BALTIC SEA ENVIRONMENT PROCEEDINGS

No. 36

SEMINAR ON NUTRIENTS REMOVAL FROM MUNICIPAL WASTE WATER

4-6 September 1989
Tampere, Finland

BALTIC MARINE ENVIRONMENT PROTECTION COMMISSION
– HELSINKI COMMISSION –

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PREFACE

The Ninth Meeting of the Helsinki Commission in February 1989 approved a Finnish invitation to a seminar on Nutrients Removal from Municipal Waste Water to be held in Tampere 4-6 September 1989. The seminar was arranged under the auspices of the Helsinki Commission and the Nordic Council of Ministers and organized jointly by the Finnish Ministry of the Environment and the National Board of Waters and the Environment. About 50 people took part in the seminar and in the excursion to the municipal wastewater treatment plants of the cities of Hämeenlinna and Hyvinkää. Experts from Denmark, Finland, the German Democratic Republic, the Federal Republic of Germany, Norway, Poland, Sweden and the Union of Soviet Socialist Republics attended the program.

Dr. Tapani Kohonen of the Finnish Ministry of the Environment opened the seminar and stressed the need of seminars for fulfilment of the scientific-technological co-operation provided by the Article 16 of the Helsinki Convention. In the position of the vice-chairman of the Scientific-Technological Committee, he also reminded that the implements of some HELCOM Recommendations and the Ministerial Declaration demand precise information about the possibilities of reducing load of nutrients entering into the marine environment.

The participants were pleased with the high quality of the presentations and with the lively and professional discussions resulted in the conclusions of the seminar. They agreed on the need of further information on the results of ongoing investigations to be considered by the next meeting of the experts in 1990 in Karlskrona.

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

CONCLUSIONS OF THE SEMINAR

According to the papers and information presented in the seminar, nutrient removal is considered very important in all Baltic Sea States and Norway, and a lot of research is going on.

It appears from some of the reports presented that 50-80 % nitrogen reduction as an annual average is technically and in practice possible with the activated sludge processes used at present for nitrogen removal.

The experience in Denmark indicates that the goal of 8 mgN/l in the effluent can be achieved.

For practical reasons, such as possibilities to adopt the proper process combinations at the existing treatment plants, and the need for further research to develop optimal removal methods, the implementation of timetables and final goals need further consideration.

At present, measures to remove phosphorus are intensified all around the Baltic Sea.

An effluent concentration of less than 1 mgP/l can be achieved by a combination of biological methods and different precipitation methods or by plain chemical treatment without any biological phases and simultaneous-, pre- or postprecipitation. Simultaneous precipitation, especially, can be easily adapted at activated sludge plants without considerable construction and running costs.

In Finland and Sweden the goal of 1.5 mgP/l given by HELCOM Recommendation 9/2 (1988) has already widely been achieved.

It was pointed out by the Seminar that a proper running and operation of treatment plants are an essential part in achieving the reduction targets.

Further exchange of information on research and results achieved is necessary.

NATIONAL REPORT ON RESEARCH AND DEVELOPMENT ON PHOSPHORUS AND NITROGEN REMOVAL

DENMARK

Dr. Tage V. Andersen
National Agency of Environmental Protection

1 The Action plan against pollution of the Danish marine environment by nutrients.

The pollution of the aquatic environment with nutrient salt has the las decades changed from being a local pollution of rivers, lakes and coastal areas to a more general and a much more severe problem for all aquatic areas.

As a consequence of this problem the Danish Parliament in January 1987 in the so called Action Plan against pollution of the Danish marine environment by nutrients, decided before 1993 to reduce the nitrogen discharges by 50 % and to reduce the phosphorus discharges by 80 % to the levels shown below.

Nitrogen	Discharge reported 1984 tonnes/year	Discharge when plan completed tonnes/year
Agriculture	260 000	133 000
Municipal wastewater plants	25 000	10 000
Direct industrial discharges	5 000	2 000
Total	290 000	145 000

Phosphorus	Discharge reported 1984 tonnes/year	Discharge when plan completed tonnes/year
Agcriculture	4 400	400
Municipal wastewater plants	7 200	2 000
Direct industrial discharges	3 400	600
Total	15 000	3 000

For the municipal wastewater plants, which is main topic of this seminar, nitrogen removal shall be done down to 8 mg/l (annual average) for all plants greater than 15 000 person -equivalents (p.e.) and phosphorus removal shall be done down to 1,5 mg/l (annual average) for all plants greater than 5 000 p.e.

In 1990 it will be decided whether nutrients removal also shall be required for smaller plants.

The cost of the extension and the improvement of the municipal wastewater plants, which are covered by the demands in the Action Plan, are approximately 7 400 million Danish crowns. A great part (about the half) should yet have been paid anyway according to the normal rules in the Danish Environmental Protection Act.

The work with the extension and the improvement of the municipal wastewater plants is well started. Untill now about 40 % of the total investments have been disposed, and at the end of 1989 more than 75 % will have been disposed.

2 Research and Development on Phosphorus and Nitrogen removal in Denmark

As a support to **the implementation of the Action Plan, the Govern**ment has started and given money to several research and development programmes of which those clearly relating to nutrients removal are listed below.

Programme	**Public support in million Danish Crowns**	**Period**
Pollution from agriculture (nitrogen, phosphorus, organic matter)	50	1986-1990
Marine environment	60	1989-1991
Municipal wastewater	35	1988-1991
Technology relation to aquatic environment	30	1988-1989

For the nutrients removal from municipal wastewater, which is the main topic of this seminar, especially the two last mentioned programmes have interest. Even if they are handled by two different ministries (The Ministry of Environment and The Ministry of Industry) have been administrated as one common programme with the shown 6 main areas:

1. Process automation and regulation
2. Process techniques
3. Measuring equipment and sensors.
4. Problems of industrial wastewater for the municipal wastewater plants.
5. Sludge.
6. Renewal of sewer networks.

In these main areas 80-85 projects have been started with a public support of 65 million Danish Crowns and a private financing of 23 million Danish Crowns.

These projects have been organized in the following 12 coordination groups:

1	Control, regulation and monitoring of purification plants and sewer systems	(11 projects)
2	Regulation of rainwater runoff	(11 projects)
3	Databases/standards/norms	(4 projects)
4	Measuring equipment and sensors	(7 projects)
5	Purification methods and better operation of municipal purification plants	(11 projects)
6	Pretreatment of industrial wastewater	(5 projects)
7	Low-technology plants	(8 projects)

8 Purification for heavy metals, substances alien to the environment, oils and dyes	(7 projects)
9 Sludge treatment	(9 projects)
10 Sludge applicatios	(7 projects)
11 Renewal of sewer networks	(7 projects)
12 Production management/testing/Danish produces equipment/export markets	(5 projects)

(Some projects is in more than 1 group).

The projects have been described in the publication "Research and Development Projects in the Fields of Waste Water Treatment and Aquatic Environment Technology in Denmark 1988-1991", which can be ordered at the national Agency of Environmental Protection, Strandgade 29, DK 1401 Copenhagen K, Att.: The Information.

In relation to the topic of the seminar, I think the projects in coordination group nr. 5: "Purification networks and better operation of municipal purification plants" will be of special interest.

The titles of the 11 projects in this group are:
Nitrogen stripping from reject water in purification plants.

Improvement of the beach water quality by reduction of the quantity of rainwater runoff.

Pre-precipitation with integrated liming of sludge.

The importance of the anaerobe pre-tank for biological removal of phosphorus.

Biological nitrification in purification plants with simultaneous precipitation.

