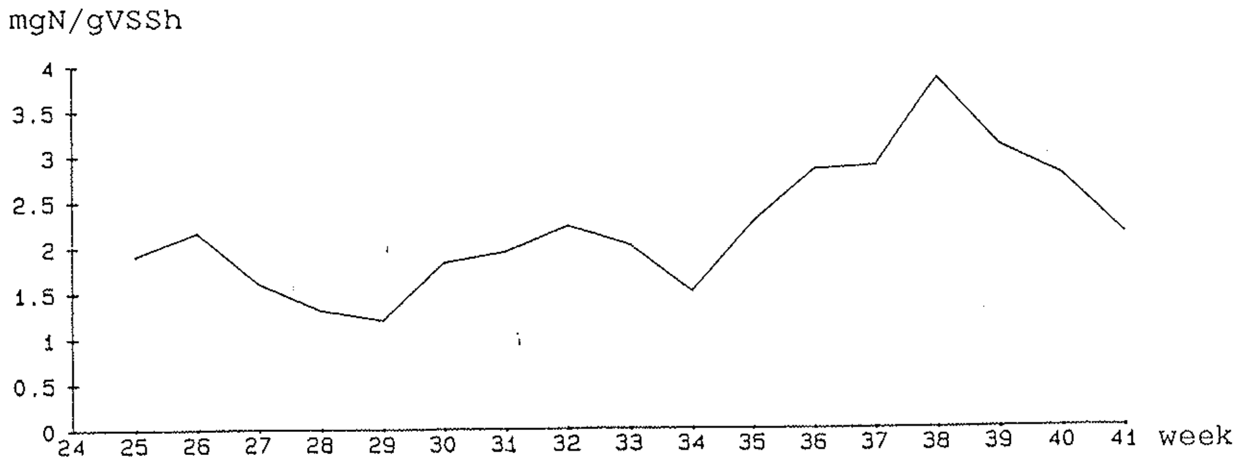

Figure 3 Nitrification rate - Kn

The denitrification efficiency was calculated by

$$DNE = \frac{\text{tot-Ni - NH4-Ne - NO3-Ne}}{\text{tot-Ni}}$$

DNE = denitrification efficiency
NO3-Ne = effluent NO_3-N, mg/l

As it is shown in figure 2, the denitrification efficiency varied between 8 and 55%, with an average value for the whole period of 34%.

The reason for not obtaining higher nitrogen reduction was lack of organic carbon. The denitrification efficiency is primarily dependent on the carbon/ nitrogen ratio.This ratio is presented in figure 4. To verify that the reason for bad denitrification efficiency was carbon shortage, methanol was dosed as a carbon source during two weeks, 34 and 35. The results confirm the theory that the content of organic carbon in the water was too low.

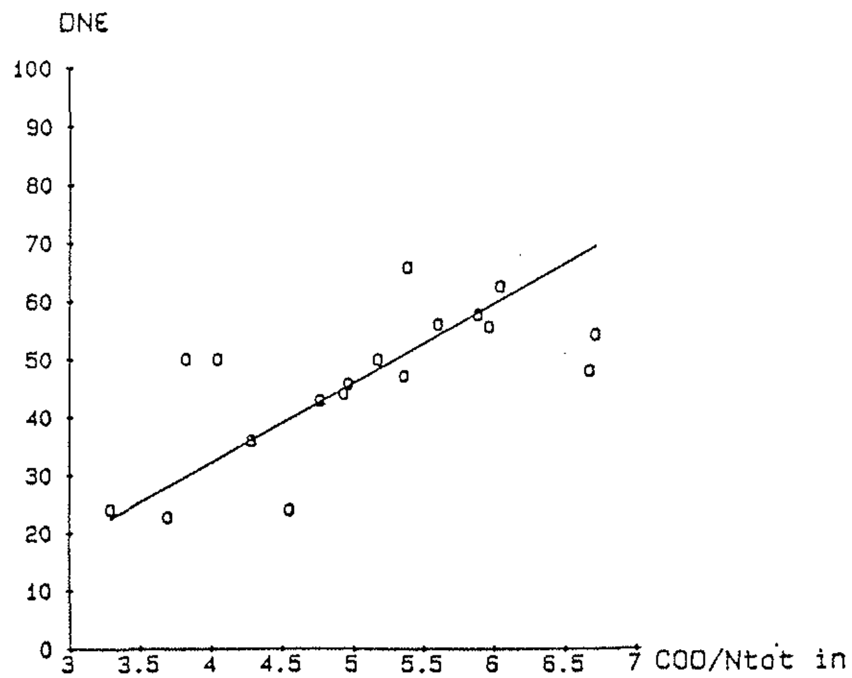

Figure 4 C/N ratio to denitrification efficiency

Another reason for the low denitrification efficiency was too short retention time in the anoxic zone. The intention of the experiment was that the retention time in the anoxic zone should be high enough to utilize internal carbon sources. This could not be obtained due to bad sedimentation properties of the biological sludge. The return sludge flow had to be increased to higher flows than expected which caused too short retention time in the anoxic zone.

The conclusion of the post-denitrification experiments was that it was impossible to achieve a high denitrification efficiency in the existing plant with the actual wastewater composition and flow.

Pre-denitrification

During 1985 a tank with one complete mixed anoxic zone at the inlet part of the aeration tank was investigated. In spring time, before the snow melting period, 30% denitrification efficience was reached. The nitrification efficiency was only 65% and limited the denitrification.

During the summer period almost complete nitrification was obtained with exception of some periods when the sludge content decreased in the tank due to bad sludge properties (figure 5).

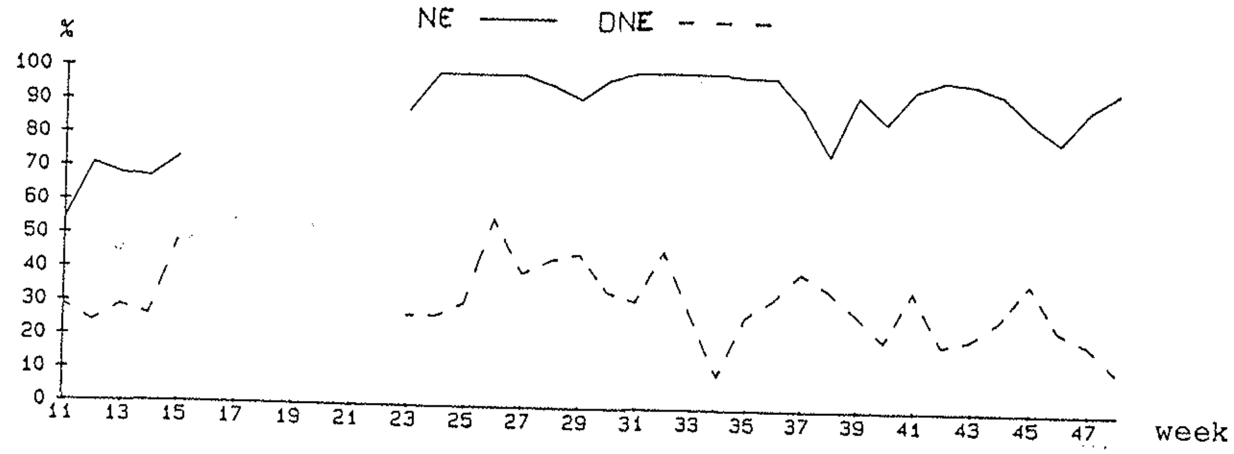

Figure 5 Nitrification and denitrification efficiency

The nitrification rate is shown in figure 6. It varied between 2,5 and 9,4 mg N/g VSS h. The mean value for the period was 5,5 mg N/g VSS h.

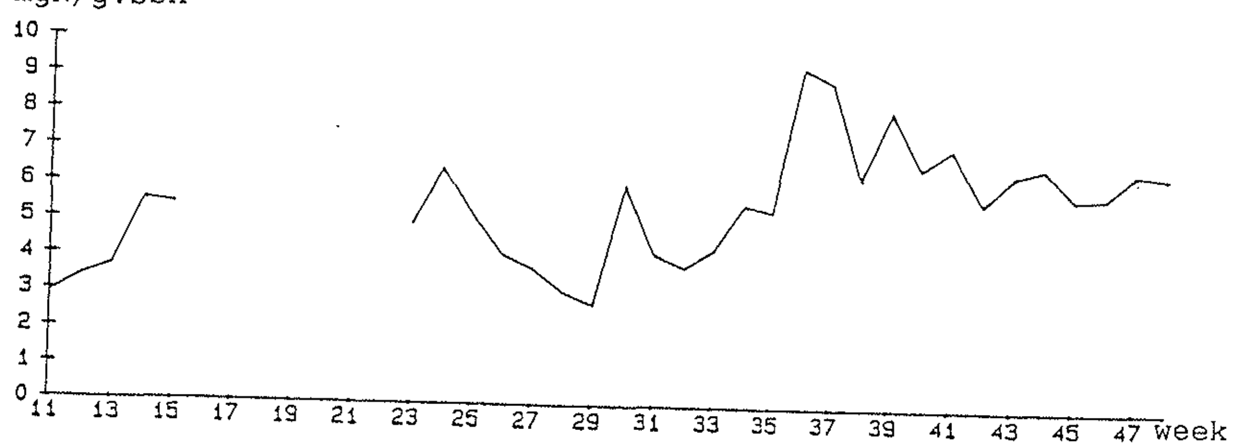

Figure 6 Nitrification rate - Kn

The denitrification efficiency during the summer became 40% (see figure 5). The theoretical value was 50%, because the return sludge flow was 100% of the incoming flow. The primary reason for the limited denitrification was, even in this experiment, the lack of easily degradable organic material as shown in figure 7. In the diagram the *reached DNE/possible DNE* is plotted against the *influent COD/influent NO3-N.*

A strong relation between the denitrification efficiency and the organic carbon in the influent water was observed. In the literature it is reported that the carbon-nitrogen ratio of the raw sewage has to exceed the critical ratio 3-5 mg BOD_5/mg total nitrogen.

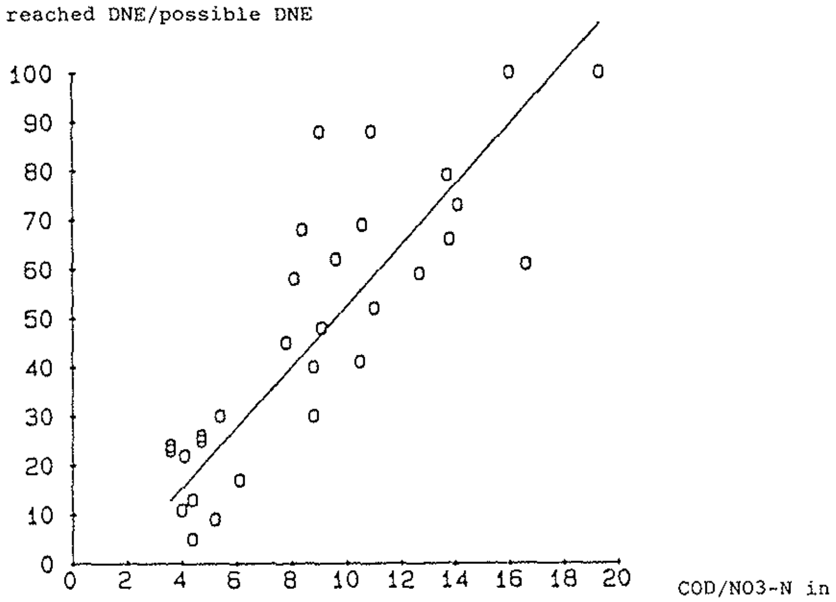

Figure 7 C/N ratio to denitrification efficiency

Another contributing reason for the low denitrification efficiency could be the rather short retention time in the anoxic zone. Taking in account only the incoming flow, the retention time was 32 minutes, and with 100% recirculation flow, the actually retention time became 16 minutes. Corresponding retention times in the aerated zone were 2,8 h and 1,4 h respectively.

In opposite to studies reported by other authors on pre-denitrification, the bad sludge settleability caused troubles in keeping the concentration of suspended solids in the tank at a high level. To try to overcome the bad sludge properties, another tank, L1, was reconstructed and started in the summer 1986. In this tank the anoxic zone was divided into three parts by wooden walls. The first part is small to give a fast mixing of incoming water and return sludge. The second and third part is mixed with mechanical stirrers. The anoxic zone has also been increased in volume compared to the old tank, L2.

Results from 1986

Some results from this year, 1986, can be presented but must be regarded as preliminary. The nitrification and denitrification efficiency for the old pre-denitrification tank is presented in figure 8, and for the new tank in figure 9.

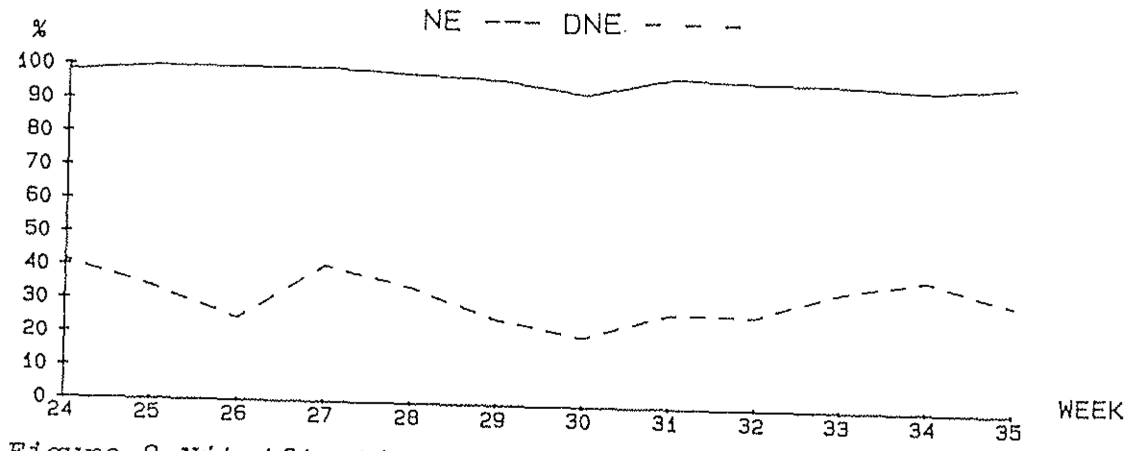

Figure 8 Nitrification and denitrification efficiency, L1

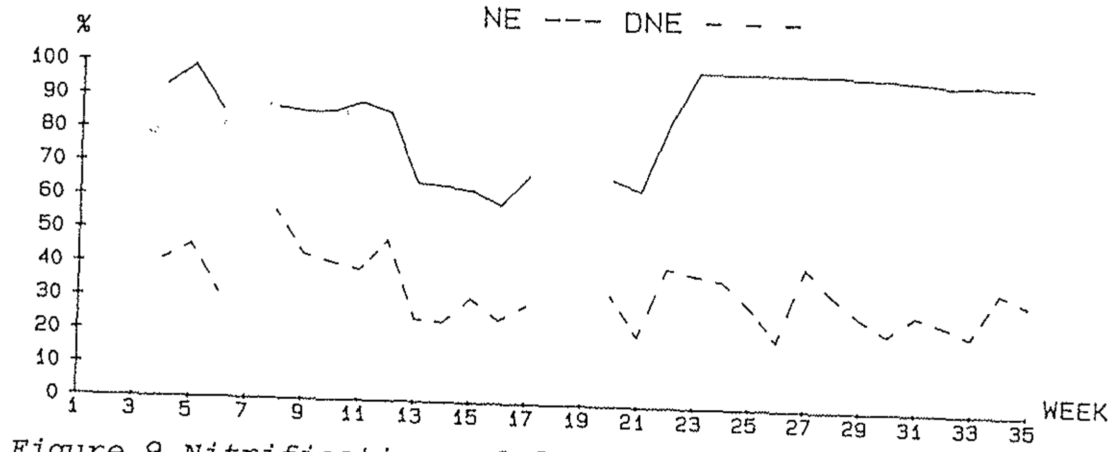

Figure 9 Nitrification and denitrification efficiency, L2

The results from the summer period is very similar for the two tanks. Any significant improvement in efficiency for the larger anoxic zone can not be shown. Still the denitrification efficiency is rather low, about 30%, depending on shortage of organic carbon, as shown in figure 10.