Light-weight sludge.

Wastewater purification with fluid filters.

Precipitation properties of activated sludge in plants for removal of nutritive salts.

Hygienic quality of effluent from purification plants with removal of nutritive salts.

Winter operation of purification plants with nitrogen removal.

Optimization of contact filter system for removal of phosphorus etc.

Some of the projects will be presented in more details later on in this seminar, so therefor I don't want to go in deeper details here.

Most of the projects will be finished late in 1990 or early in 1991.

In connection to the descriptions of the projects there are also the address and the phonenumber of the contactpersons of the projects, so that it will be possible to establish a direct contact to those, who work on the projects.

I hope in this way to have given a contribute to make it easier to the people, who make research and development in this field to get in contact to people in Denmark, who work in this field, in the hope, that this will result in a better water quality in the Baltic See and the countries around it.

NATIONAL REPORT ON RESEARCH AND DEVELOPMENT ON PHOSPHORUS AND NITROGEN REMOVAL

FEDERAL REPUBLIC OF GERMANY

1 Situation

In the field of nutrient removal from municipal waste water, comprehensive research has been done for many years. The results and experiences were partly realised. For example, in the catchment area of Lake Constance covered by parts of Southern Germany, Switzerland and Austria the first phosphorus removing waste water treatment plants became operational in the mid-sixties. Plants with systematic nitrification and fewer ones with systematic denitrification are being operated particularly in areas with small and problematic waters.

Aware of the importance of nutrients in respect to eutrofication, the Federal Government planned to amend the appropriate administrative regulation on minimum requirements for the discharge of municipal waste water into waters by adding new requirements for phosphorus and nitrogen. This comparatively progressive amendment became obsolete because of the events in the North and Baltic Seas in the early summer of 1988. Consequently the Federal Minister for the Environment set up a 10-Point-Action-Programme on intensified measures for the protection of the North and Baltic Seas containing inter alia a tightening of the above mentioned requirements on municipal waste water discharged into waters. This will be pointed out in section 2.1.

2 Legal measures

2.1 Amendment of the First General Administrative Regulation on Minimum Requirements for the Discharge of Waste Water from Communities into Waters

The more rigorous amendment of this administrative regulation will shortly be published and shall enter into force by 1 January 1990. According to the 10-Point-Action-Programme, phosphorus and nitrogen among others shall be limited in the following way:

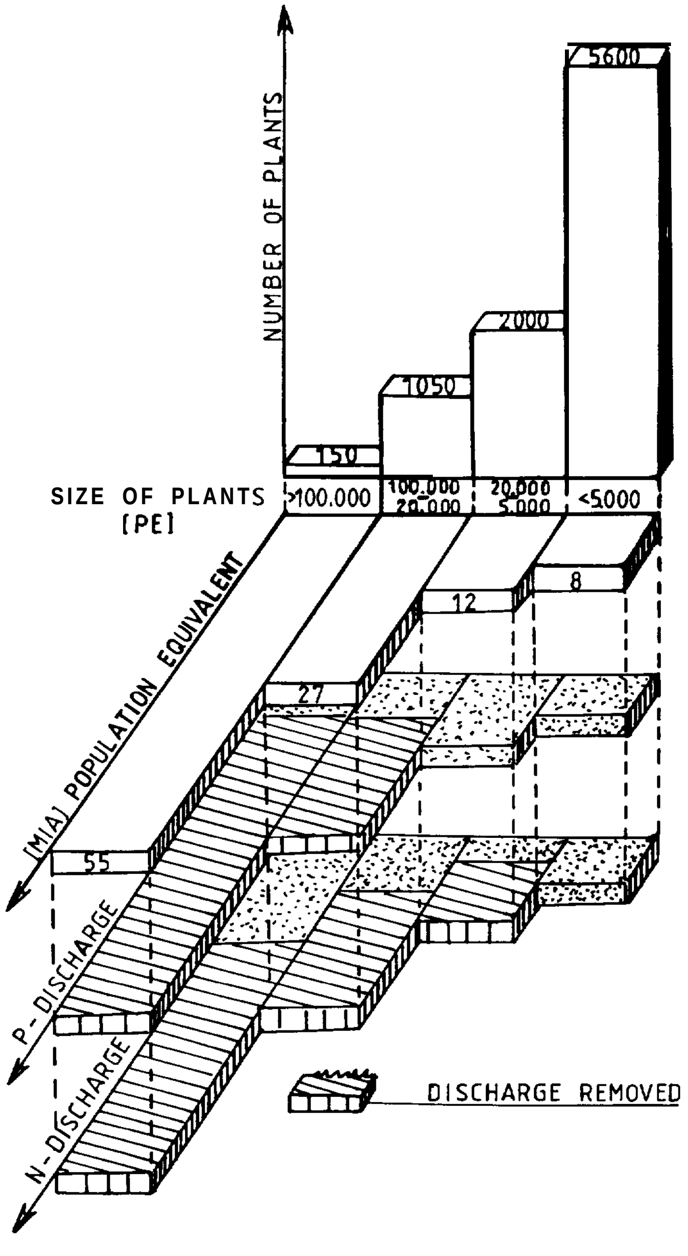
Size of waste water treatment plant (population equivalent)	Total Phosphorus	Ammonia- Total Nitrogen
smaller than 5000 PE		
5000 PE to 20000 PE		**10** mg/l *
20000 PE to 100000 PE	2 mg/l	**10** mg/l *
100000 PE and beyond	1 mg/l	10 mg/l *

*)

With regard to total nitrogen, the requirements include the introduction of systematic denitrification where feasible. It is expected to take 1 or 2 years for the corresponding generally acknowledged technical rules to be worked out allowing minimum requirements consisting of concrete values to be drawn up.

The effect of these requirements is shown in figure 1 which gives the proportion of the number of plants in comparison with their size.

Figure 1



It is estimated that the above mentioned amendment will reduce the input of phosphorus by municipal waste water by about 75 %. In respect of nitrogen, similar effects are expected.

2.2 Amendment to the Waste Water Charges Act

According to the Waste Water Charges Act the waste water charge depends on the content of certain pollutants in the waste water and is calculated on the basis of the discharge values authorised in the official notices relating to water legislation, taking differently evaluated pollutants and groups of pollutants as its base.

The 10-Point Action Programme for the protection of the North and Baltic Seas includes a proposal to make phosphorus and nitrogen subject to the waste water charge. An according bill will enter into force by 1991. This will provide an additional incentive for necessary investments in waterprotection measures in order to reduce phosphorus and nitrogen inputs as quickly as possible. The possibility of deducting these investments from the waste water charge for a limited period of time will act as an added incentive to accelerate the construction of new sewage treatment plants and the expansion of existing ones equipped for phosphorus and nitrogen elimination.

2.3 Washing and Cleansing Agents Act

The detergents industry, for its part, has responded to the stricter requirements and has increasingly developed phosphatefree detergents. At the beginning of 1988, two thirds of all detergents were already phosphatefree. The supply of these detergents and the phosphate reduction resulting from the Ordinance on Maximum Amounts of Phosphates in Washing and Cleansing Agents means that sewage treatment plants and water bodies in the Federal Republic have been relieved of considerable amounts of phosphate. It is expected that washing and cleansing agents will contribute only 10 to 50 % of the overall phosphorus input into the water bodies of the Federal Republic of Germany by the end of 1988.

3 Research and Development Activities

3.1 General

Due to the necessary briefness of this report on activities in the Federal Republic, it is only possible to look very roughly at one or two aspects. Thus the report cannot go into any great detail. The statements represent an extract from the current reports in special periodicals and those of seminars. Thus it may be that this report is incomplete and not representative in some parts, particularly in this section.