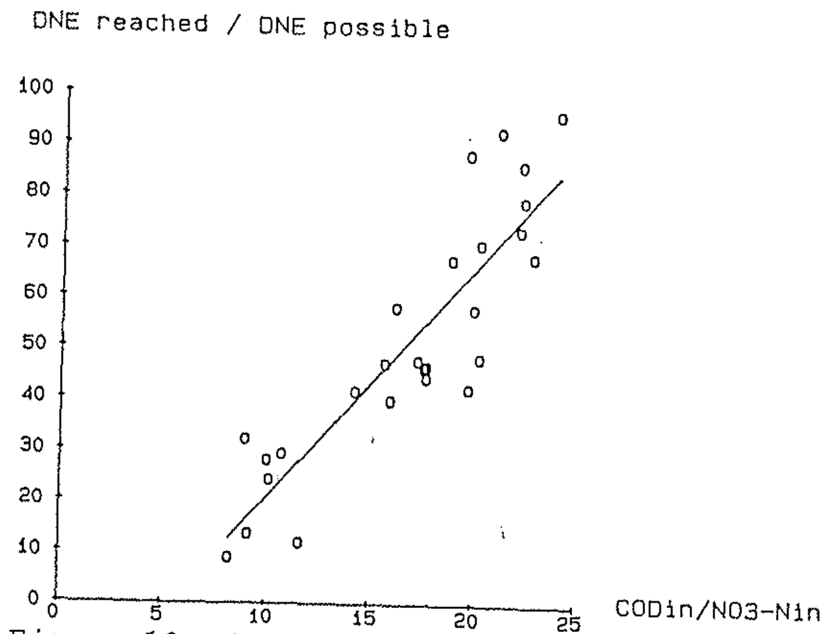

Figure 10 C/N ratio to denitrification efficiency

In the spring time, when the organic load to the plant was higher, even the denitrification efficiency was higher, about 43%, when the nitrification efficiency was not the limiting factor.

The increased plug-flow in the new tank has not improved the settling properties of the sludge. The reason for this will be more investigated the autumn 1986.

Respiration tests

As the limiting factor for the denitrification efficiency seemed to be the access of readily degradable organic carbon, some respiration tests were done in laboratory scale to prove it. Sludge from an aeration tank was aerated and then sewage, both settled and pre-precipitated, was added and the respiration rates were measured. As shown in figure 11, respiration rates are similar for settled and pre-precipitated sewage, which proves that pre-precipitation do not decrease the content of easily degradable organics, essential for the denitrification.

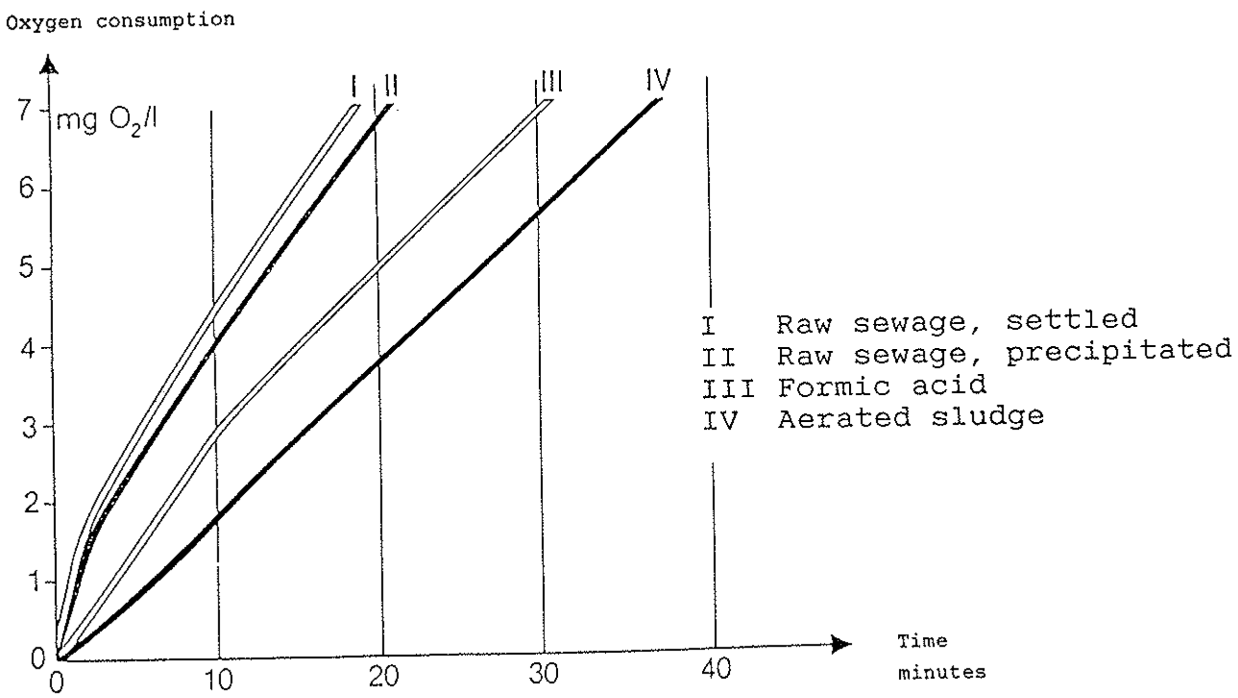

Figure 11 Respiration rate

Conclusion

The conclusion of the experiments so far, must be that there is no uniform solution how to manage biological denitrification. It is a question of many factors of which the composition of the raw sewage is one of the most important and must be taken into consideration when nitrogen removal at sewage treatment plants is discussed.

DENITRIFICATION - POSSIBILITIES AND COST ASPECTS

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1 INTRODUCTION

During the mid-sixties in Sweden, a common concern of the environment spread through the country. The importance of protecting the receiving waters was rapidly politically accepted. This resulted in the formation of the National Environmental Protection Board 1969 and shortly after, subsidies for constructing sewage and waste water treatment plants were introduced. As a result, more than 800 advanced treatment plants are today serving almost 100 % of the population in Sweden.

In the sixties and earlier, the interest had been focused on BOD-reduction, and very little had been done with regard to nutrient removal. In the discussion on possible future action for the protection of the receiving waters, it was clearly proven, that the impact from nutrients causing secondary pollution, could be more crucial than that from the BOD in the sewage. This fact was due to the particular characteristics of the inland waters. Phosphorus was shown to be the limiting growth factor in most inland waters and partly along the Baltic coast, while nitrogen limited the growth in some coastal receiving waters.

At that time there was almost no experience on nitrogen removal available, and possible technical solutions based on the present technology should also require a very large investment program. Furthermore, a demand for only nitrification in the Swedish climate would be very costly. For phosphorus removal, however, some experience as well as technical-economical solutions were available, which directed the legislation and practise towards phosphorus removal.

During the last years, however, the nitrogen load on some recipients has grown to an alarmingly high level. Even if most of the nitrogen can be referred to as diffuse sources from agriculture, nitrogen removal in treatment plants in sensitive areas is of great interest.

A new technology for nitrogen removal has been presented, mainly based on the development in South-Africa during the seventies. The process will give lower investment and operation costs, compared to the original process solutions, so the possibility for successful application of nitrogen removal in colder climate has considerably been increased.

Although satisfactory results have been achieved in full scale operation, some care is imperative. Compared to the situation in the sixties, when phosphorus removal was introduced in Scandinavia, it must be stressed that nitrification-denitrification is a far more complex process, which need further studies for optimal application.

The investment as well as operational costs for nitrogen removal are dependent on many factors, which might vary from one plant to another. This paper has no ambition to cover all possibilities, but will point at some important technical-economical criteria for the choice of process solutions.

2 BASIS FOR NITROGEN REMOVAL

The nitrogen in nature is continuously circulating from mineral to organic nitrogen, which then is biologically degraded and released as inorganic nitrogen.

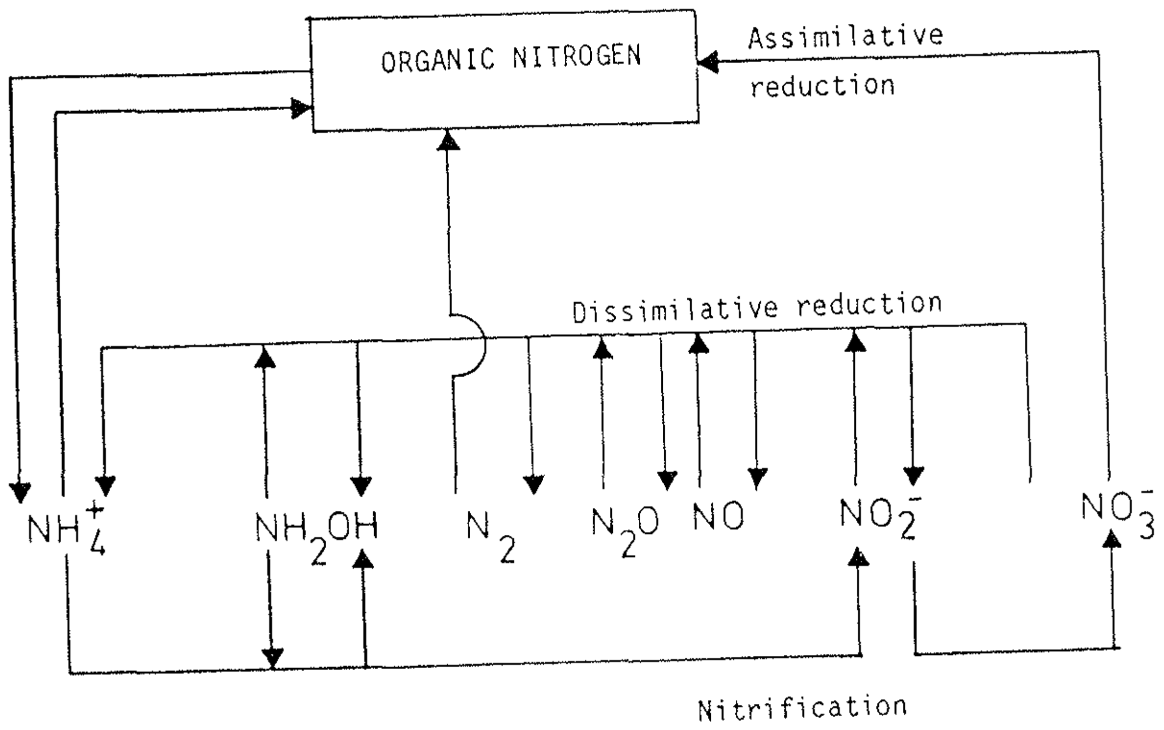

Fig.1. The microbiological nitrogen cycle

The biological treatment of waste waters is a technical adaption of nature's own methods. The most important microbiological reactions in the nitrogen cycle are illustrated in **Fig.1**, and the different stages are summed up below.

1. **degradation of organic material**, e.g. proteins, which releases N-NH4.

2. **nitrogen is incorporated in the microorganisms** during the sludge growth

3. **nitrification in two stages**, NH4 - NO2 - NO3, where hydrogen ions are released.

   NH4 + 2 O2 NO3 + H2O + 2 H

   The oxygen consumption is 4.57 g O2 per g N oxidized.

4. **denitrification**, NO3 - N2, if accessible carbon source is available, where hydrogen ions are consumed in the required oxygen-free (anoxic) environment.

   2 NO3 +2 H N2 + H2O + 2.5 O2

   The oxidation corresponds to 2.86 g BOD per g N reduced.

Because of the chemical oxygen demand and toxicity, caused by ammonia-nitrogen (>0.5 mg/l of NH4 may harm some organisms), nitrification sometimes is imperative.

The nitrification is primarily dependent on temperature, oxygen concentration and sludge age. The oxygen content in the nitrifying zones should be kept above 2 mg/l. Compared to the microorganisms removing BOD, the nitrifying bacteria have a much slower growth. As a consequence, the F/M-ratio (sludge load) must be lower:

at 20 degrees C, 0.15 kg BOD/kg VSS, sludge age > 5d
at 5 degrees C, 0.05 kg BOD/kg VSS, sludge age > 15d

The temperature dependence on the system might be expressed by the nitrification and denitrification potential of the sludge, obtained in the Falkenberg study, presented below:

Temperature	Nitrification rate	Denitrification rate
6.5- 7	5-10 g N/kg SS	20-30 g N/kg SS
17-18	40-50 g N/kg SS	40-60 g N/kg SS

As can be seen from the figures above, **nitrification is more temperature dependent than denitrification.**

The denitrification rate is dependent on an easily accessible carbon source, which was demonstrated in the Falkenberg study by adding acetate to the waste water. This increased the denitrification rate from 30-60 to 180-200 g N per kg SS. The available carbon source might be illustrated by the BOD/TKN or COD/TKN-ratio, which should exceed 5 resp. 10, according to practical experience, using only raw sewage as energy and carbon source.

As a consequence, the pretreatment should not be too efficient in carbonaceous removal, e.g. the process sometimes operates better without than with primary clarifiers, or an external carbon source might be necessary.

The change in alkalinity during the nitrification and denitrification process may be used as a means for optimizing the chemical dosage and pH-value in post-precipitation systems.

It should be stressed, that the denitrification of nitrates to gaseous nitrogen is not the only possible reaction for nitrogen removal. A reduction of nitrate to ammonia may occur. The mechanisms for these reactions are not clearly understood.

3 SYSTEM DEVELOPMENT AND DESIGN FOR NITROGEN REMOVAL

The activated sludge process is degrading and transforming the organic compounds into biological flocs, a process during which organic nitrogen is transformed to ammonium nitrogen, **Fig.2a**.

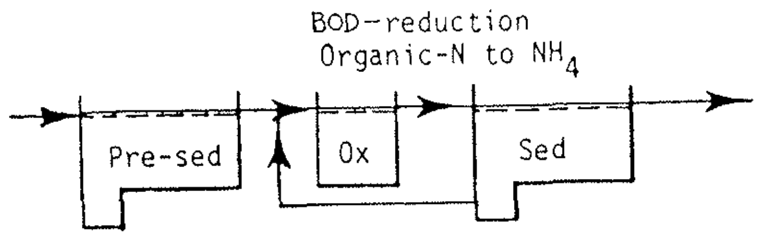

Fig.2a. Activated sludge process for organic carbon removal.

The original design for nitrification was carried out as a second biological stage, **Fig.2b** (two-sludge system). In modern design, nitrification is carried out in a one-sludge system together with the BOD-removal by having a longer sludge age in the system.

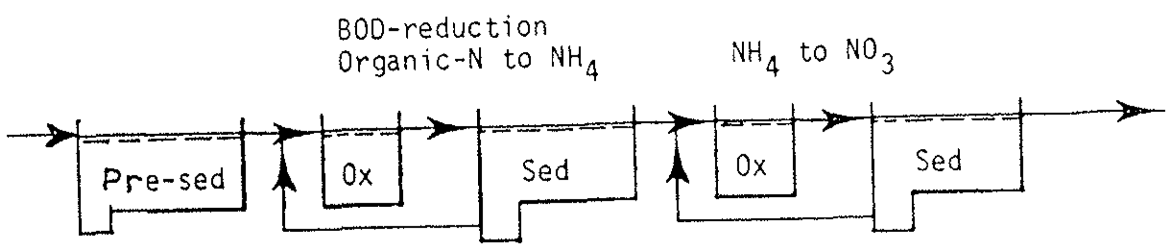

Fig.2b. Two-stage activated sludge for nitrification

In order to achieve denitrification, a third anoxic stage after the nitrification stage was originally included, **Fig.2c**, where an external carbon source, generally methanol, had to be added.