In order to define the generally acknowledged technical rules, a working group consisting of several Universities set up a series of cooperative meetings. First results of these joint conventions appear in special periodicals and in seminars and contain recommendations for designing waste water treatment plants in order to remove nitrogen by nitrification and denitrification. An algorithm for designing those plants is derived from these available reports and is shown in section 3.2. Furthermore, according to those reports it seems to be an indisputable fact that

- an adequate N-removal requires an intensivation of plant control and management providing the use of improved measuring techniques,

- primary and simultaneous denitrification are preferable to secondary denitrification,

- in spite of certain reservation, it seems that there is no longer any great need for research on P-removal by precipitation,

- since legal requirements will cause both of N- and P-removal in all plants with 20 000 PE or more, research also puts emphasis on questions that might appear in this respect.

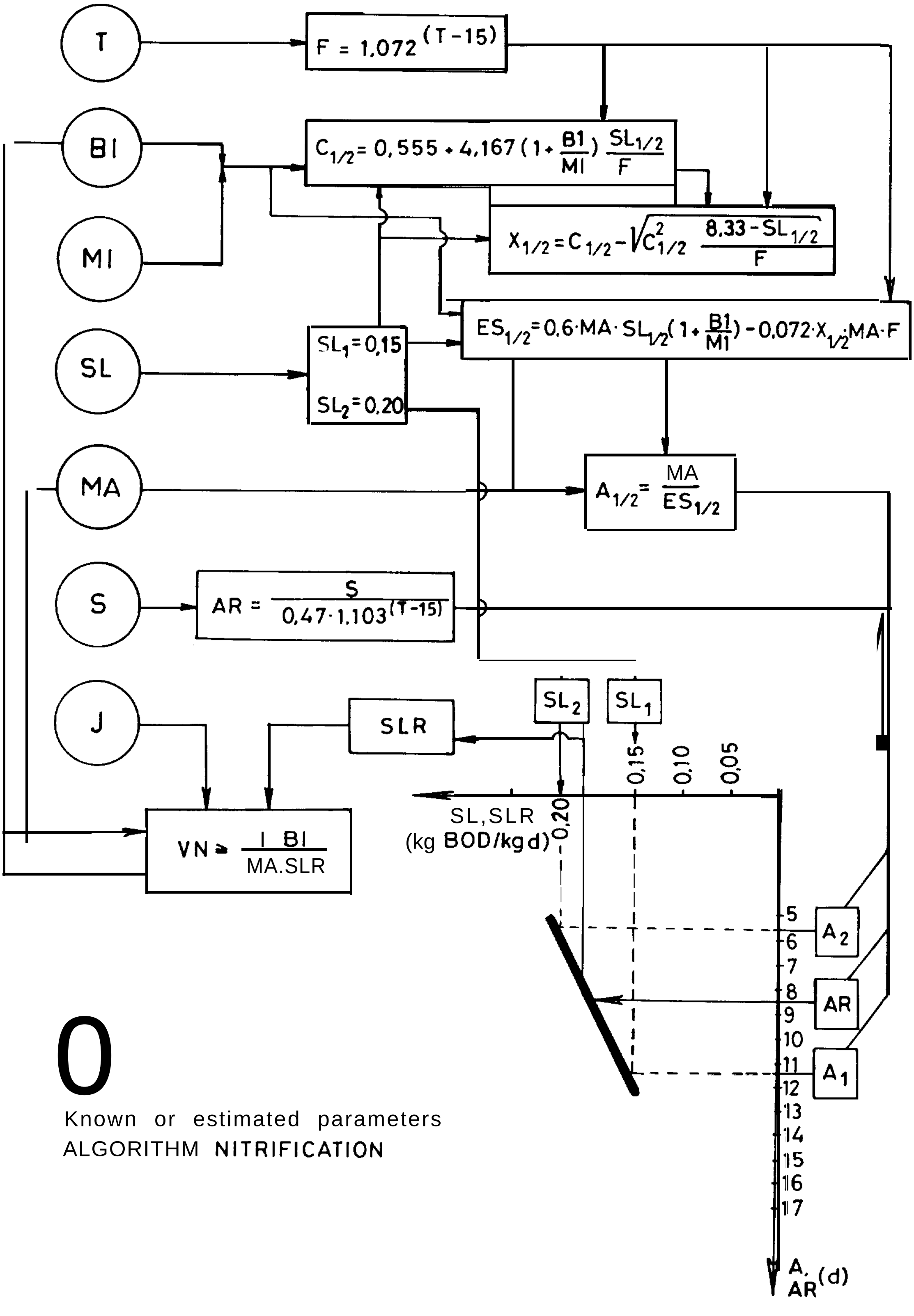
3.2 Nitrification and Denitrification

The experts' discussion is also aimed at formulating recommendations for the designing of N-removing treatment plants. Based on current publications on design rules, particularly set up by Kayser in 1983, the following proposed algorithm for nitrification and denitrification was derived. It must be admitted that it is merely a suggestion of the lecturer and thus cannot consider all possible conditions. Nevertheless this algorithm might give a basic outline of the question. It includes a graphical method which enables even the non-computerized designer (or proving water authority) to get results quickly and with sufficient accuracy.

Algorithm nitrification

The following abbreviations have been used:

T (°C) water temperature required for sufficient N-removal
F (-) growth rate of nitrosomas etc. depending on temperature
BI (gBOD/m^3) BOD-concentration of influent
MI (kg/m^3) mixed liquor suspended solids of influent
SL (kg BOD/kg MI d) sludge loading per day
C (-) auxiliary calculation factor
MA (kg/m^3) mixed liquor suspended solids in aeration tank
s (-) margin of safety
X (-) rate of active sludge
ES (kg/d m^3) excess sludge
A (d) sludge age
AR (d) required sludge age resulting from growth rate
I (m^3/d) influent
VN (m^3) aerated volume required for nitrification
SLR (kg BOD/kg d) relevant sludge loading