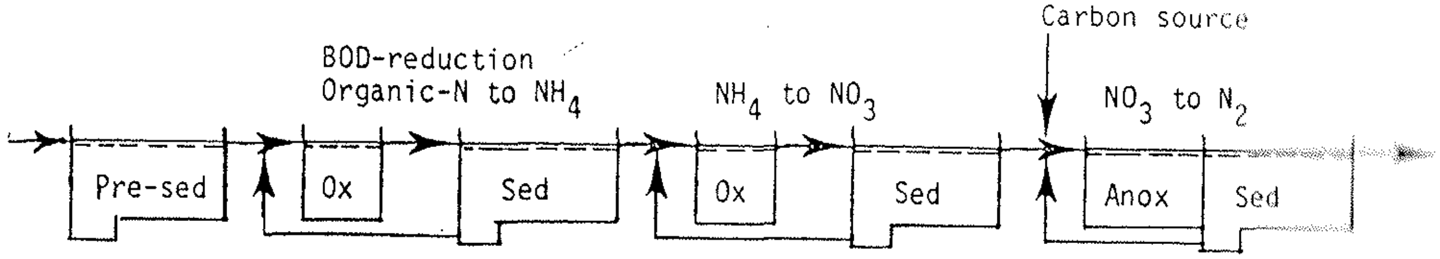

Fig.2c. Three-stage activated sludge for denitrification

A three-sludge system as described above leads to unrealistically high investment and operational costs, which has been inhibiting the use of the process.

The process, however, can also be carried out as a one-sludge system, originally developed by Dr James Barnard during the seventies in the BarDenPho-system. After modifications of the system, good results have been obtained, however mostly in warm climates.

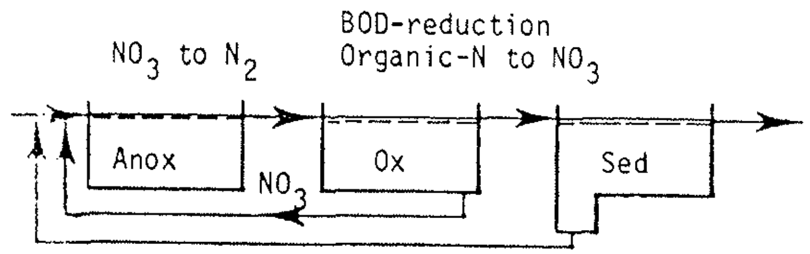

Fig.2d. The BarDenPho one sludge-system

The process involves a first anoxic stage. The raw sewage is used as the carbon source, and is mixed with recirculated nitrified water from the second, aerobic, stage in the process and with the sludge from the secondary clarifier, **Fig.2d**. The denitrifying stage is thus not only avoiding the use of chemicals, but is also reducing the organic load on the nitrification stage, which then is leading to less oxygen and energy consumption.

The denitrification rate is dependent on anoxic conditions, the temperature and the available carbon source. Oxygen may be present in lower concentrations, without

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inhibiting the process. In practise, the anoxic detention time should be 1-2 hours, using 3-400% recirculation of nitrified water.

One application of the one-sludge system is the Bio-Denitrosystem, with double aeration tanks, which are operated in series in a cycle. The first tank is fed with raw sewage without aeration and the second with aeration (cycle 1, 1-2 h). Then both tanks are aerated (cycle 2, 1/2 h) and after that the second tank is fed with raw sewage under anoxic conditions while the first tank is aerated, starting the cycle again:

Raw sewage	Tank 1 (anoxic)	Tank 2 (**nitrification**)
Raw sewage	Tank 1 (aerated)	Tank 2 (**nitrification**)
Raw sewage	Tank 2 (anoxic)	Tank 1 (**nitrification**)
Raw sewage	Tank 2 (aerated)	Tank 1 (**nitrification**)

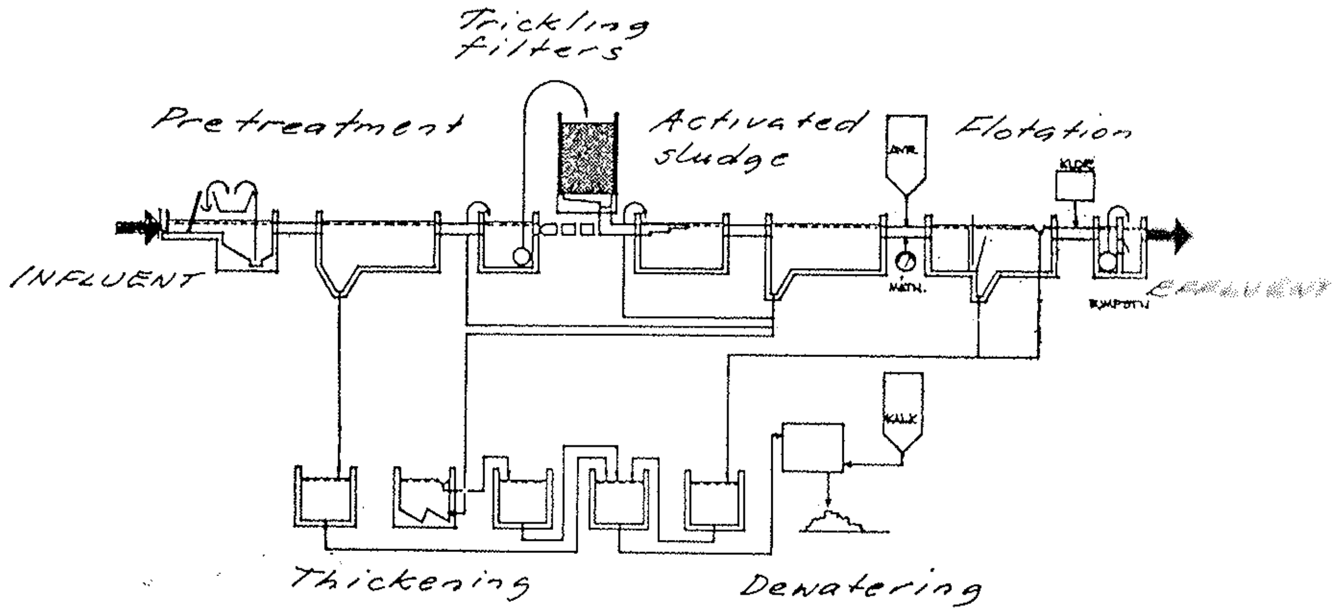
The results have been good, but large sites are required.

4 PRACTICAL EXPERIENCES FROM THE FALKENBERG PLANT

Some treatment plants in Sweden have recently been applying different systems for nitrification and sometimes denitrification in full scale tests. The first one is the treatment plant in Falkenberg, which is situated in an area, where nitrogen removal is im- portant. It has been in full scale operation since May 1983, using the new approach for biological nitrogen removal. As a result from the experiences, Falkenberg is the first plant in Sweden, where denitrification has been required from the Environmental Court (Koncessionsnämnden).

The treatment plant in Falkenberg was taken into operation 1978. It was designed for 13.000 kg BOD7/d, and approximately. 30.000 m3/d, for the treatment of sewage as well as waste waters from e.g. dairy and brewery industries. The plant is a typical Swedish plant, with original effluent requirement in accordance to Swedish standards, i.e. 15 ppm of BOD7 and 0.5 ppm of total phosphorus in the effluent. The demand for phosphorus removal is not really imperative for the receiving water, which is Kattegatt, but should more be seen as a way to express the need for a safe and reliable system.

The treatment comprises, **Fig.3:**



mechanical treatment in screens, grit removal and primary clarifiers

two-stage biological treatment with high rate trickling filters followed by the activated sludge process

chemical treatment by flocculation and flotation

sludge treatment by thickening and dewatering in filter presses

After some years' operation, the organic load was reduced due to internal changes in the major industries, resulting in a load of only 3.000-5.000 kg BOD7/d and 10-15.000 m3/d. This decrease in load made it possible to modify the operation of the plant. Falkenberg city together with PURAC got a grant from the National Environmental Board (SNV) to study the possible nitrogen removal through the year.

The four aeration tanks were changed into two different nitrification-denitrification systems,carried out as modified BarDenPho-systems, **Fig.4.** The difference between the systems is the location of the anoxic zones, which have the same overall volume. System 1 has one anoxic zone before a circulating nitrification zone, while System 2 has two anoxic zones, each followed by a nitrification zone.

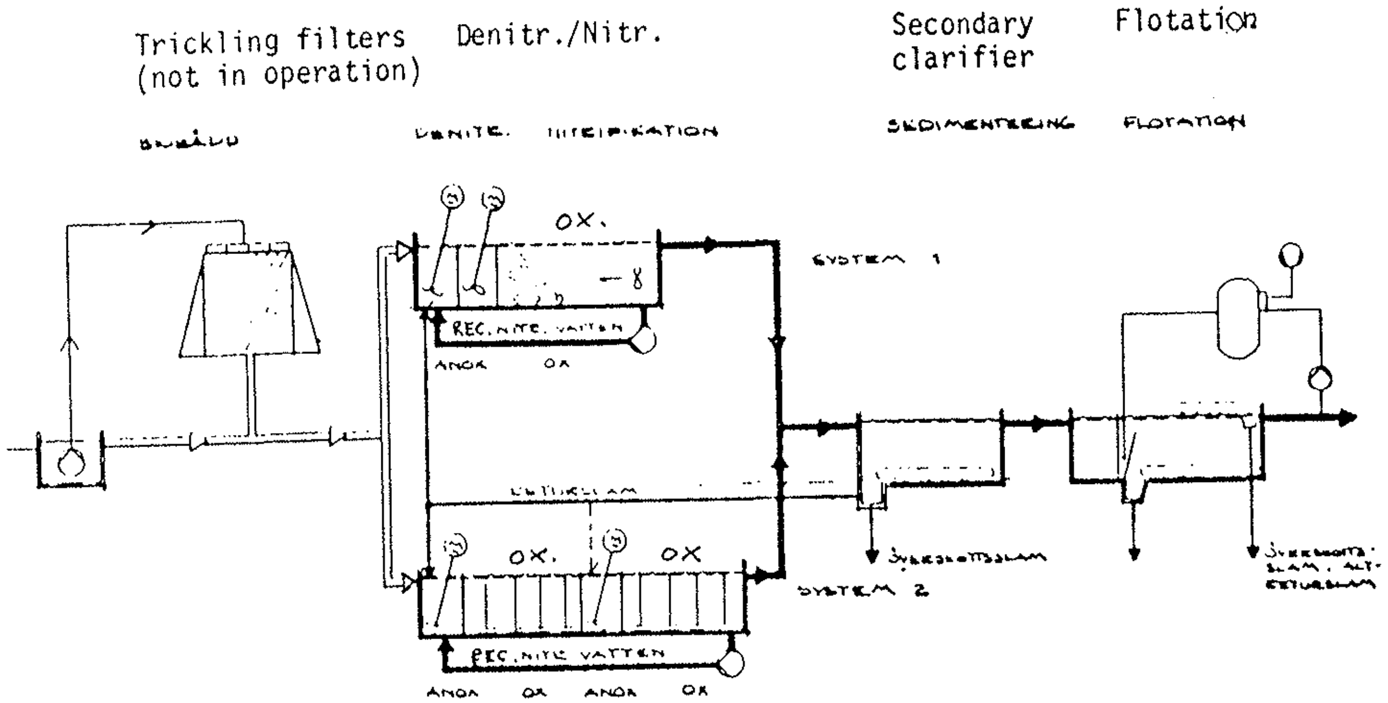


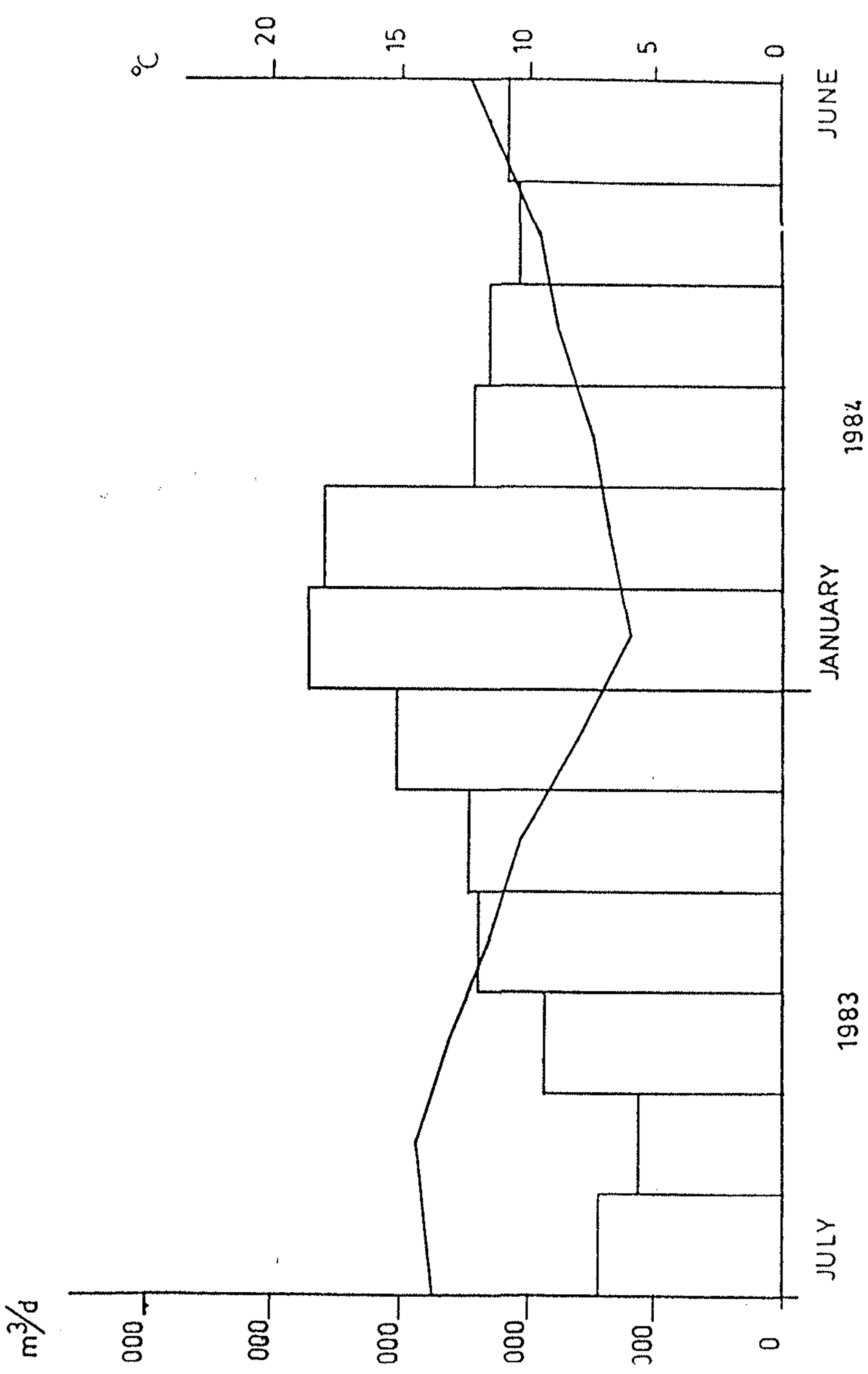
Fig.4. The Falkenberg plant, modified for denitrification

The operation was carried out without the addition of any coagulant, but with the flotation in operation, in order to study the effect of two-stage separation. That part of the study was integrated, as it has more and more clearly been proven, that keeping the sludge in the biological systems is one of the most common problems all over the world. The possible biological phosphorus removal was also studied.