○ Known or estimated parameters

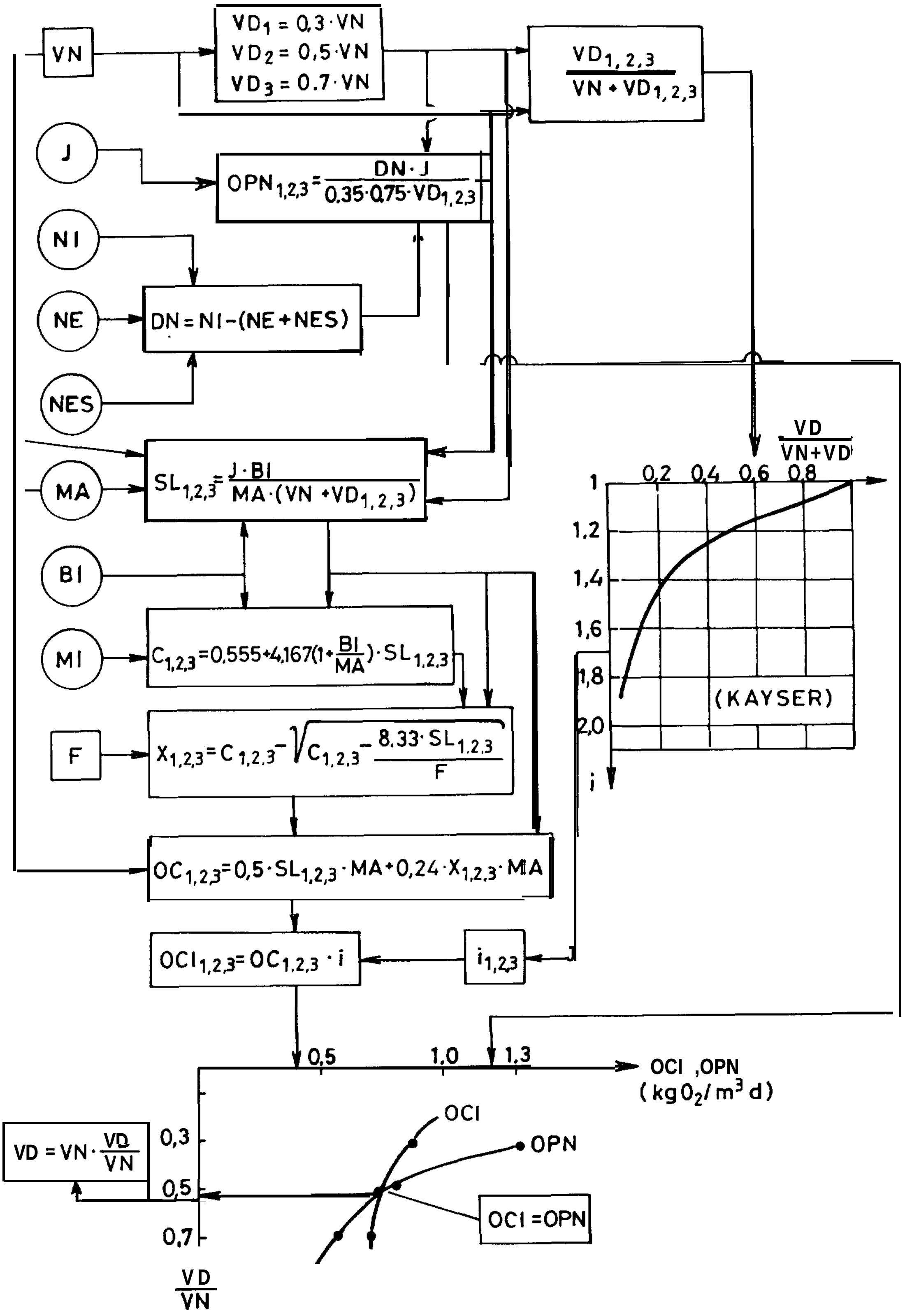
ALGORITHM **NITRIFICATION**

Algorithm denitrification

The following abbreviations have been used:

VD (m^3)	volume required for denitrification
DN	nitrogen to be removed
NI	nitrogen influent
NES	nitrogen removed via excess sludge
NE	nitrogen influent

OPN	(kg O_2/m^3d)	oxygen production by denitrification
oc	(")	oxygen consumption
OCI	(")	intensified oxygen consumption by primary denitrification
i	(-)	coefficient regarding intensivation of oxygen consumption by primary denitrification
0,35		N/O_2-rate
0,75		rate of denitrifying organism



ALGORITHM DENTRIFICATION

3.3 Biological Phosphorus Removal

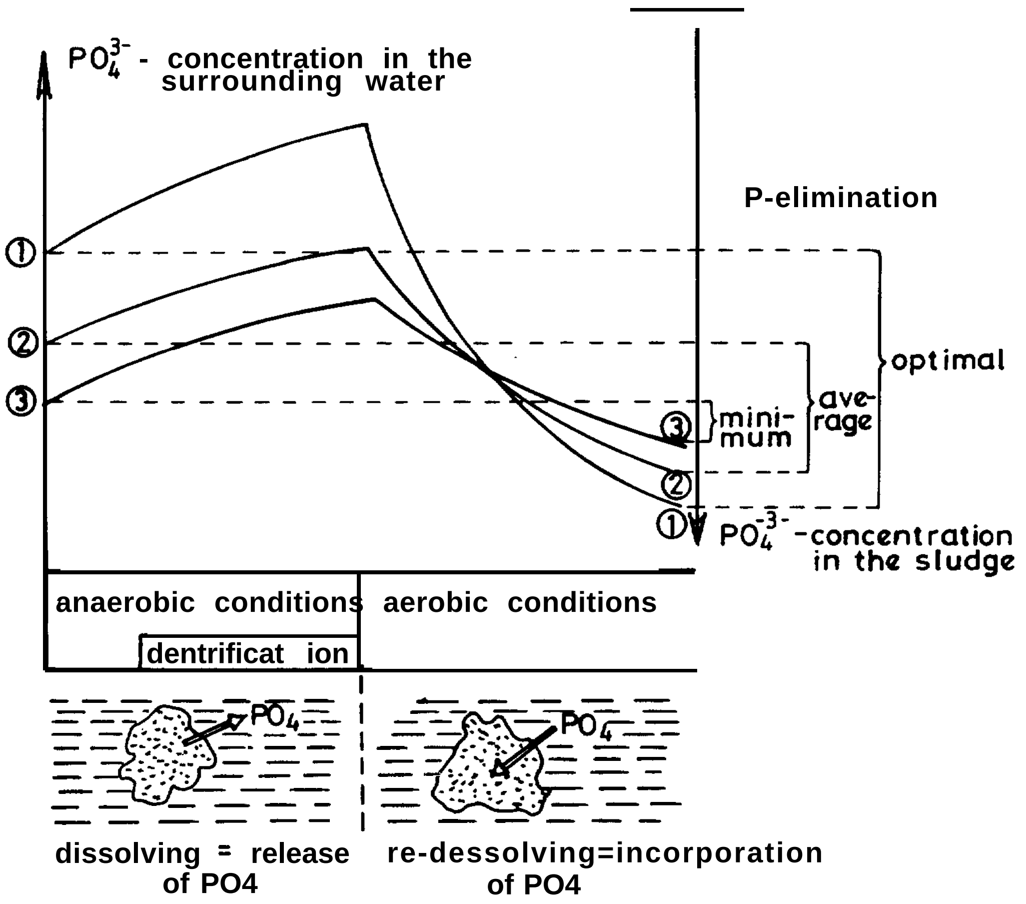
The classical methods of P-removal by precipitation are well known. Now the biological P-removal is being subject to research. According to preliminary results, it seems that this method may be applicable for plants which have to meet the 2 mg/l value.

The main advantages of biological P-removal are:

- no additional salt input by precipitants
- no additional excess sludge.

Up until now, the biological P-removal has not been completely explored. But it seems to be based on the fact that some micro-organisms are able to incorporate phosphate. The alternating change of an anaerobic environment to an aerobic one seems to be advantageous to these micro-organisms, which can thus grow faster than others. In the anaerobic zone the micro-organisms release incorporated phosphate whereas is incorporated in the aerated zone. The incorporation exceeds the amount released. The incorporation/release-rate increases with the phosphate release as shown in figure 2.

Figure 2

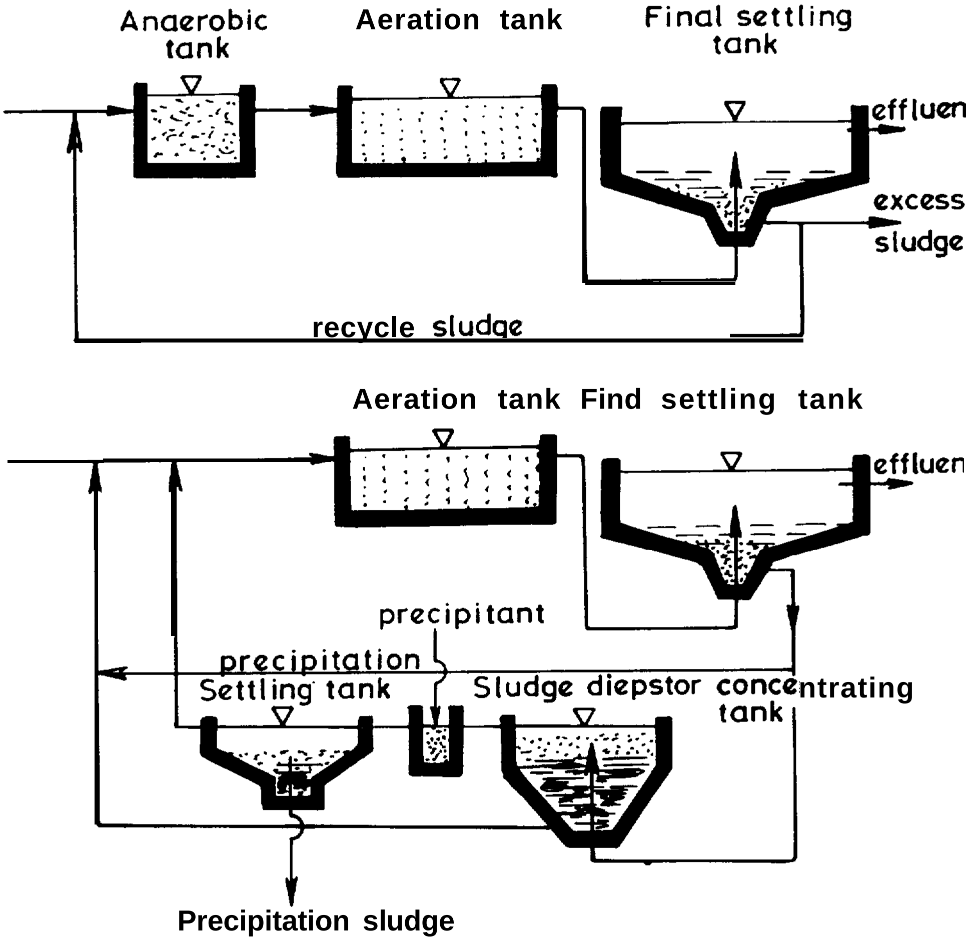

PO4 3- - concentration in the surrounding water
P-elimination
①
②
③
optimal
ave-rage
mini-mum
③
②
①
PO4 3- -concentration in the sludge
anaerobic conditions
aerobic conditions
dentrificat ion
PO4
PO4
dissolving = release of PO4
re-dessolving=incorporation of PO4

Further pre- conditions for biological P - removal are

- the presence of easily degradable organic substrate
- the presence of organic acid
- the absence of NO_3/NO_2 (i.e. denitrification provided)
- sufficient aeration detention time.

The outlined substantials and these pre - conditions might lead to the following configurations of plants:

Figures 3a and 3b



It must be taken into account that the process of biological P-removal is reversible. Thus the dissolving of PO, could occur in the final settling tank or during sludge treatment. Beyond that the needed long sludge age for nitrification, causing a low excess sludge production might limit the biological P-removal depending on a higher excess sludge production.

4 Conclusion

This report describes the legal measures in the Federal Republic and their expected impact on the reduction of nutrient discharges into waters. Later, the report points out briefly current activities, notably in the field of biological P-removal as derived from current publications at hand. For designing a N-removing waste water treatment plant by nitrification and denitrification an algorithm is suggested.

NATIONAL REPORT ON RESEARCH AND DEVELOPMENT ON PHOSPHORUS AND NITROGEN REMOVAL

FINLAND

Dr. Markku Mäkelä
National Board of Waters and the Environment

ABSTRACT

Present level of municipal wastewater treatment

The public sewerage systems serve 3.7 million people which corresponds to 74 % of the total population of Finland. The wastewaters of 1.7 million people are discharged to coastal waters.

Phosphorus is an important growth limiting factor for algae in all inland water bodies and coastal waters. As much as 99 % of municipal wastewaters is treated by applying chemical phosphorus removal, in most cases simultaneous precipitation, achieving 90 % reduction and concentration of less than 1 mg P/l as the weighted annual average values of all wastewaters. The total treatment results in inland and coastal areas are almost equal.

Nitrogen is also considered an important factor in algal growth in some areas, especially on the southern coast. So far, however, no requirements exist concerning total nitrogen removal. The best results have been achieved at nitrifying plants by utilizing denitrification in order to reduce running costs. There are some ten nitrification-denitrification plants with 50-60 % removal of nitrogen.

At present, slightly less than 500 tons of phosphorus and 15,000 tons of nitrogen are discharged annually to inland water bodies and coastal waters from the public sewers.

Future goals of nutrient removal

On 6 October 1988, the Finnish Council of State issued a decision-in-principle on a programme of objectives for water protection to

be achieved by 1995. In the programme, Finland's international commitments concerning the reduction of loading to the Baltic Sea and its Gulfs have been taken into account.

According to the programme, a treatment efficiency of at least 90 % in the removal of phosphorus is required on average. Removal of 95 % of phosphorus (corresponding to an effluent concentration of 0.3-0.5 mg P/l) is required when the receiving water body is of particular significance. As far as nitrogen is concerned, a feasibility study will be made into more effective nitrogen removal, particularly when the nitrogen load produces a significant increase in eutrophication. The required measures to improve nitrogen removal will be taken.

In practice, phosphorus removal will be further improved by proper operation and management of existing treatment plants. In 1995, the phosphorus concentration of all wastewaters, discharged from the public sewer systems, will be near 0,6 mg P/l as a weighted annual average value.

On the basis of the present plans, effective nitrogen removal should be adopted first in the largest communities on the southern coast. The preliminary target is about 70 % reduction within 10-15 years.

Research

A study on the need for nitrogen removal and a study on removal technology were initiated this year. Both projects are financed by the Ministry of the Environment and the National Board of Waters and the Environment.

As a first step of the study on the need for nitrogen removal, a compilation will be made during this year of the earlier studies on the effect of nitrogen on the eutrophication of coastal waters.

The study on nitrogen removal technology will last three years. Most of the earlier studies have primarily been based on the need to reduce the running costs of nitrifying plants by means of denitrification. At present, the most important case study on the removal of total nitrogen is carried out by the Helsinki city sewage works in co-operation with the Espoo city sewage works in order to find useful methods for nitrogen removal in the region of the capital where the wastewaters of 800 000 people are discharged to the Gulf of Finland.

NATIONAL REPORT ON RESEARCH AND DEVELOPMENT ON PHOSPHORUS AND NITROGEN REMOVAL

GERMAN DEMOCRATIC REPUBLIC

In pursuance of the Declaration on the Protection of the Marine Environment of the Baltic Sea Area adopted on 15 February 1988 on the occasion of the 9th Meeting of the Helsinki Commission as well as the Helcom Recommendation 9/2 concerning measures aimed at the reduction of discharges from urban areas by the use of effective methods in waste water treatment, the efforts undertaken by the GDR in the field of research and development related to the removal of P and N from municipal waste water have been intensified considerably taking into account likewise the values on limitations given in the documents referred to above and an optimization of economical necessities.

The position of the delegation of the GDR to the 9th Meeting of the Helsinki Commission regarding the state of affairs of the reduction of discharges of nutrients that had been already achieved by then and the targets of the GDR till 1990 formed the starting point for all national institutions involved now in research, development, design and construction, above all within the VEB Kombinat Wassertechnik und Projektierung Wasserwirtschaft and its partners in other areas of the national economy.