5 RESULTS AND CONCLUSIONS

The results from the study is presented in **Fig.5-8**, showing the temperature and flow variations over the year, **Fig.5**. The significant influence of temperature is evident, which is shown in the monthly nitrogen removal, **Fig 6**. During the summer, nitrogen removal exceeded 80%, while only 60% during the winter time was achievable.

Addendum: During the winter 1986-87, nitrogen removal has been high, 70-75 % as monthly average, in spite of the cold winter, with water temperatures below 10 degrees. Furthermore, the importance of easy accessable carbon was stressed, as more than 80 % removal was achieved when the industry was in operation, and only 40 % during the weekends with no or little industrial waste water in the influent.



Flow and temperature in the aeration tanks.

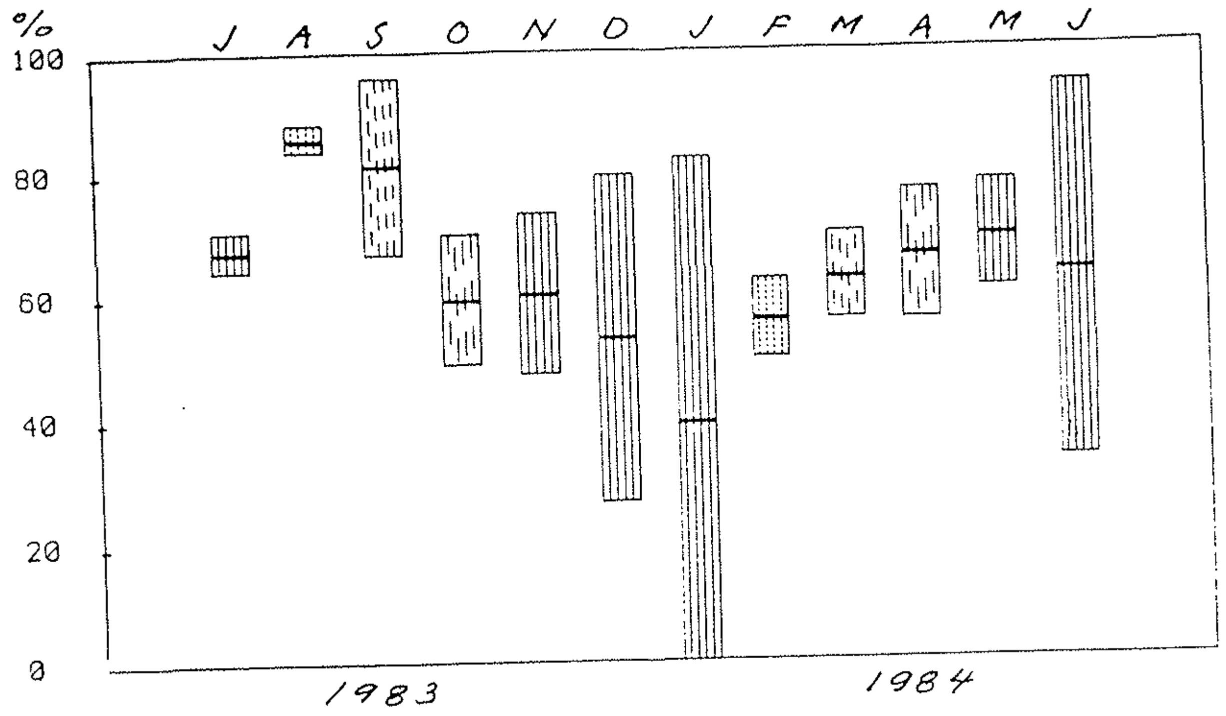


Fig.6. Nitrogen removal, average values with standard deviation

The tests started with having the trickling filters in operation, but they had to be by-passed. The combination of high oxygen content in the trickling filter effluent, combined with the possible removal of easy accessible carbon, caused problem in the denitrification process.

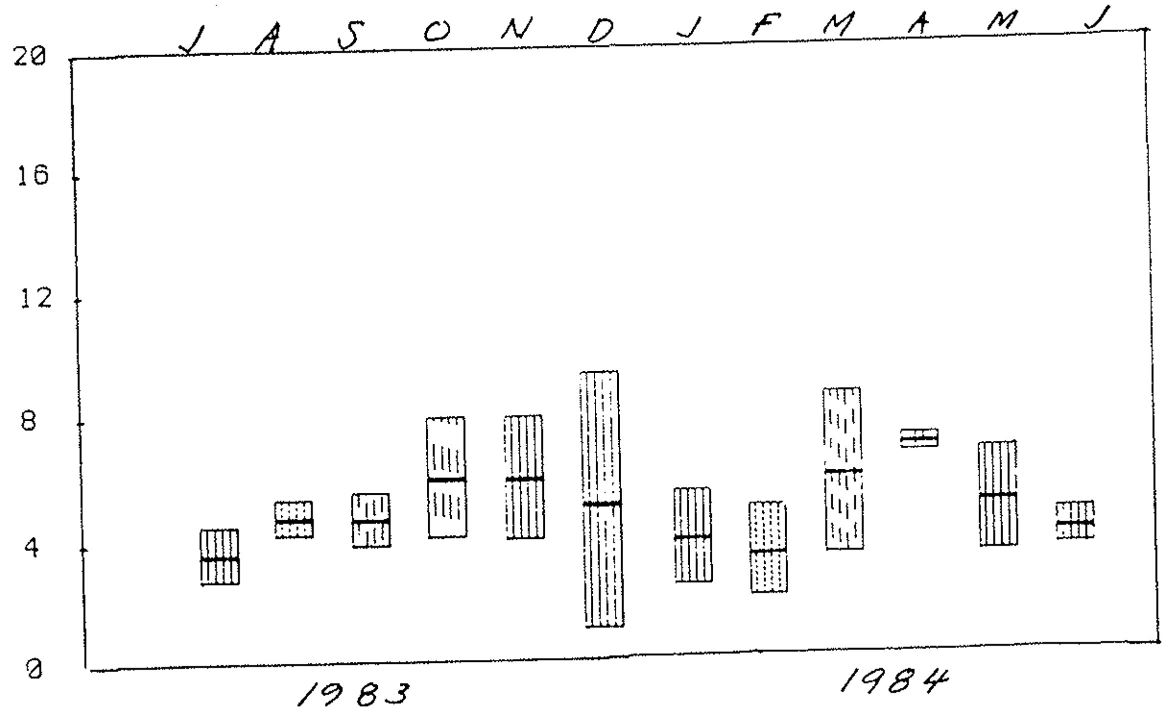
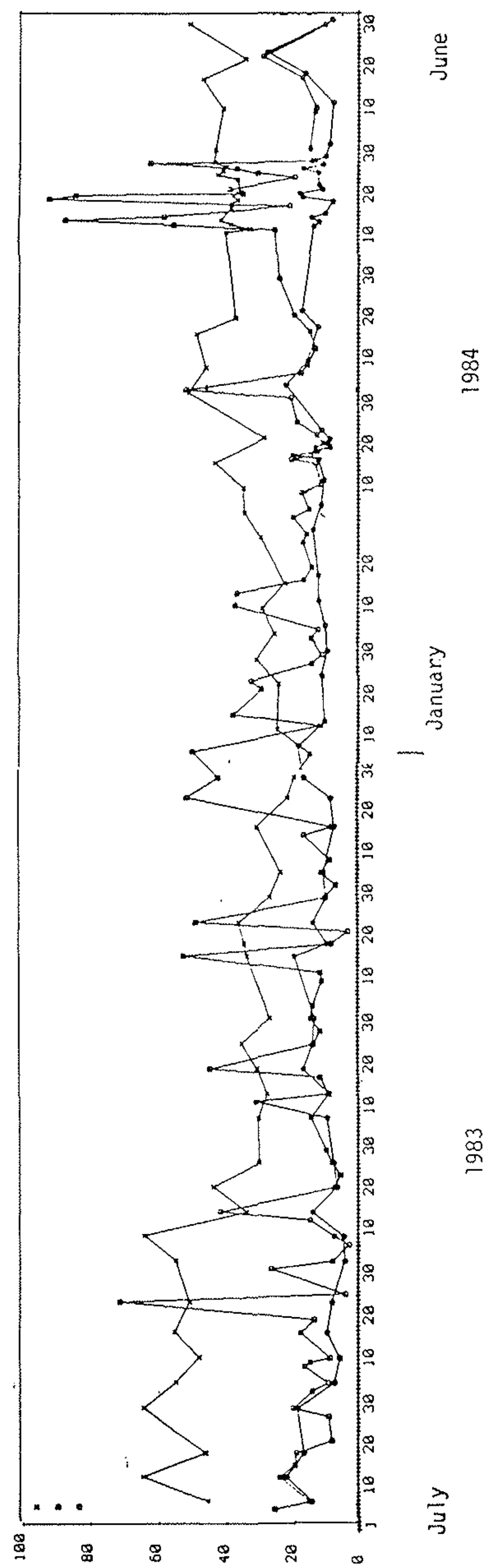


Fig.7. The ratio of BOD/total-N after primary treatment



8. Total nitrogen-influent (x), after secondary settling (□), after flotation (*).

The Falkenberg treatment plant makes different operational modes possible, which might be exemplified by the present operation, which is using one of the trickling filters during the week in order to obtain successful nitrification. As the industries are not working over the weekends, the load decreases, and causes problems with denitrification as well as alkalinity in the tertiary treatment. Consequently, the trickling filter is taken out of operation Friday afternoon. On the Sunday, however, part of the primary sludge is fed to the anoxic zones in order to offer sufficient amount of carbon source.

Another issue was the importance of efficient removal of suspended matter, particularly for low phosphorus and BOD content in the effluent. Because of the high sludge content in the system, necessary to achieve nitrification, suspended solids carry-over from the secondary clarifiers frequently occurred. This fact, however, did not influence the effluent, because of the second separation stage, the flotation, Fig.9-10.

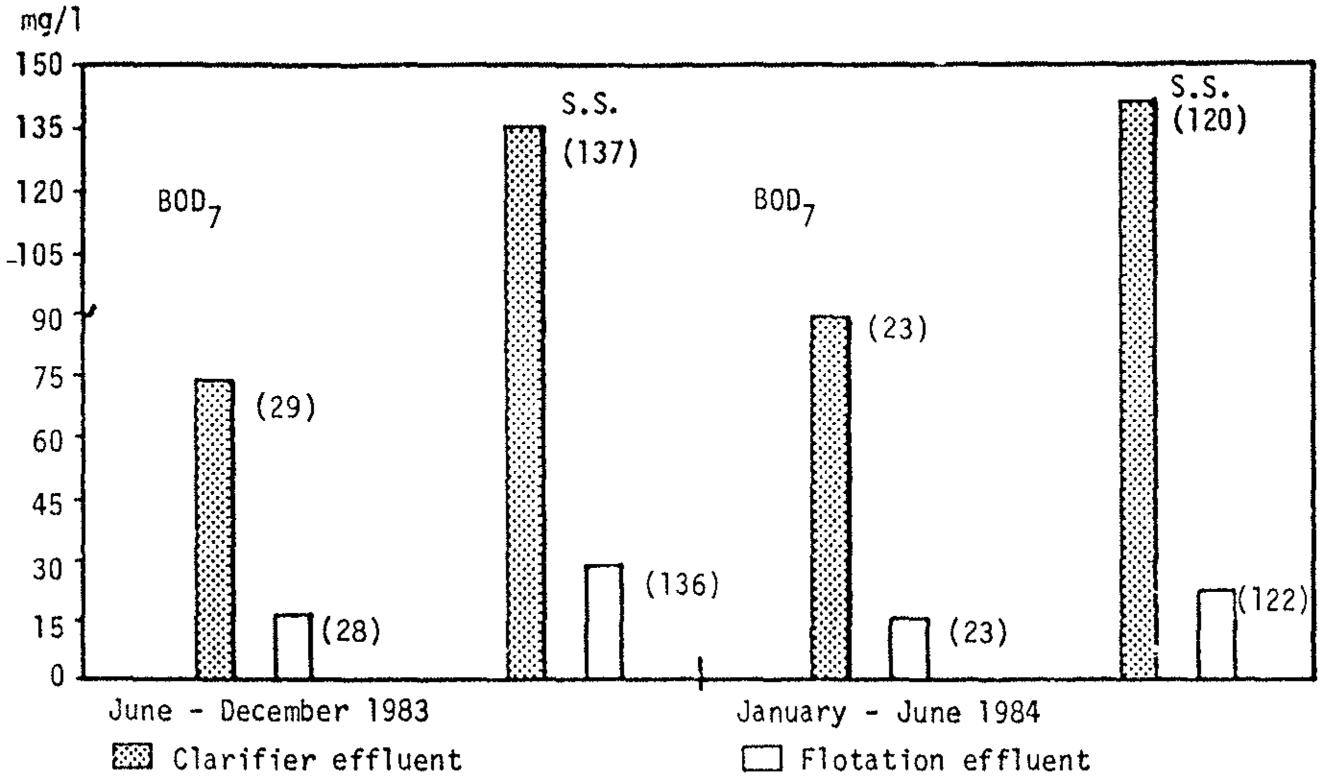


Fig.9. Suspended solids in secondary and flotation effluent

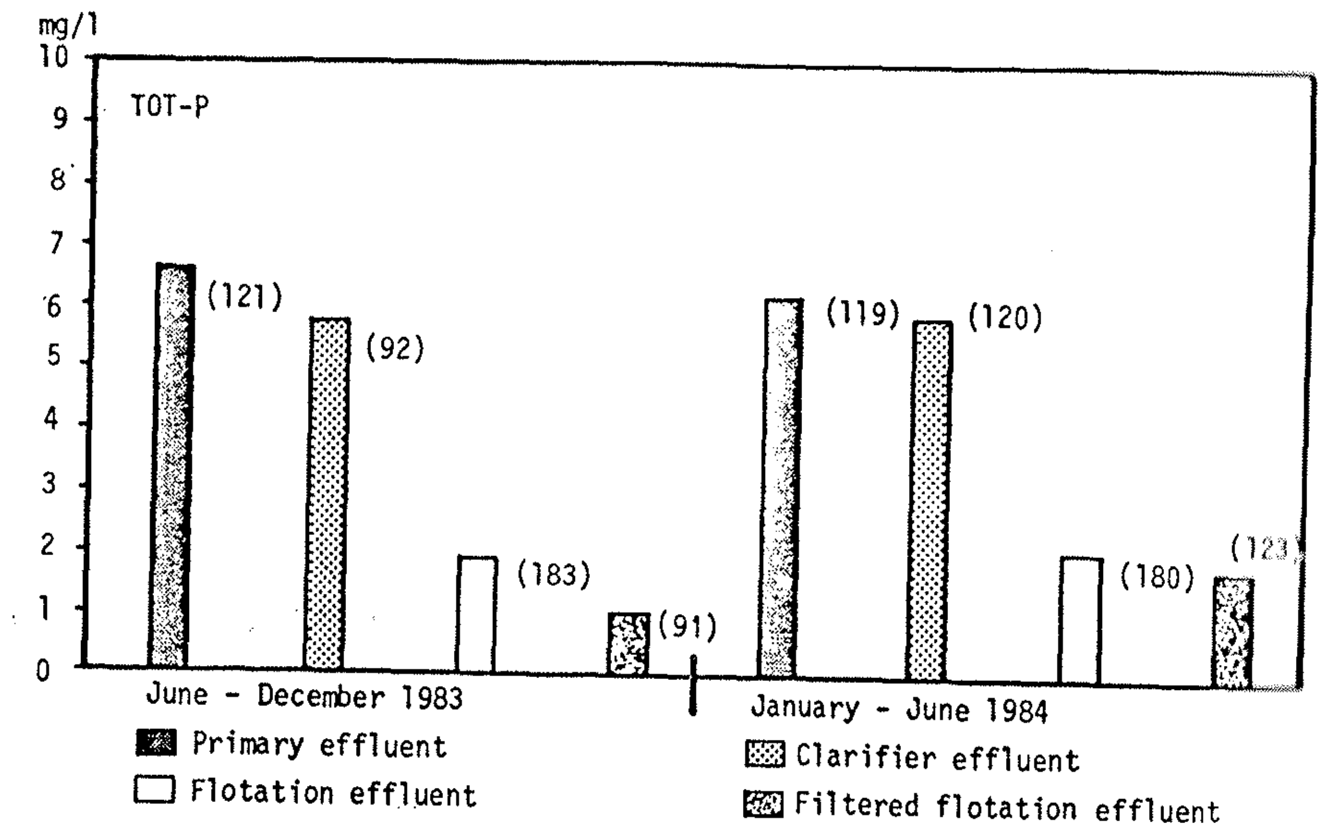


Fig.10. Total phosphorus in secondary and flotation effluent

Conclusion from Falkenberg:

The one-sludge nitrification-denitrification system can be used in colder climates. Nitrification can be achieved, also at lower temperatures, provided that the sludge age is sufficiently high, and consequently the F/M-ratio can be kept low. Nitrogen removal will also occur, provided that a carbon source is available and that anoxic conditions are maintained.