Long-term plans have been worked out to minimize the nutrient discharges, among them N and P into the water bodies bearing fully in mind the size of the national catchment area of the Baltic Sea which is approximately 22 000 km^2, i.e. 1/5 of the territory of the GDR. These plans being based on the Water Law of the GDR as adopted in 1982 and allowing for example the most recent stipulations regarding the conditions of discharges by industry, agriculture and urban areas are characterized by qualitative and quantitative limiting values; they demand to continue working on the basis of specific programmes on rational use of water and pollution abatement.

Prerequisits have been created to tackle the objectives of the Declaration and the recommendation 9/2 with regard to a further reduction of landbased pollution including Phosphorus and Nitrogen by likewise constructing, reconstructing or extending waste water treatment plants of the industry and the municipal sector; among them are new biological sewage treatment plants as in Neubrandenburg, Pasewalk, Kühlungsborn, Malchin-Stavenhagen, Güstrow, Altentreptow und Teterow.

Till 1995 additional 25 plants will be constructed respectively implementing the most progressive knowledge. The main project in this respect is the extension of the sewage treatment plant in Rostock in order to achieve there a reduction of waste load of 300 000 P.E..

Within the last 3 years results could be obtained in developing and successfully running the first sewage works with biological phosphorus removal. We consider this to be an interim solution on our way to a combined P- and N-removal. In order to accelerate the research and the development of the most modern technologies of a combined P- and N-removal in the GDR at present one examines carefully the direct applicability of internationally known technologies or their further development in accordance with the specific conditions on the spot including such problems as the environmentally-sound utilization of the sewage sludge.

It appears to be obvious that a close cooperation of all parties to the Helsinki Commission is to the best advantage to achieve the targets given concerning the removal of P and N. In this connection it is as well essential to make full use of all technological possibilities that are available at national level as to have access to any better solution of the other parties to the Commission, particularly in promoting the comprehensive employment of e.g. the most modern instrumentation and control systems, adjustable stirring devices and aerators and also computer-aided operation control.

Therefore, the GDR would like to profess its full support for the initiative of Finland to organise the Seminar on Nutrient Removal from Municipal Waste Water, 1989. We expect to receive important impulses and as many as possible relevant perceptions which will enable us to force the national projects in the interest of the Baltic Sea.

NATIONAL REPORT ON RESEARCH AND DEVELOPMENT ON PHOSPHORUS AND NITROGEN REMOVAL
POLAND

Prof. Paweł Błaszczyk
Institute of Environmental Protection

1 Decreasing of loads of biogenic compounds of nitrogen and phosphorus discharged to the Baltic Sea is one of very important resolutions of the Convention on the Protection of the Marine Environment of the Baltic Sea Area/Helsinki Convention/signed by Baltic States on 12th March 1974 and ratified by Poland in April 1977.

This resolution was described with full particulars among other with regard to municipal waste water in recommendations to the abovementioned Convention/Helcom Recommendations/.

Necessity of limitation of biogenic pollution loads was also underlined by co-signatory states of the Convention in “Declaration on the Protection of the Marine Environment of the Baltic Sea Area” signed in February 1989.

According to “First Baltic Sea Pollution Compilation” /Helsinki 1986/ from territory of Poland the biggest from Baltic States load of biogens and very big load of organic pollution are discharged. Essential part of this load comes from point sources: towns and settlements and industrial plants discharging waste water to Vistula and Odra rivers.

This is why limitation of these loads is very important with a view to protection of Baltic Sea against pollution being at the same time very important economic problem for Poland. Therefore introducing of high-effective processes and technologies of treatment enabling removal of biogenic compounds to level determined in Helcom Recommendations/1,5 gP/m^3, 15g N/m^3/ to Polish waste water treatment plants must be preceded by choice of the most appropriate technologies of treatment, motivated in respect of energy-consumption, material consumption index and economics of solutions.

Table 1

Compilation of loads after "First Baltic Sea Pollution Load Compilation", Helsinki 1986 and verified loads for Poland

Country	BOD,	Nitrogen /thous.T/year/	Phosphorus
Denmark	159,7	69,1	9,5
Finland	249,8	69,5	4,4
GDR	13,3	3,6	0,4
FRG	22,7	16,4	2,4
a/Poland	392,6	109,9	19,1
b/	358,4	231,8	18,0
Sweden	361,6	129,5	6,9
USSR	504,7	130,3	5,9

a/load after "First Baltic Sea Pollution Load Compilation"
b/verified load

Table 2

Compilation of pollution loads discharged to the Baltic Sea for 1 inhabitant

Country	**Number of inhabitants in Sea catchment area /mln/**	**BOD,**	**Nitrogen /kg/inhab. x year/**	**Phosphorus**
Denmark	4,041	39,5	17,1	2,35
Finland	4,512	55,4	15,4	0,98
GDR	2,072	6,4	1,7	0,19
FRG	1,101	20,6	14,9	2,18
Poland	39,700x/	9,0	5,8	0,45
Sweden	7,203	50,9	6,7	0,30
USSR	19,500	25,9	6,7	0,30

x/ including 0,6 from GDR and 0,97 from Czechoslovakia

2 In order to introduce into practice the most appropriate processes and technologies of removal of biogenic compounds from municipal and industrial waste water it was considered necessary to elaborate proper guidelines and principles of design on the base of research carried out in different scales including demonstration projects in pilot treatment plants. Ministry of Environmental Protection and Natural Resources charged Institute of Environmental Protection with this task/2/.

In 1988 "Technological guidelines of high-effective methods of waste water treatment" were elaborated in the Institute of Environmental Protection.

Aforenamed guidelines comprise:

- application of fluidized beds for denitrification of waste water,
- treatment of small quantities of waste water in ponds,
- application of ponds for removal of biogenic compounds,
- simultaneous precipitation of phosphorus in the most popular in Poland package treatment plants,
- application of filters for ultimate treatment of waste water.

It is foreseen that in 1990 this elaboration will be completed with a supplement containing guidelines concerning processes and technologies, which are now subjects of investigations of research institutes, universities and producers of equipment.

It should be noticed that processes and technologies recommended in elaboration of 1988 year and results of actually conducted research concern as well protection of the Baltic Sea against eutrophication and protection of the waters of lakes in Poland.

3 The object of investigations carried out in Poland in years 1986-90 is to evaluate new methods of removal of biogenic compounds in respect of technological effects of their application with utilization, for this aim, of available in Poland coagulants as well as ways and cost of their implementation /1/.

These research works are carried out in two main directions:

- removal of phosphorus from municipal waste water by methods of reacting substance with application of activated sludge or trickling filter as basic processes of treatment,

- removal of nitrogen and phosphorus from waste water by biological methods.

In a result of research with application of aluminium sulfate as reacting substance conducted on a pilot plant in large scale feeded with waste water from town agglomeration with composition characteristic for other Polish towns, it was found that the effect of phosphorus removal to the level determined in Helcom Recommendations can be achieved irrespective of the way of leading the process. The conditions are that the dose of aluminium sulfate is adjusted to pollution of waste water /molar ratio Al $/P \geq 2,3$ and full biological treatment is made. Application of filtration as final stage of treatment improves effects obtained.

Research including precipitation of phosphorus by application of $FeSO_4$ conducted in the same conditions as preceding and with dose $Fe/P \geq 2,3$ has shown that only methods of preliminary and simultaneous precipitation can be taken into consideration. Method of final precipitation cannot be used because of too little utilization of dosed reacting substance, which goes to outflow and cannot be eliminated from it even with application of filtration.