If a 'green-field' plant is designed properly for nitrification, the introduction of denitrification in a one-sludge system will not increase the investment costs, but will decrease the operation costs.

If nitrification is required, denitrification pays off!

6 FACTORS LIMITING NITROGEN REMOVAL

The conditions for nitrification-denitrification, as discussed above, also indicate the limitations of the process.

Depending on the temperature, a sufficient amount of active microorganisms (sludge) must be kept in the system, during the right physical conditions, having access to substrates and nutrients. If not the process cannot work properly.

Critical 'key-words' are :

sufficient amount of active microorganisms
sufficient sludge age, depending on the temperature
sludge to be kept in the system
right physical conditions
access to easy degradable substrates
efficient separation

7 INCORPORATING DENITRIFICATION IN EXISTING PLANTS

In almost all existing Swedish plants, the biological treatment stage is not designed for nitrification. Because of the actual load situation, however, which might be 50-75 % of the design load, nitrification frequently will occur during the summer. In order to achieve nitrification all over the year, the F/M-ratio must be decreased, which means either increasing the total active sludge mass in the plant, or lowering the BOD-load on the biological stage, or possibly a combination of both.

The evident solution is increasing the size of the plant, which however in most cases might be neither economically nor politically possible. The following discussion is consequently stressing possible extensions by internal means.

By simply increasing the sludge concentration in an activated sludge system, nitrification might be achieved, provided that the sludge can be kept in the system. This requires a very efficient separation system because of the possible carry-over, as the Falkenberg study stressed. In such a case the introduction of an anoxic zone and recircula-ting the nitrified water will give a solution at a very low investment costs. The oxygenation capacity must probably be increased in order to maintain more than 2 mg O2/l.

Another way of increasing the sludge mass in the system is the introduction of submersed trickling filter media in the aeration tanks. Recent studies have shown promising results. Apart from the added attached growth on

the media, the longer detention time for the air bubbles will give better utilization of the oxygen in the air, increasing oxygen transfer with some 30 %.

A third approach to achieve nitrification is to decrease the load on the biological stage, which might be achieved by more efficient pretreatment. The introduction of pre-precipitation or a polishing high rate trickling filter might give an economic solution, which is exemplified below. The risk, however, in such a system, is that the easy accessible carbon might be removed, causing problem in the denitrification process. This problem might be solved by adding some carbon source to the anoxic zone.

8 FACTORS INFLUENCING THE COSTS

There are several factors that influence the costs for the nitrification-denitrification. Some of the most important are listed below:

Effluent requirement

It is evident that more stringent effluent values also will lead to higher investment and operational costs. The demands should be adapted to the characteristics of the receiving waters, taking into consideration the temperature impact on the process.

If phosphorus removal also is required, a most complex situation will occur, evaluating the possible biological and chemical process systems, and integrating and optimizing them.

Waste water characteristics

The character and variation of the waste water has a great influence on the costs. Temperature, alkalinity, BOD/TKN-ratio and easy accessible carbon source are some important parameters. Large variations in characteristics and flow will also affect the costs.

Influence from industry

Waste waters from industries may have a positive or negative effect on efficient nitrogen removal, depending on their characteristics.

All waste waters, containing BOD, but little or no nutrients, e.g. from food industry, will give a positive effect on nitrogen removal, partly because the BOD will 'consume' nutrients for the cell metabolism, partly because the easy accessible carbon will accelerate the denitrification. This fact partly explains the good results from the Falkenberg plant.

Waste waters, on the other hand, containing much nutrients but little BOD, will have a negative influence. Waste waters with inhibiting or toxic substances are always a nuisance, and their impact might be more crucial to the more sensitive nitrifying bacteria than to a normal activated sludge system.

The normal models for charging industry for its waste water discharge into the sewage system are based on flow and BOD or COD, letting the industry pay more the more BOD they let out.

If nitrification-denitrification is the issue, more weight should be put on nutrient discharge. Potentially toxic waters should only be accepted, provided that the actual industry operates a satisfactorily efficient pre-treatment process.

Existing plant design

The design and process solution at an actual plant will of course influence the costs.

Existing primary clarifiers will make it possible to use pre-precipitation, and also simplify the introduction of a polishing trickling filter, if necessary.

A large aeration volume, combined with efficient separation will make possible simple changes in the operational mode.

In case of possible extension, e.g. available land and costs thereof, as well as soil conditions, will affect the choice of process and consequently costs.

9 COSTS

The correct cost evaluation of any process choice is imperative for taking the right decision. The different cost affecting factors, however, are unique for each case, depending on the local condition and actual premises for the project. There are many ways of designing a treatment plant, however leading to different overall costs. Nitrification and denitrification will not only affect the costs for directly meeting the effluent demands, but will influence sludge production and possible coagulant consumption as well.

All general cost studies must consequently be used with utmost care, and more as an indication of possibilities. First after being correctly applied to the actual case, a real cost evaluation can take place.

For an actual case in Canada, the following relative cost evaluation for a plant of the same size as Falkenberg has been presented. Average flow 15.500 m3/d, effluent requirement: $NH_4 < 1$ mg/l, $NO_3 < 5$ mg/l.

Process	**Investment**	**Operation**
After denitrification, 2-sludge system	1.07	1.10
After denitrification, 1-sludge system	1.00	1.03
Pre-nitrification, 1-sludge system	**1.01**	**1.00**
Ammonia removal (lime treatment)	1.32	1.35
Ion exchange	1.68	1.58
Irrigation	2.04	1.56

It is evident that the one-sludge systems are most favorable, and further analysis of the one-sludge pre-denitrification, based on the Falkenberg case, is presented in the Appendix and below.

Operation costs

This discussion is based on the Falkenberg case, and possible operational modes of that particular plant:

average BOD-load: 4.000 kg/d
primary treated: 2.500 (1.500) kg/d

average flow: 15.000 m3/d,

average N-load: 300 kg/d
primary treated: 250 (150) kg/d

N to be reduced: 60 % of the N to be nitrified.

(figures within brackets include pre-precipitation)

The cost effect of different operational modes is shown in enclosed Appendix, Tables. As a summary, the most cost-effective solution for phosphorus and nitrogen removal in the Falkenberg plant is the use of two-stage biological treatment and post-precipitation, Table 1, column 2

Investment costs

As been stated before, the investment costs are unique for each plant in each country. Consequently there is of little use to try to generalize the investment costs. On the other hand, the information in the enlosed Tables on possible different operational modes of the Falkenberg plant, and the resulting volumes for trickling filters and aeration, will give an indication of investment costs. As a rule of thumb, the specific investment costs (e.g. SEK/m3) for the activated sludge (aeration) volume are approximately half of that of the trickling filters.

10 FUTURE POSSIBILITIES

There are some different process development and operational modes to be further studied, which are looking very promising.

One is the submerged trickling filter, **Fig.11**, which has given interesting results, and further studies are planned, based on further development of this concept.

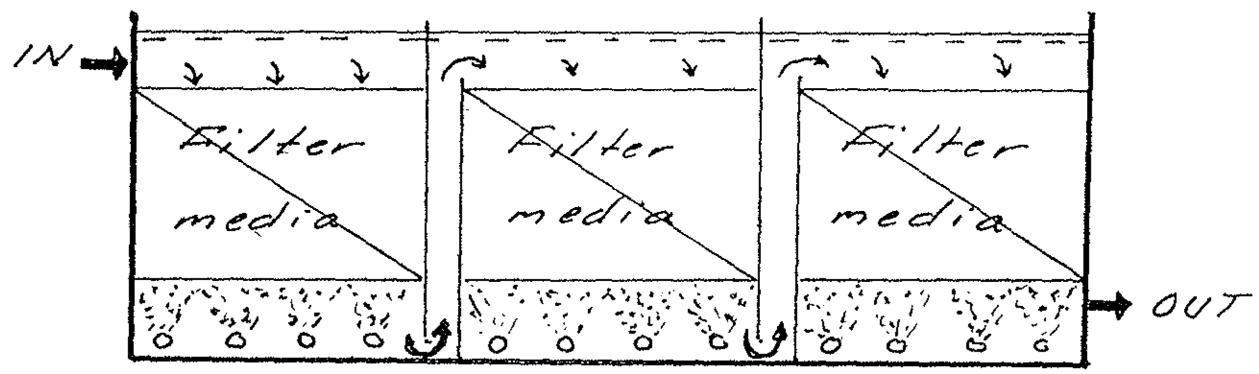


Fig.11. Submerged trickling filter

High BOD and COD removal has been reported by ödegård, when using very high loads, more than 10 kg BOD/m3.d (10 g BOD/m2.h for BOD-removal, and 5 g BOD/m2.h for nitrification). The positive results can be explained by the increased biomass in the system, caused by the attached growth. If values from the sludge growth on aerobic trickling filter media is used, which has been meassured to be approximately 50 g/m2, the growth may correspond to an increase in sludge concentration of 5-10 g/l. As a consequence, a sludge content in the biological process stage of up to 10-15 g/l can be calculated on the overall volume. The F/M-ratio will then be correspondingly lower, which makes the system particularily interesting for extending existing facilities.

Recent studies by Bengt Andersson on moderately loaded trickling filters, using high rate plastic media, and carried out in the Malmö city sewage treatment plant at Sjölunda, show very good nitrification. The results, **Fig.12**, show full nitrification during summertime and 50 % nitrification during the winter. The BOD-removal (of soluble BOD) is accomplished already after 1 m, corresponding to only 2 minutes detention time. Full nitrification has been reached after 3 m, or approximately. 6 minutes detention time.

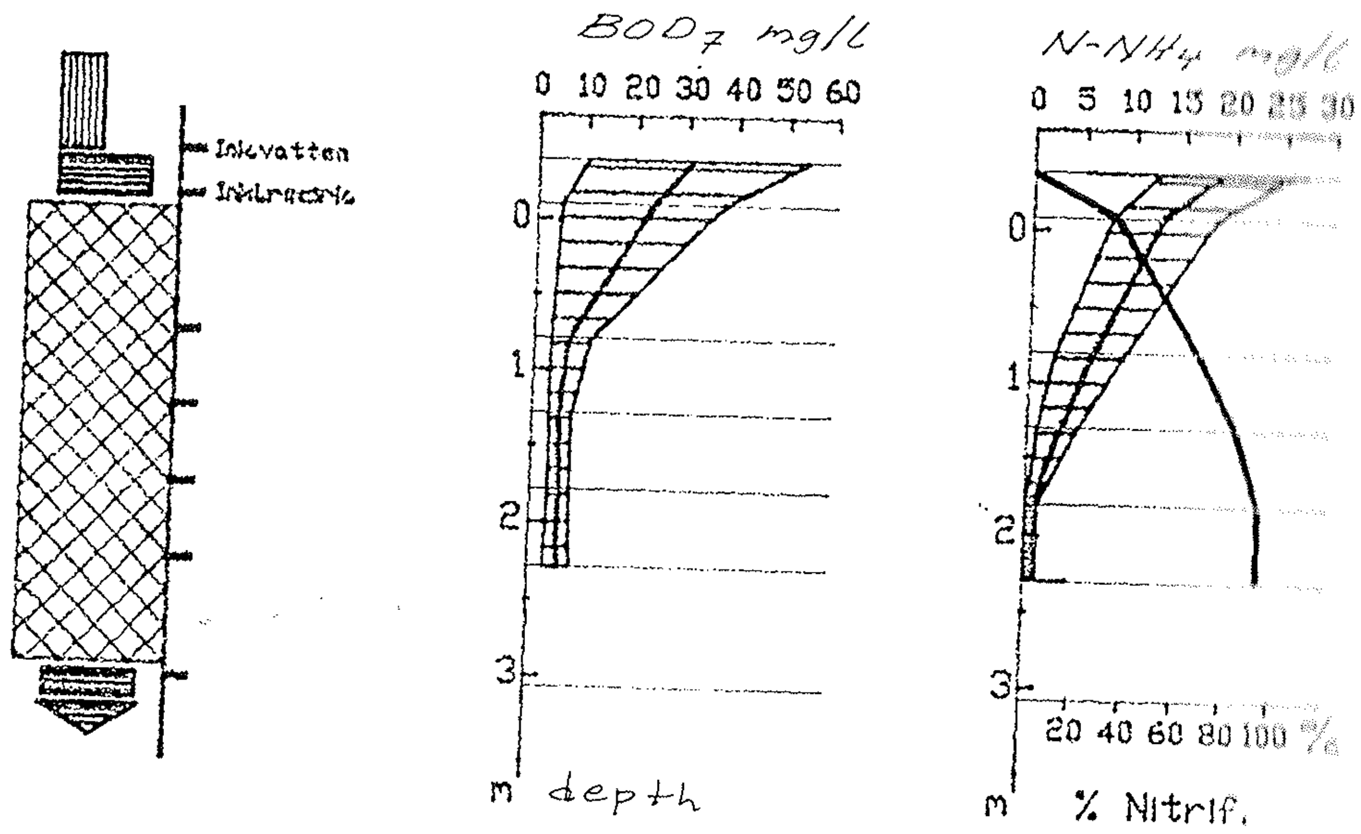


Fig.12. BOD and Nitrification profile in trickling filters

The study will be continued through the winter and might lead to very interesting process solutions, where investment and operational costs might be far lower than in existing denitrification systems.

11 SUMMARY

During the last years, the nitrogen load on some receiving waters has grown to an alarmingly high level. Even if most of the nitrogen can be referred to as diffuse sources from agriculture, nitrogen removal in treatment plants in sensitive areas will be necessary.

The development and practical experience of the biological removal of nitrogen has led to good results in warmer climates, using integrated processes.

Full scale operation for nitrification and denitrification has been excuted in some existing plants in Sweden with promising results, in spite of low temperatures in the winters. The aim of the chosen process mode has been to utilize existing facilities, without too costly investment.

The results show that satisfactory nitrogen removal might be possible to reach, provided that certain criteria can be met. Further studies of e.g. the importance of an easy degradable carbon source as well as development of e.g. the fixed bed processes and the practical configuration of the process are imperative for good and economical application of the process.

12 ACKNOWLEDGEMENT

The Authors would like to express their deep gratitude to the operating crew at the Falkenberg treatment plant for an excellent performance not only in their general work, but also for the engagement and enthusiasm in all the extra work, which was needed to get the overall grip of the nitrification and denitrification process. Without their efforts, the proposed goals might not have been achieved.

The first full-scale tests in Falkenberg were carried out with the economic assistance of the Swedish Enviromental Control Board (SNV).

Furthermore, the Authors would like to thank Bengt Andersson at the Sjölunda treatment plant in Malmö for the preliminary results on the nitrification in trickling filters.