In a result of research including precipitation of phosphorus by lime applied only in final phase of the process of treatment it was shown that effects can be comparable with precipitation by aluminium sulfate or preliminary and simultaneous precipitation by iron salts but doses must be much bigger.

Quantities of sludge originating when salts of aluminium and iron were used, have been from 75 to 100 % greater than in the process of conventional activated sludge and when lime was used - even 2,5 times greater. Mixed sludge with participation of products of precipitation by iron can be dewatered well in comparison with mixture with content of aluminium.

It is considered that implementation of chemical precipitation of phosphorus should be carried on in an elastic way according to standards of protection of the receiver, means in disposition and local conditions.

As the first method - the less expensive and using up waste products /$FeSO_4$- preliminary and simultaneous precipitation by cheap and easily available in Poland $FeSO_4$ can be used. Examined in pilot implementations equipment for preparation and dosing of coagulants placed in mobile containers finds full employment in treatment plants from 10 to 15 thous.m^3/d/4/. As the demands, concerning standards of discharges exceeding actually recommendations of Helcom, grow-it is considered motivated to introduce additional final precipitation by aluminium sulfate and eventual filtration. However these solutions are expensive because of necessity of construction of additional objects for waste water treatment and processing of difficult in treatment sludge.

In a result of research on chemical precipitation of phosphorus in treatment plants with trickling filters it was found that the best effects of process are obtained when the dose is devided into two points of dosage: ahead of the filter and after the filter. The bigger dose of $FeSO_4$ before the filter -the greater effects of phosphorus removal in the filter. Yet the danger of silting up the filter does not allow to direct the whole dose before the filter. It was determined the most proper division of the dose: 60 % of $FeSO_4$ before filter and 40 % after filter /5/.

Unfortunately in treatment plants with trickling filters it was not succeeded to achieve standards of Helcom in the runoff even with doses reaching Fe/P = 2,3. Maximal effect of precipitation was not higher than 1,9 gP/m^3 of waste water in the discharge of the treatment plant.

Presence of iron compounds in outflow creates also a limitation of this technology.

Research on removal of nitrogen compounds from waste water was undertaken first of all in connexion with the process of low loaded activated sludge and prolongated aeration, especially widespread in Poland in treatment plants of medium size. In this process integration of removal of carbon, nitrogen and phosphorus from waste water by creating alternating aerobic and anaerobic conditions was achieved /6/.

In this technology 90 % removal of ammonia nitrogen and total nitrogen and 60-80 % limitation of BOD, and phosphorus compounds can be achieved. Common changes of carbon, nitrogen and phosphorus consist in simultaneous oxidation of carbon, processes of nitrification and denitrification and fixing the phosphorus under biological way in combination with biosorption and sorption, intensification of which was following transition from anaerobic to aerobic zone. Process of removal of phosphorus goes better if the relation of BOD, to P in waste water conveyed to treatment plant is higher. Course of process depends very much on the temperature. When temperature comes down to 1 O-l 2°C speed of nitrification deminishes by 50 % and speed of denitrification by 80 %.

Parameters of chambers for anaerobic zones are determined as follows:

Anaerobic chamber:

- retention time: 2 h,
- recirculation : 200 %
- content of oxygen dissolved in chamber: 0 g O_2/m^3.

Aeration chamber:

- retention time: 6-7 h,
- loading of activated sludge: 0,1-0,2 kg BOD_5/kg,d,
- content of oxygen dissolved: 2 g O_2/m^3.

Zone of secondary denitrification:

- working periodically: capacity of chamber = 20 % of capacity of aeration chamber,
- content of oxygen dissolved below 0,5-0,8 g O_2/m^3,
- secondary settling tank with retention time at least 2 h.

Obtaining of high effectiveness of the process in winter is conditioned by isolation of the system of treatment plant from the exterior.

Discussed research works which have been conducted in pilot scale are being verified now in full technical scale in small treatment plants and in plants with flow capacity 20 thous.m^3/d.

Also conducted is research concerning optimization of process of nitrogen and phosphorus compounds removal by activated sludge method in multiphase reactors including combination of biological and chemical methods.

Criteria of optimization are: effectiveness of process, energy consumption and expenditure of money for construction and exploitation of objects /7,8/.

It is foreseen that results of these research will find application in construction of biological part of treatment plant Gdansk-East and modernization of treatment plant in Cracow.

The results of research which have been obtained hitherto create sufficient base to implement in engineering practice the technologies prepared for Polish conditions.

The basic obstacles in implementation conducted on a large scale in municipal waste water treatment plants are economic conditions of the country, lack of financial means for investments in budgets of local authorities and in water supply and sewerage companies dealing with exploitation of sewerage systems in towns.

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NATIONAL REPORT ON RESEARCH AND DEVELOPMENT ON PHOSPHORUS AND NITROGEN REMOVAL

SWEDEN

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The National Swedish Environment Protection Board

Summary

The research and development work in Sweden concerning nitrogen reduction is for the most part conducted at wastewater treatment plants. From 1988 to 1991 municipalities will be investing at least SEK 70 million in nitrogen projects, of which a minimum of SEK 25 million represents follow-up and evaluation costs. Research carried out at universities and institutes of higher education directed at process technology turns over something like SEK 2-3 million per year. The Swedish research and development work on nitrogen reduction is at present entirely focused on biological processes.

Background

In June 1988, the Swedish Parliament decided that treatment plants which discharge into certain coastal areas that are particularly sensitive to pollution should have at least 50 % nitrogen reduction ($<$ 15 mg N/l) by 1992 at the latest. The ambition shall also be that treatment plants with discharges to other coastal areas from Strömstad (the Norwegian border) up to and including the Stockholm archipelago should have the same degree of nitrogen reduction before the year 1995. Certain inland treatment plants may also be affected by these requirements. The technical and economic preconditions for additional nitrogen reduction up to about 75 % ($<$ 8 mg N/l) shall be investigated.

The treatment plants at Laholm Bay on the south-west coast of Sweden is covered by a special Government decision which means that the ambition shall be to achieve approximately 75 % nitrogen reduction by 1992 at the latest.

An updated review is currently being made at the Environment Protection Board of the sources of nutrient salt loads on coastal regions and what measures it is possible to take in order to reduce the loads. This work will probably not lead to any changes in the above level of ambition with regard to nitrogen reduction at municipal wastewater treatment plants. On the other hand, it can be expected that the phosphorous requirements will be made more stringent for the large coastally-based plants so that discharges in the future may be at the most **0,3** mg of total phosphorus per litre in the discharge.

Targets for the research and development work

On the basis of the attitudes adopted by politicians and authorities, we can distinguish a number of requirement levels that research and development work must be directed at during the immediate future. The various requirement levels are shown in Table 1.

Table 1. Requirements to be met by the discharge from Swedish treatment plants

	Nitrogen mg tot-N/l	Phosphorus mg tot-P/l	**BOD7 mg/l**	Treatment plant size **pe**
i	**<15**	co.5	cl5	10 000-50 000
ii	**<15**	co.3	**<15**	**>50** 000
iii	< 8	co.5	**<15**	10 000-50 000
iv	**< 8**	co.3	**<15**	**>50** 000

Each of the four requirement levels may lead to a special strategy for how the tasks are to be solved from the point of view of process engineering, Another factor that is also of crucial importance is, of course, the design of and load on each individual treatment plant today. It should be an overriding goal for the requirements to be met at as low a cost as possible.