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14 APPENDIX, Cost analysis

14.1 Introduction

The calculations are based on the Falkenberg case, and possible operational modes of that particular plant:

average BOD-load: 4.000 kg/d
primary treated: 2.500 (1.500) kg/d

average flow: 15.000 m3/d,

average N-load: 300 kg/d
primary treated: 250 (150) kg/d

N to be reduced: 60 % of the N to be nitrified.

(figures within brackets include pre-precipitation)

The oxygen consumption is based on

0.5*BODrem + 0.1*sludge mass + 4.57 Noxidized - 2.86*Nreduced

Sludge mass = 5 g/l * 3.660 = 18.300 kg
N-load 10 % of the BOD-load
N-reduced 6 % of the BOD-load

Operational modes, x marks function in operation

	Table 1						Table 2						Table3					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Pre-precipitation	–	–	–	–	–	–	x	x	x	x	x	x				x	x	x
Denitrification	x	x	x	–	–	–	x	x	x	–	–	–	x	x	x	x	x	x
N-reduction		60 %						60 %						80 %			80 %	
Trickling filter 1	–	x	x	–	x	x	–	x	x	–	x	x	–	x	x	–	x	x
Trickling filter 2	–	–	x	–	–	x	–	–	x	–	–	x	–	–	x	–	–	x
Aeration tank 1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Aeration tank 2	x	x	x	x	–	–	x	x	–	–	–	–	x	x	x	x	x	–
Aeration tank 3	x	x	–	–	–	–	x	–	–	–	–	–	x	x	x	x	–	–
Aeration tank 4	x	–	–	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–
Post-precipitation	x	x	x	x	x	x	–	–	–	–	–	–	x	x	x	–	–	–

Postprecipitation with denitrification is using 100 mg AVR/l compared to 125 mg/l with normal activated sludge operation. Pre-precipitation will use a somewhat higher dosage, 150 mg/l.

The operation for nitrification is based on a sludge load (F/M-ratio) of 0.10 kg BOD/kg VSS*d. The normal activated sludge operation is based on 0.4-0.5 kg BOD/kg VSS*d. The corresponding aeration volume is chosen between possible alternatives, resulting in that the necessary sludge content in aeration tanks varies between 2.5 to 7 g/l.

In order to get some evaluation of possible operational costs, different aeration volumes are used in the different examples, combined with no, one (1300 m3) and two (2600 m3) trickling filters in operation.

Table 1 is presenting Post-precipitation with and without nitrogen removal.

14.2 Table 1, primary treatment, 60 % N-reduction

Operation mode	1	2	3	4	5	6
Flow, m3/d	15000	15000	15000	15000	15000	15000
BODin	4000	4000	4000	4000	4000	4000
BODprimary effluent	**2500**	**2500**	**2500**	**2500**	**2500**	**2500**
BODpre-precipitation						
Est. dosage, mg/l	**100**	**100**	**100**	**125**	**125**	**125**
Trickl.filters nos	**0**	**1**	**2**	**0**	**1**	**2**
Trickling filter load		1.92	.96		1.92	.96
Trickl.filter energy	0	720	1440	0	720	1440
BOD-removal	**0**	**60**	**75**	**0**	**60**	**75**
BOD to aeration	2500	1000	625	2500	1000	625
Aeration tanks nos	**4**	**3**	**2**	**2**	**1**	**1**
Volume	**3660**	**2745**	**1830**	**1830**	**915**	**915**
Sludge content	7	3.50	3.30	3	2.50	1.50
F/M-ratio	**.10**	**.10**	**.10**	**.46**	**.44**	**.46**
N to be oxidized, kg/d	250	250	250	0	0	0
N-rem, % of N-load	60	60	60	0	0	0
Oxygen need	4526	2174	1630	1799	729	450
Oxygen content, mg/l	2	2	2	2	2	2
Oxygen saturation	12	12	12	12	12	12
Alfa factor	.80	.80	.80	.80	.80	.80
Aerator, g O2/m3.m	12	12	12	12	12	12
Aerator depth, m	4	4	4	4	4	4
Energy, kwh/d	2357	1132	849	937	380	234
Recirculation, m3/d	22500	22500	22500	0	0	0
Pumping energy, kWh/d	163	163	163	0	0	0
TOTAL ENERGY, kwh/d	**2521**	**2016**	**2452**	**937**	**1100**	**1674**
Energy cost Kr/kWh	.25	.25	.25	.25	.25	.25
Energy cost Kr/d	**630**	**504**	**613**	**234**	**275**	**419**
Chemical need, kg/d	1500	1500	1500	1875	1875	1875
Chemical cost, Kr/t	800	800	800	800	800	800
Chemical cost, Kr/d	**1200**	**1200**	**1200**	**1500**	**1500**	**1500**
TOTAL COST, Kr/d	**1830**	**1704**	**1813**	**1734**	**1775**	**1919**
Investment cost basis						
Trickling filter, m3	0	1300	2600	0	1300	2600
Volume	3660	2745	1830	1830	915	915

14.3

Table 2 is presenting Pre-precipitation with and without nitrogen removal.

14.4 **Table 2, pre-precipitation, 60 % N-reduction**

Operation mode	1	2	3	4	5	6
Flow, m3/d	15000	15000	15000	15000	15000	15000
BODin	4000	4000	4000	4000	4000	4000
BODprimary effluent	2500	2500	2500	2500	2500	2500
BODpre-precipitation	**1500**	**1500**	**1500**	**1500**	**1500**	**1500**
Est. dosage, mg/l	**150**	**150**	**150**	**150**	**150**	**150**
Trickl.filters nos	0	1	2	0	1	2
Trickling filter load		1.15	.58		1.15	.58
Trickl.filter energy	0	720	1440	0	720	1440
BOD-removal	0	50	**60**	0	**50**	**60**
BOD to aeration	1500	750	600	1500	750	600
Aeration tanks nos	**3**	**2**	**1**	**1**	**1**	**1**
Volume	**2745**	**1830**	**915**	**915**	**915**	**915**
Sludge content	5.50	4	6.60	4.00	2.00	1.60
F/M-ratio	**.10**	**.10**	**.10**	**.41**	**.41**	**.41**
N to be oxidized, kg/d	150	150	150	0	0	0
N-rem, % of N-load	60	60	60	0	0	0
Oxygen need	2688	1535	1332	1116	558	446
Oxygen content, mg/l	2	2	2	2	2	2
Oxygen saturation	12	12	12	12	12	12
Alfa factor	.80	.80	.80	.80	.80	.80
Aerator, g O2/m3.m	12	12	12	12	12	12
Aerator depth, m	4	4	4	4	4	4
Energy, kwh/d	1400	800	694	581	291	233
Recirculation, m3/d	22500	22500	22500	0	0	0
Pumping energy, kWh/d	163	163	163	0	0	0
TOTAL ENERGY, kwh/d	**1563**	**1683**	**2297**	**581**	**1011**	**1673**
Energy cost Kr/kWh	.25	.25	.25	.25	.25	.25
Energy cost Kr/d	**391**	**421**	**574**	**145**	**253**	**418**
Chemical need, kg/d	2250	2250	2250	2250	2250	2250
Chemical cost, Kr/t	800	800	800	800	800	800
Chemical cost, Kr/d	**1800**	**1800**	**1800**	**1800**	**1800**	**1800**
TOTAL COST, Kr/d	2191	2221	2374	1945	2053	2218
Investment cost basis						
Trickling filter, m3	0	1300	2600	0	1300	2600
Volume	2745	1830	915	915	915	915

14.5

Table 3 is presenting operational modes to achieve 80 % nitrogen removal with post- and preprecipitation respectively.

14.6 **Table 3, 80 % N-reduction**

Operation mode	1	2	3	4	5	6
Flow, m3/d	15000	15000	15000	15000	15000	15000
BODin	4000	4000	4000	4000	4000	4000
BODprimary effluent	**2500**	**2500**	**2500**	2500	2500	2500
BODpre-precipitation				1500	1500	1500
Est. dosage, mg/l	**100**	**100**	**100**	**150**	**150**	**150**
Trickl.filters nos	0	1	2	0	1	2
Trickling filter load		1.92	.96		1.15	.58
Trickl.filter energy	0	720	1440	0	720	1440
BOD-removal	**0**	**60**	**75**	**0**	**50**	**60**
BOD to aeration	2500	1000	625	1500	750	600
Aeration tanks nos	**4**	**3**	**2**	**3**	**2**	**2**
Volume	**3660**	**2745**	**1830**	**2745**	**1830**	**1830**
Sludge content	7	3.50	3.30	5.30	4.00	3.20
F/M-ratio	**.10**	**.10**	**.10**	**.10**	**.10**	**.10**
N to be oxidized, kg/d	250	250	250	150	150	150
N-rem, % of N-load	80	80	80	80	80	80
Oxygen need	4383	2031	1487	2547	1449	1228
Oxygen content, mg/l	2	2	2	2	2	2
Oxygen saturation	12	12	12	12	12	12
Alfa factor	.80	.80	.80	.80	.80	.80
Aerator, g O2/m3.m	12	12	12	12	12	12
Aerator depth, m	4	4	4	4	4	4
Energy, kwh/d	2283	1058	774	1327	755	640
Recirculation, m3/d	60000	60000	60000	60000	60000	60000
Pumping energy, kWh/d	436	436	436	436	436	436
TOTAL ENERGY, kwh/d	**2719**	**2214**	**2650**	**1763**	**1911**	**2515**
Energy cost Kr/kWh	.25	.25	.25	.25	.25	.25
Energy cost Kr/d	**680**	**553**	**663**	**441**	**478**	**629**
Chemical need, kg/d	1500	1500	1500	2250	2250	2250
Chemical cost, Kr/t	800	800	800	800	800	800
Chemical cost, Kr/d	**1200**	**1200**	**1200**	**1800**	**1800**	**1800**
TOTAL COST, Kr/d	1880	1753	1863	2241	2278	2429
Investment cost basis						
Trickling filter, m3	0	1300	2600	0	1300	2600
Volume	3660	2745	1830	2745	1830	1830

POSSIBILITIES OF IMPLEMENTING NITROGEN REMOVAL AT SWEDISH WASTEWATER TREATMENT PLANTS

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INTRODUCTION

Problems related to eutrophication and oxygen consumption have been considered as the major factors in deterioration of the water quality in Swedish lakes, rivers and coastal areas. Technical solutions to reduce oxygen-consuming materials and eutrophication have up to now been directed towards the removal of biochemical oxygen demand (BOD) and phosphorus. Thus, biological and chemical treatment of municipal wastewater is usually prescribed, and at present about 90% of the municipal wastewater from Swedish urban areas is treated both biologically and chemically. Most plants are designed for post-precipitation, although the treatment plants may now be operated in a modified way, for example, with the use of pre-precipitation, two-point precipitation or recirculation of chemical sludges. Hultman and Moore (1982) have presented an overview of Swedish practice in municipal wastewater treatment.

Although Swedish treatment of municipal wastewater concentrates on the removal of biochemical oxygen demand and phosphorus, the environmental and operational effects of nitrogen have been discussed for many years. These include:

Environmental effects:

- o Oxygen consumption due to nitrification (oxidation of ammonium to nitrate)
- o Eutrophication due to nitrogen compounds
- o Role of nitrate in preventing phosphorus leakage from sediments
- o Acidification due to nitrification
- o Toxic properties of ammonia, nitrite, nitrate and nitrosoamines
- o Solubilization of metals by NTA (nitriloacetic acid; NTA is a potential substitute for phosphates in detergents and was used to some extent in Sweden in the middle of the 1970's).

Operational effects:

- o Increased demand for oxygen and energy due to nitrification
- o Decreased sludge production and increased sludge stabilization due to high sludge ages in nitrification
- o Decreased production of digester gas due to the use of high sludge ages in nitrification
- o Decreased sludge production during anoxic conditions compared with aerobic conditions
- o Savings of oxygen and energy in denitrification compared with nitrification only
- o Savings of precipitation chemicals in post-precipitation due to alkalinity decrease in nitrification
- o Increased corrosion due to alkalinity decrease in nitrification
- o Decreased corrosion due to alkalinity increase in denitrification
- o Increased concentration of soluble phosphorus in pre-precipitation or simultaneous precipitation due to sludge mineralisation in nitrification
- o Decreased chlorine or hypochlorite demand in wastewater disinfection due to ammonium oxidation in nitrification
- o Floating sludge due to denitrification
- o Formation of foam at high sludge ages
- o Increased need for process control in nitrification and denitrification, as compared with removal of organic material only.

The environmental effects of nitrogen compounds are more complex to evaluate than those of phosphorus, where the eutrophication effects are the main concern. It can also be seen that the effects of nitrification and denitrification are important for operation of plants. These effects may significantly increase the operational costs and may cause considerable operational problems. However, some of the effects of these reactions are beneficial to plant operation.

At a few Swedish municipal wastewater treatment plants, nitrification is prescribed in order to avoid oxygen deficiency in the recipient. In one municipal wastewater treatment plant, Falkenberg, on the west coast of Sweden, an average nitrogen removal of 60 per cent is prescribed. A few plants have been required to evaluate the possibilities of removing nitrogen.

NITROGEN REMOVAL SYSTEMS

Several methods are available for nitrogen removal and are discribed by Grönquist and Hultman (1977), Haglund and Norrman (1984), Martin (1979) and WPCF (1983). The methods include:

- o Assimilation of nitrogen by micro-organisms (bacteria, algae etc.) and plants
- o Biological reduction (denitrification)
- o Chemical reduction (for example use of ferrous ions in acid solutions)
- o Ammonia stripping (air or steam)
- o Selective ion exchange
- o Oxidation of ammonium to nitrogen gas (use of chlorine or electrolytical oxidation)
- o Precipitation of magnesium ammonium phosphate
- o Extraction
- o Electrodialysis and reverse osmosis

Several of these methods were studied at a fairly early date on a small scale in Sweden, both theoretically and experimentally (Westberg and Gustafsson, 1963, Lundberg, 1971, Hultman, 1973a, Neretnieks et al., 1973, and Ericsson, 1975).

Although several of these methods may have a potential for use in nitrogen removal at municipal wastewater treatment plants in Sweden, the main focus of interest at present is biological nitrogen removal by use of nitrification and denitrification. Several systems for biological nitrogen removal have been discussed in the literature (Barnes and Bliss, 1982, Christensen and Harremoës, 1977, EPA, 1975, Martin, 1979, Särner, 1983, and WPCF, 1983).

Biological nitrogen removal systems may be classified according to such factors as energy source for denitrification, operational modes, number of separate sludge systems, and type of reactor. An example of classification of biological removal systems is presented in Figure 1.

ENERGY SOURCE FOR DENITRIFICATION

x Internal (sewage and endogeneous respiration)
External: organic (methanol, industrial wastes)
inorganic (hydrogen gas, sulphur compounds)

PROCESS SYSTEM

SINGLE SLUDGE (COMBINED)
x Pre-denitrification
Simultaneous denitrification
x Post-denitrification
SEPARATE SLUDGE

OPERATIONAL MODE
x Continuous
Intermittent

REACTOR
x Suspended growth (activated sludge process)
Fixed film (trickling filters, rotating discs, fluidized beds)

Figure 1. Example of classification of biological nitrogen removal systems, where x indicates process factors or systems that have primarily been considered in Sweden.

EARLY OBSERVATIONS AND STUDIES OF BIOLOGICAL NITROGEN REMOVAL

Possible effects of nitrogen in eutrophication and methods to remove nitrogen from municipal wastewater have been known for a long time. This is illustrated by the following summation in Chemical Abstracts (1910): "The author's experiments have shown that the growth of green seaweeds of the Ulva and Enteromorpha species in tidal species is mainly due to the presence of ammonium salts and, to a less extent, of nitrates derived from sewage. The following method of sewage treatment has therefore been recommended to the Belfast Corporation: - (1) Removal of solid matter by means of screens, catch pits, and continuous flow sedimentation. (2). Treatment of a portion of the sedimentated sewage by percolating filters followed by a short period of sedimentation. (3). A process of denitrification consisting in submitting a mixture of the highly nitrated effluent from the percolating filter with the septic tank effluent, to treatment on a contact bed, so as to effect a destruction of nitrates in the one and purification in the other. Experiments on a large scale have given good results, and it is estimated that the method will effect a reduction of over 80 per cent in the factors that promote the growth of these seaweeds in Belfast Lough." (Letts, 1910).

In this early study separate steps were used for nitrification and denitrification. However, it was shown that a high degree of nitrogen removal could be attained in activated sludge processes with a high sludge age. This is illustrated from early studies of the activated sludge process in Illinois, USA (Table 1).

Table 1. Results of experiments on nitrogen balance in the activated sludge process (Metcalf and Eddy, 1935)

Test	Nitrogen, g N/m^3 Influent	Effluent	Sludge	Per cent loss (-) or gain (+)	Per cent of sewage nitrogen in sludge
Chicago, Ill.					
Aug. 1 to Oct. 22, 1916	56.2	21.9	10.8	-41	19
Oct. 23, 1916 to Mar. 26, 1917	71.0	38.8	15.6	-23	22
Mar. 27 to Nov, 1917	45.6	19.3	10.2	-35	22
Champaign, Ill.					
May 3 to Dec. 28, 1921	39.4	29.6	10.6	+2	27

A possible explanation for the nitrogen loss in the Chicago plant is that nitrification was obtained and that there were anoxic particles (particles with no oxygen but with nitrate) inside activated sludge flocs or in the aeration basin during high loads of organic materials. Anoxic conditions in flocs have been suggested as a mechanism for nitrogen removal (Rüffer, 1966).

Rittmann and Langeland (1985) have shown that simultaneous nitrification and denitrification may occur in oxidation ditches. The process may be controlled by the oxygen transfer rate, which should be sufficient to transfer enough oxygen to satisfy nitrification and aerobic COD oxidation and maintain a suitable dissolved oxygen concentration to obtain anoxic conditions inside flocs. Average concentrations of between 0.1 and 0.5 mg O_2/l were successful in this respect at two field sites studied.

Early observations have shown that nitrogen loss may also be obtained at low-loaded trickling filters as a result of nitrification and denitrification (Lemoigne, 1910). The reason for this may be the presence of anoxic parts in the biofilm, especially in the beginning of the bed where nitrate rich wastewater is recirculated and meets the influent wastewater containing high concentrations of

organic materials. The loss of nitrogen to the atmosphere varies between 15 and 60 per cent at a BOD-load of about 100-300 g BOD_5/m^3/day (Pallasch, 1969). Kissel et al. (1984) have shown by use of models that it is possible to have nitrification in the outer portions and denitrification in the deeper portions of biofilms.

SWEDISH STUDIES ON NITRIFICATION AND BIOLOGICAL NITROGEN REMOVAL

At the beginning of the 1970's, the Swedish National Environment Protection Board performed about one hundred studies on the operation of full-scale plants. The time period for the studies was 1-4 days (normally 2 days). On the basis of data from 50 municipal wastewater treatment plants examined during the period 1971 - July 1973, Ulmgren (1975) gives the following values for the influent wastewater (Table 2).

Table 2. Quality of influent wastewater at 50 Swedish municipal wastewater treatment plants (Ulmgren, 1975)

Parameter	Average value, g/m^3	Median value, g/m^3	Standard deviation, g/m^3	Number of analyses performed
BOD_7	123	116	±60	122
COD	266	259	±115	78
SS	122	103	±66	122
Ptot	5.7	5.5	±2.5	124
Ntot	26	24	±9	89

In 1971, the Swedish National Environment Protection Board prepared "Guidelines for design of sewage treatment plants" to guide those preparing or considering proposals for treatment plants. Some of the design data that was standardized is shown in Table 3 (Ulmgren, 1975).

Table 3. Design for activated sludge plants with primary sedimentation followed by a post-precipitation step (Ulmgren, 1975)

	Loading kg BOD_7/kg SS/d	kg BOD_7/m^3/d	Detention time in aeration tank (h)
High-loaded	1.0-1.5	3.0-4.5	0.8-1.2
Normally loaded	0.4-0.8	1.2-1.8	1.5-2.0
Low-loaded	0.2-0.3	0.6-0.9	1.5-4.0

A summary report of the studies performed by the Swedish National Environment Protection Board was made by Eklund (1974). The results concerning residence time and sludge load for the aeration basin of the activated sludge process are presented in Table 4.

Table 4. Residence time and sludge load for the aeration basin of the activated sludge process (Eklund, 1974)

	Residence time, h	Sludge load kg BOD_7/kg SS/d
Highest value	20	0.70
Lowest value	1.5	0.01
Average value	5.6	0.19
Median value	4.5	0.14
Number of values	76	64

It can be seen from Table 4 that the spread of values for the detention time and the sludge load is very large. The median values for the residence time and the sludge load are about the values necessary for nitrification, at least during the summer. This means that a significant number of Swedish municipal wastewater treatment plants have the possibility of increasing the efficiency of nitrogen removal with only reasonable modifications in plant design and operation. For a significant number of treatment plants, however, requirements for improved nitrogen removal would mean large new investments. Larger plants are normally less over-dimensioned than smaller plants.

The reasons for the over-dimensioning of aeration basins include over-estimation in population and water consumption forecasts. At the beginning of the 1970's, the prognosis for per capita water consumption in 2000 was much higher than the prognosis current in the mid-1970's, which latter prognosis seems to be quite accurate. At the time of the investigations of the Swedish National Environment Protection Board, pre-precipitation was only used at a few plants. Today pre-precipitation has become a fairly common process, in which nitrification is facilitated as a result of increased removal of organic material in the pre-sedimentation basin.

Pilot-plant studies on biological nitrogen removal have been reported for Käppala (Ericsson, 1975) and Rya (Balmér, 1985) treatment plants in Lidingö and Gothenburg, respectively.

Some full-scale studies on nitrification and biological nitrogen removal have been performed in Sweden in a controlled way. Results from such studies are shown in Tables 5 and 6.

Table 5. Operational conditions in controlled studies of nitrification and biological nitrogen removal at Swedish municipal wastewater treatment plants.

Treatment plant	Design flow m^3/h	Actual flow as percentage of design flow	Total retention time in plant based on actual flow, h	Retention time in aeration basin based on actual flow, h
Örebro	90 000	56	-	6.8
Eskilstuna	74 000	72	14	4.4
Bromma	160 000	95	9.5	3.5
Himmerfjärden	207 000	55	17.7	2.7/5.3[a]
Falkenberg	30 000	50	17.2	4.3

a Residence time in aeration basin 2.7 h in pre-denitrification and 5.3 h in post-denitrification experiments

Table 6. Operational results in controlled studies of nitrification and biological nitrogen removal at Swedish municipal wastewater treatment plants

Treatment plant	Time period of study	Anoxic zone	BOD_7/N_{tot} g/g	Sludge age, days	Nitrification efficiency, %	Nitrogen removal in biological step, %
Örebro	June-Dec. 1983	No	-	8	96	-
Eskilstuna	1980-1983	Yes	2.5	11	0-98	a)
Bromma	May-Oct. 1984	No	3.5	4	88	44, b)
Himmerfjärden	March-Dec. 1985	Yes	2.1	20	90	23, c)
	June-Oct. 1985	Yes	2.1	50	98	30, d)
Falkenberg	July 1983-Aug. 1984	Yes	4.8	6-7	84	47, e)

a) insignificant denitrification
b) denitrification degree estimated to 15-25 per cent of total influent nitrogen
c) pre-denitrification
d) post-denitrification; average denitrification degree 54 per cent with methanol
e) maximum nitrogen removal more than 90 per cent

In the study at Örebro it was found that a significant saving of aluminium sulphate (Boliden AVR) could be achieved in post-precipitation due to the decrease of alkalinity in nitrification (Ericsson et al, 1976). Similar experience has been obtained in the case of aluminium sulphate at Himmerfjärden and Huskvarna wastewater treatment plants (Hultman and Moore, 1982) and with lime precipitation (Grönquist et al., 1978).

Results from Eskilstuna wastewater treatment plant are shown in Figure 2. It can be seen that the increase of nitrate is followed by a decrease in the alkalinity over the biological step. The nitrification is high in the summer and low during the winter due to temperature effects. Similar results have been reported by Elfving et al. (1975) for Borlänge and Motala.

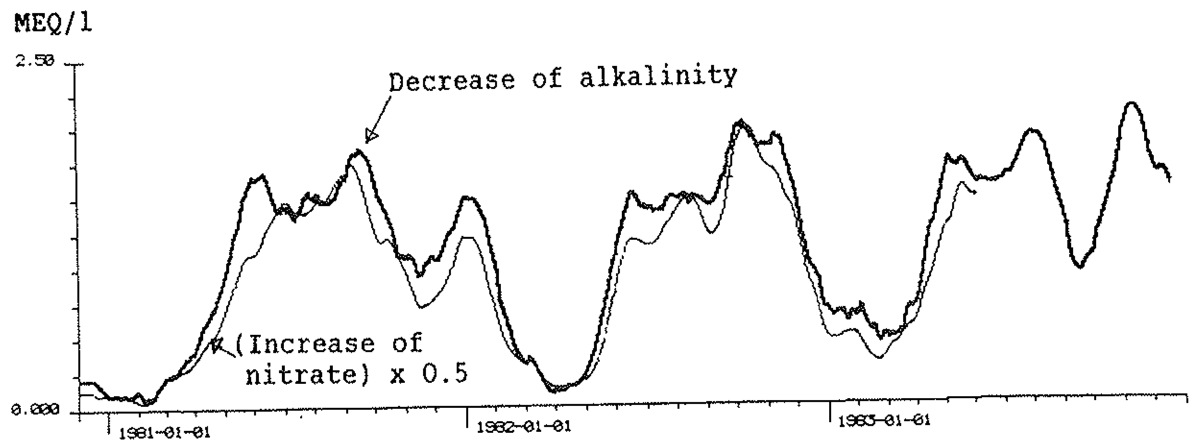

Figure 2. Curves showing the decrease in alkalinity and the increase in nitrite and nitrate, respectively, over the activated sludge stage at Eskilstuna wastewater treatment plant (Lilja, 1985).

The studies at Bromma wastewater treatment plant were performed owing to a temporary effluent standard of ammonium nitrogen of maximum 4 mg N/l on average during the period June-October (Hultgren, 1986). Results from studies at Himmerfjärden treatment plan have been reported by Bosander et al. (1986) and Hellström et al. (1986). The studies at Falkenberg wastewater treatment plant have been described by Lind et al. (1985).

Preliminary results at Halmstad municipal wastewater treatment plant indicate that a nitrogen reduction of 80% may be obtained at certain conditions (Ericsson, 1986).

Many Swedish plants seem to be operated with nitrification during the summer. This is the case for the treatment plants studied by Elfving et al. (1975) (see Table 7).

Table 7. Average values for nitrogen in wastewater effluent at the treatment plants Själevad, Leksand, Borlänge, Vikmanshyttan, Motala, and Eolshäll from July 1973 through July 1974 (Elfving et al., 1975)

Treatment plant	NH_4^+-N g/m^3	NO_2^--N g/m^3	NO_3^--N g/m^3	Total N g/m^3	Number of samples
Själevad	10.8	0.13	4.5	22.0	241
Leksand	5.1	0.15	3.0	12.2	146
Borlänge	14.7	0.49	4.4	25.1	356
Vikmanshyttan	2.1	0.14	4.8	11.6	350
Motala	8.8	0.12	4.9	17.1	362
Eolshäll	8.6	0.10	3.5	15.5	90

DESIGN OF PLANT FOR BIOLOGICAL NITROGEN REMOVAL

Design procedures have been described by EPA (1975), Barnes and Bliss (1983), WPCF (1983), Winkler (1984) and ATV (1987). The two main design criteria are:

- o Possibilites for obtaining nitrification
- o Nitrogen removal due to assimilation and denitrification

The possibilities of obtaining nitrification are dependent on sludge age and temperature. Results from Finnish and Swedish plants are shown in Figures 3a and 3b (Valve, 1984) and compared with results from EPA (1975). Figure 3c shows data from Eskilstuna (Lilja, 1985); the results are also compared with EPA (1975). The results show that a nitrification degree of at least 80 per cent is normally obtained for a sludge age above 3 days at 20 °C, above 10 days at 10 °C, and above 16 days at 6 °C.

There is a stoichiometric relationship between removed organic material and removed nitrogen by assimilation and denitrification. Hultman (1986) has suggested the following empirical relationship (see Figure 4):

Pre-denitrification:

$$N_r = s_o(a/3.7 + 0.044) \tag{1}$$

Post-denitrification:

$$N_r = s_o(a/5.6 + 0.044) \tag{2}$$

in which N_r = total nitrogen removed, g N/m^3
s_o = influent total BOD concentration, g/m^3
a = fraction in nitrification-denitrification reactor that is not aerated (fraction of denitrification zone)

Figure 3A

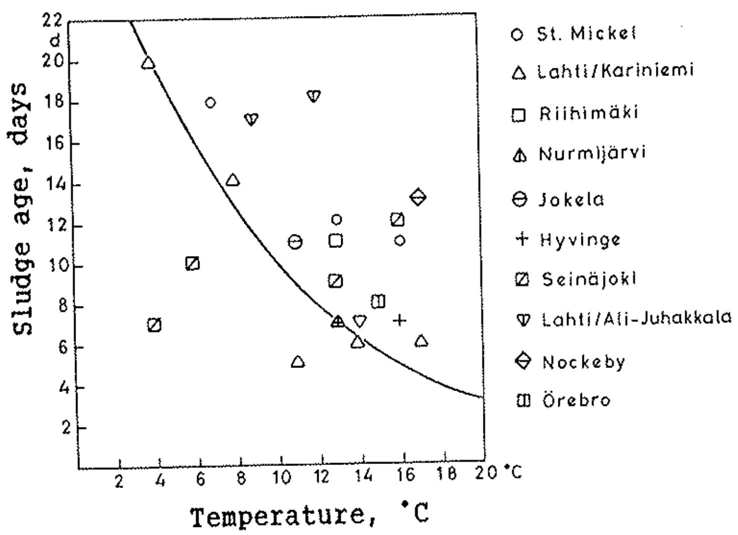

Figure 3B

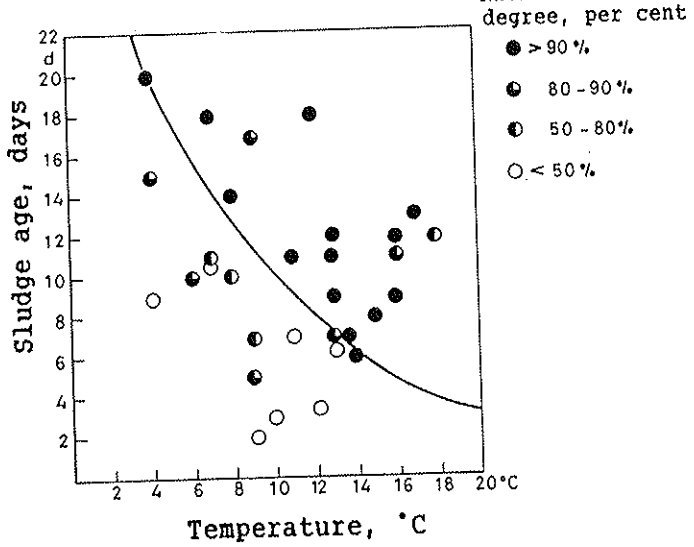

Figure 3C

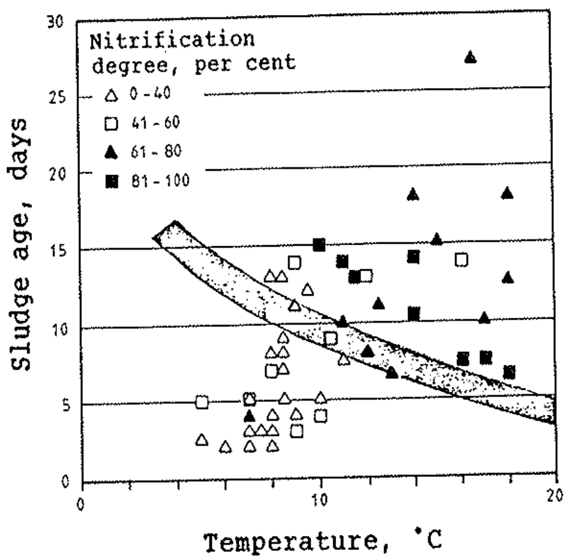

Figure 3. Nitrification dependency on sludge age and temperature. The curve represents the minimum sludge age as a function of the temperature to obtain nitrification according to EPA (1975).

A. Wastewater treatment plants (from Finland and Sweden) with a nitrification degree of more than 80 per cent at different temperature and sludge age (Valve, 1984)

B. Nitrification degree at different values for the temperature and sludge age for Finnish and Swedish wastewater treatment plants (Valve, 1984).

C. Nitrification degree at different values for temperature and sludge age at Eskilstuna wastewater treatment plant (data from Lilja, 1985).

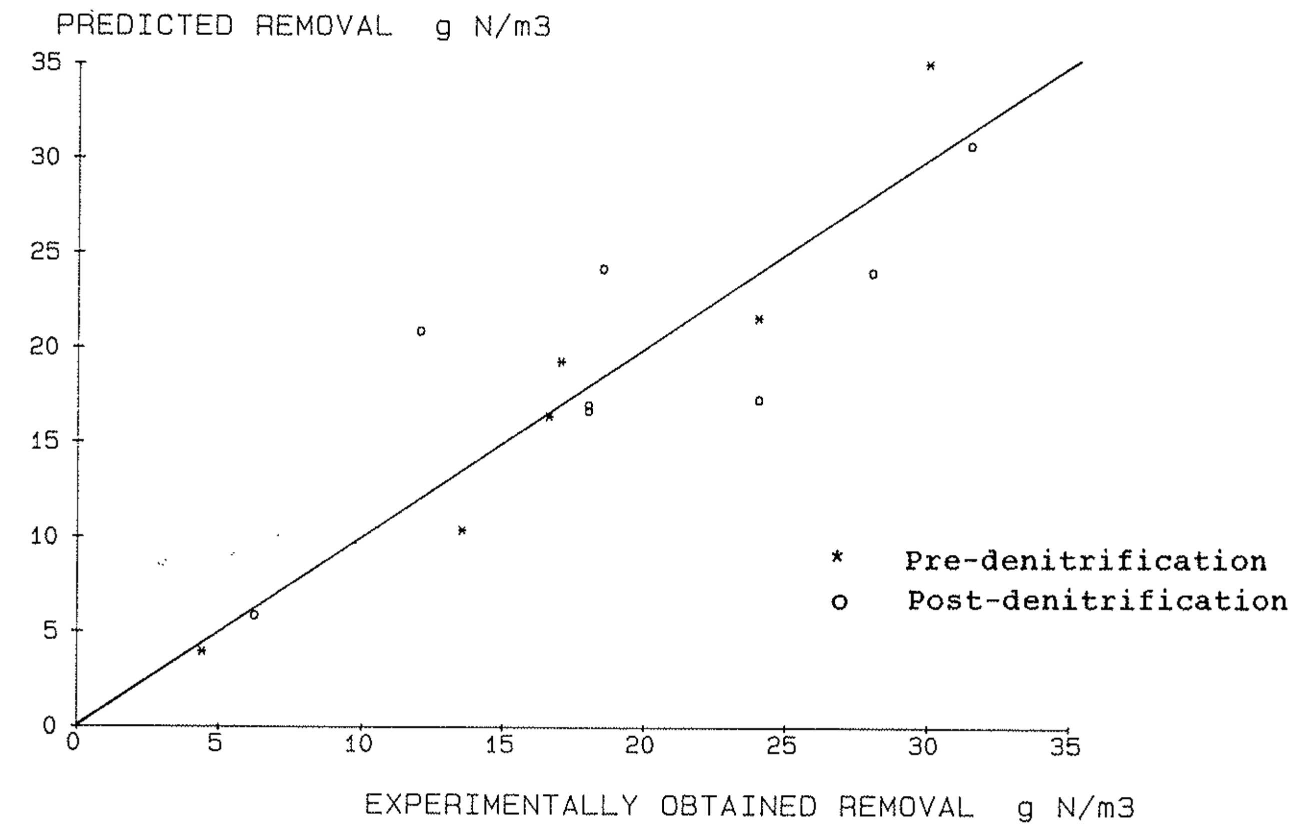

Figure 4. Relationship between predicted and experimentally obtained removal of total nitrogen in pre-denitrification (formula 1) and post-denitrification (formula 2) plants. Data for pre-denitrification are mainly from full-scale plants in the Nordic countries and for post-denitrification, results are from studies on different scales reported in the literature (Hultman, 1986).

The volume necessary for nitrification and denitrification, V_{tot}, is determined from the relationship:

$$V_{tot} = \frac{V_{nitr}}{(1 - a)} \qquad (3)$$

in which V_{nitr} = volume necessary for nitrification

The volume necessary for nitrification, V_{nitr}, may be written:

$$V_{nitr} = \frac{\Theta_d QY(s_o - s)}{X} \quad (4)$$

in which Θ_d = sludge age for nitrification bacteria, d
Q = substrate yield coefficient, g/g
s = effluent BOD concentration, g/m^3
X = average sludge concentration in aerated parts, g/m^3

The value of Θ_d may be chosen from Figure 3, a suitable value for a from formula 1 or 2 and the total volume for nitrogen removal may be calculated from formula 3.

If a high degree is required of nitrogen removal, it is important to consider the effluent concentration of soluble organic nitrogen (Parkin and McCarty 1981a and 1981b; Jansen and Kristensen, 1985). Minimum effluent soluble organic nitrogen are predicted to result from operation of municipal activated sludge plants at conventional loadings with solids retention times of 6 to 10 days. Under these conditions and with near steady-state operation, an estimated 20 to 40 per cent of the effluent soluble organic nitrogen is produced biologically during activated sludge treatment and the remainder represents residual organics from the influent wastewater (Parkin and McCarty, 1981a). In Table 7 it is shown that the effluent total nitrogen concentration is considerably higher than the sum of the concentration of ammonium, nitrite, and nitrate nitrogen.

OPERATIONAL PROBLEMS

These problems include:

- Floating sludge due to the formation of nitrogen gas in denitrification
- Foam formation by for instance Nocardia due to the use of a high sludge age in nitrification
- Solubilisation of phosphorus due to mineralisation of sludge at high sludge ages
- Decrease of pH and alkalinity due to nitrification
- Increased corrosion

These operational problems must be carefully considered in implementation of nitrogen removal.

IMPROVEMENT OF NITROGEN REMOVAL

Increased sludge concentration

The sludge concentration may be increased by:

- Use of contact stabilisation, by which process a high average sludge concentration may be used (Balmér, 1985)
- Use of contact materials in the aeration basin
- Improvement of sludge sedimentation and thickening properties

The last point will be discussed here. Studies on sludge sedimentation and thickening indicate that the main two factors affecting these properties are sludge density and structure. The sludge density is a function of the sludge volatile fraction, and the influence of the volatile fraction on the sedimentation velocity has been described by an empirical model (Hultman 1986). A measurement of the floc structure is given as floc filament length per g of sludge. Rittman (1987) has shown an empirical relationship between the solids flux due to sedimentation, the sludge concentration and the length of filaments.

By use of contact stabilisation, contact materials, and methods to improve sludge sedimentation and thickening properties, it is possible to achieve significant reductions in the volume necessary for nitrification and denitrification.

Recirculation

An intrinsic weakness of the pre-denitrification process is that only the nitrate that is recirculated into the anoxic stage can be removed by denitrification. Thus, for a high percentage of denitrification, a high degree of recirculation is necessary. By applying 100 per cent recirculation, only 50 per cent of nitrate can be removed, theoretically, by denitrification. However, a high degree of recirculation may cause a decrease in denitrification efficiency. This is due to the facts that the hydraulic retention time diminishes with increasing recirculation ratio and that the denitrification bacteria need some time to acclimatize from aerobic to anoxic conditions (Krauth, 1986).

Process control

The influent organic material may be degraded under aerobic or anoxic conditions. If organic material is a limiting factor for denitrification, it is important to avoid unnecessary organic degradation under aerobic conditions. This may be accomplished by operating the nitrification process only to a certain level of the effluent ammonium concentration, for instance, to 1-3 g NH_4^+-N/m^3 in the effluent. The degree of nitrification may be controlled by the air supply.

It is desirable to control the nitrate concentration from the anoxic stage. As long as the nitrate concentration is above 2-3 g NO_3^--N/m^3, it may be useful to decrease the sludge recirculation ratio.

Improved process control in nitrogen removal process systems can be achieved mainly by use of suitable measurement instruments and operational control strategies. Examples are:

- Use of selective ammonium electrodes
- Control of oxygen supply with the aid of nitrate measurements (Kayser and Ermel, 1985)
- Use of redox potential (Charpentier et al, 1986)
- Use of alkalinity measurements (Strandsäter, 1979)
- Measurement of dinitrogen oxide in the gas phase (Nogita et al., 1981)

Process reactors

Nitrogen removal by use of nitrification and denitrification has mainly been studied in the form of single sludge processes with the activated sludge process and to some extent with fixed film reactors. Special reactors such as fluidised beds, sand filters and the addition of suspended support materials may be of interest.

Process systems

Although single sludge systems constitute the most common process for nitrogen removal, it may be advantageous to separate the sludge systems or to use nitrogen removal in two or several stages. Examples of such systems include:

- The use of a denitrification upflow reactor before an activated sludge process with denitrification and nitrification (Klapwijk et al., 1979).
- The use of two-stage nitrification with partial nitrification of sidestreams from dewatering of digested sludge and seeding of the formed nitrification bacteria into an activated sludge process with denitrification and nitrification (Tendaj-Xavier, 1985, and Tendaj-Xavier et al., 1985).

COST CONSIDERATIONS

Costs for different nitrogen removal processes have been reported in several Swedish studies, often based on foreign studies (Lundberg, 1971, Hultman, 1973b, Neretnieks et al., 1973, and Haglund and Norrman, 1984). In a recent study, Holmström (1987) has estimated the costs for installation of nitrogen removal at Swedish municipal wastewater treatment plants using conventional technology for nitrification and denitrification at existing plants dimensioned for more than 10000 person equivalents and situated on the coast (a total of 7 million person equivalents). The necessary investments were estimated at SEK 1800 million and SEK 5000 million for a nitrogen removal efficiency of 50 per cent and 75 per cent, respectively. The following additional costs for nitrogen removal per m^3 were estimated:

Nitrogen removal, %	Capital costs	Operational costs	Total costs
50	0.25 SEK/m^3	0.10 SEK/m^3	0.35 SEK/m^3
75	0.75 SEK/m^3	0.20 SEK/m^3	0.95 SEK/m^3

These figures may be lowered as a result of advances in technology and the transfer of experience from plant to plant.

CONCLUSIONS

- Several factors are important when considering the removal of nitrogen compounds, including oxygen consumption, eutrophication, acidification and toxicity.
- Several Swedish plants are operated with nitrification especially during the summer.
- Plants which can be operated with nitrification may in several cases significantly increase nitrogen removal by introducing an anoxic zone. This zone may be advantageous in order to saving energy, reducing corrosion, and to some extent reducing the production of sludge.
- Some operational problems may be incurred as a result of nitrification and denitrification, including floating sludge, corrosion and solubilisation of phosphorus.
- In the implementation of nitrogen removal at existing plants it may be advantageous to consider several modifications, for instance, an increase in the sludge concentration in the aeration basin, use of a separate nitrification or denitrification step before the activated sludge process, and control of the ratio of the aerobic and anoxic zones.
- If a high degree is required of nitrogen removal, it is important to consider the effluent concentration of soluble and suspended organic nitrogen.
- Nitrogen removal is a complicated process involving several operational problems such as floating sludge, foam formation and corrosion. Thus, the introduction of nitrogen removal will increase the need for better understanding and control of the process, and for training.

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PROPOSALS FOR FUTURE ACTIVITIES AGREED UPON AT THE SEMINAR ON WASTEWATER TREATMENT IN URBAN AREAS

The programme of the seminar was divided into three different sections

- Sewerage systems
- Discharge of industrial wastewater to municipal sewerage systems
- Reduction of nitrogen.

For each subject the participants of the seminar agreed upon the following proposal for future activities:

Sewerage systems

a) Combined sewer overflows (CSO).

Brief state-of-the-art reports should be compiled by the Contracting Parties. The reports should provide information on

- extent of combined sewers (in % of sewered area)
- design practices including flow equalization
- rates of inflow/infiltration
- pollution due to CSO
- current research
- trends.

A compilation of these reports may hopefully lead to the derivation of suitable effluent standards, which may be expressed as frequencies, total volumes or total amount of pollution load. The effluent standards may be expressed as monthly to yearly values.

Proposals for recommendations should be formulated on proper measures to be taken to meet eventual standards.

b) Stormwater

Brief state-of-the-art reports should be compiled by the Contracting Parties. The reports should provide information on

- extent of separate sewer systems (in % of sewered area)
- concentration of pollutants in stormwater
- regulations on connections to the stormwater system
- methods for source control
- current research
- trends
- methods used for quantitative and qualitative water budget estimations.

A compilation of these reports may hopefully lead to the derivation of congruent methods for water budget calculations. This tool in turn may lead to realistic estimation of the magnitude of problems connected to stormwater management and that proposals be made for recommendation of proper countermeasures to be taken.

c) Renovation of sewers

Brief state-of-the-art reports should be compiled by the Contracting Parties on methods used. A compilation of these reports should promote the exchange of information.

Discharge of industrial waste water to municipal sewerage systems

1. A list of guidance or limit values should be worked out for use in the countries discharging water into the Baltic.

2. Lists of limit values for industrial waste water are available in Sweden (VAV M 20), Finland (TESI 5) and West Germany and lists of maximum permissible values for different recipients are available in the USSR and Denmark.

3. Research programs dealing with micropollution is going on in Denmark and has been going on in Sweden (SWEP-project). It is recommended that the results should be utilized by the Commission.

4. We recommend that a working group is formed to develop guidelines acceptable by all Baltic countries. Each country should nominate 1-2 specialists to the working group (and supply sufficient funding for the group).

5. The working group should pay special attention to the following aspects:

   - the risks for accumulation of non-biodegradable materials in the food-chain (e.g. accumulation in sludge)
   - the operation of pre-treatment installations within the industries
   - monitoring of harmful substances.

Reduction of nitrogen

- Recognizes the problem of nitrogen control in the Baltic.
- Stresses the importance of co-ordinating activities in this field.
- Recommends
  - forming a Working Group
  - collecting available information on
    - receiving water's need
    - source of nitrogen
    - regulatory control
    - current R/D, full scale experience
    - integration in treatment systems
    - expected benefit

. advise on possible actions

. set a goal and time table.

The Scientific-Technological Committee established a new project on the topics related to sewage treatment in urban areas to carry out the tasks to be given by the STC.

The Committee expressed its appreciation to Sweden for its willingness to act as Lead Country for the new project. The project will be organized in cooperation between the National Environmental Protection Board and the Swedish Water and Waste Water Works Association.

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BALTIC SEA ENVIRONMENT PROCEEDINGS

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