Research and development work at treatment plants

With the Government decision regarding Laholm Bay and the National Environment Protection Board's action plan against sea pollution in Spring 1987, it became clear to the municipalities that requirements for nitrogen reduction in treatment plants could be imposed within the very near future.

Extensive activity commenced among municipalities in connection with planning nitrogen experiments at the same time as demands were made for government support. Today, some 30 full-scale projects are in progress, six of which have received support from the Environment Protection Board.

All of the projects involve biological nitrogen reduction. The objectives vary, but most of them are directed in the first instance at achieving a 50 % nitrogen reduction. Four of the five projects with government support shall, however, investigate the technical and economic preconditions of achieving 80 % nitrogen reduction.

The systems for biological nitrogen reduction that are being studied are:

- Activated sludge, pre-denitrification, 1- sludge systems.
- Activated sludge, post-denitrification, 1- or 2- sludge systems.
- Trickling filter, pre-denitrification, 1- or 2- sludge systems.
- Trickling filter, post-denitrification, 1- or 2- sludge systems.
- The SBR system.

A large part of the work involves the adaptation of known technology to Swedish treatment plants and Swedish conditions. However, as a whole the municipal projects represent an extensive volume of development work with features of research.

With the aim of optimizing the system with regard both to economic and operational factors, special studies of varying extent and quality are being conducted at the plants. The most extensive studies are being made within the following areas:

- Nitrogen reduction in separate reject water treatment stages.
- Different internal and external carbon sources during denitrification.

- Optimization of the anoxic-aerated zone ratio.
- The importance of pre-treatment for the nitrification and denitrification processes.
- Control, regulation and instrumentation of the nitrogen process.
- Factors that influence sludge properties.
- Fixed bed processes.
- New types of aerators.

The costs for a full-scale experiment are in many cases difficult to determine because certain costs cannot be distinguished from the normal operating costs. Table 2 shows a budget for the six projects that have received government support.

Table 2. Costs for nitrogen reduction experiments with Government support.

Treatment plant	Gov.grant SEK M	Follow-upcost SEK M	Total cost SEK M
Malmö	2.0	2.0	6.0
Halmstad	4.4	2.3	13.2
Laholm	1.35	1.2	2.7
Karlskrona	1.25	1.7	4.1
Norrköping	0.7	2.4	3.1
Käppala	1.32	1.4	4.4
Total	11.0	11.0	34.5

The total cost of these six projects is thus SEK 34 million and the follow-up cost approximately a third, or SEK 11.0 million.

On the basis of these figures, it can be estimated that from 1988 to 1991 Swedish treatment plants will spend at least SEK 70 million in nitrogen reduction experiments. The proportion that is utilized for follow-up and evaluation of the experiments is at least SEK 25 million.

Research at Swedish universities and institutes of higher education in the field of water supply and sewerage

For many years, only a limited amount of research work has been carried out at Swedish universities and institutes of higher education on water supply and sewerage, with a focus on process technology. However, there has been an increase in recent years, primarily as a result of the cooperation that has been established between municipalities and universities/institutes. There are at present at least five research students at different universities and institutes who are in some way linked with the experimental work being carried out at a treatment plant, three of whom with a direct focus on nitrogen reduction.

A list is given below of those research projects of a more traditional character, having a direct or indirect link with nitrogen and phosphorus reduction, that are either in progress or to be started shortly:

- Optimization of l-sludge systems for biological nitrogen reduction with the aid of added organic matter (Chalmers University of Technology (CTH), Gothenburg and the Royal Institute of Technology, Stockholm (KTH)).

- Nitrogen reduction in the reject water. (KTH)

- Improvement of sludge properties in order to permit biological nitrogen reduction in existing wastewater treatment plants. (KTH)

- Studies of the connection between sludge properties and discharges of suspended solids from the activated sludge process. (YK1)

- Secondary settler dynamics for controlling the activated sludge process. (CTH)

- Modular model systems for the simulation and regulation of treatment plants (Lund Institute of Technology (LTH)).

- Biological phosphorus removal. (LTH)
- Biological phosphorus removal with the SBR process. (Lulea)

Funds for research carried out at universities and institutes of higher education are granted in the first instance by the National Board for Technical Development (STU). The subsidy that is principally used for this purpose is for the current year SEK 1.3 million. A special one-off subsidy of some SEK 2 million is this year and next year being allocated for research directed towards nutrient salt reduction at municipal treatment plants.

The Nitrogen Project

In Sweden there is also a scheme referred to as "The Nitrogen Project", which is financed jointly by the Swedish Water and Wastewater Works'Association (VAV), the National Environment Protection Board (SNV) and STU. The budget is SEK 1.8 million over a three-year period and the objectives of the project are:

- To initiate and coordinate municipal nitrogen projects through advisory services and by collecting, processing and spreading information from full-scale experiments for nitrogen reduction at Swedish treatment plants.

- To produce basic data on which to base continued technical development.

The project board includes representatives of VAV, SNV and STU. The project management consists of representatives of VAV and SNV.

The project has no power to allocate funds, but the project management can be said to function as a body to which proposed measures are submitted for comment in connection with both applications for Government support for full-scale experiments and applications for research grants from STU.

The project’s own funds will in the first instance be used for the compilation and distribution of experience from the research work carried out by the municipalities.

PHOSPHORUS REMOVAL TECHNOLOGY OF MUNICIPAL WASTE WATER TREATMENT

USSR
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In the USSR the most popular method of municipal waste water treatment is traditional biological treatment. The method allows removal of basic pollutants, but it does not provide sufficient phosphorous removal compared with present more stringent requirements. Of course population growth and the more extensive use of washing agents in every day life inevitably lead to excess phosphorus concentrations in municipal waste water. This is why USSR Municipal Water Supply and Treatment Research Institute has during several years carried out experiments to identify methods of phosphorus removal from municipal waste water. First of all, attention has been paid on application of reagents at biological treatment plants as the most simple technology to be used on the plants. Preliminary results obtained from the investigations have been reported in a seminar held in Sweden/l/. The investigations indicated that the dose of iron vitriol, while introduced into the aeration tank, should be limited to avoid the negative influence of the reagent on biological treatment in the aeration tank. Moreover the MLSS in the aeration tank should be kept on a higher level than usual. The required dosages of reagent depend on the quantity of organic matter in treated water, the phosphorus concentration in the raw water and the quality criteria of effluent phosphorus concentration.

The effluent phosphorus concentration 1,5 mg P/l recommended by HELCOM in the Baltic Sea catchment area was reached within the applicable range of reagent dosages. The investigations were continued and further developed in semi full-scale conditions at a waste water treatment plant in Tikhvin in the Leningrad area. /2/. The experiments were carried out in an independent waste water treatment line side by side with the main line of the waste water treatment facilities of the town. The capacity of the experimental plant was 4 500 m^3/day. The experimental line contains two sand traps of 2 m diameter with circular water flow, a vertical primary clarifier of 10 m diameter, an aeration tank with three compartments (length 63, width 5,2 and construction height 3 m) and two vertical secondary clarifiers of 10 m diameter. One similar clarifier was equipped with air and technical water supply in order to prepare reagent solution. The solution was made of standard pure aluminum sulphate which is used in water treatment.

Based on average daily observations of influent to the aeration tank the waste water had following characteristics: BOD 100-120 mg/l, COD 200-300 mg/l, suspended solids SS 100-150 mg/l, total phosphorus 5-7 mg P/l, phosphates 2-3 mg P/l.

Before the experiments on biological-chemical treatment aeration was put into operation with the following aeration basin parameters: MLSS 3 g/l, activated sludge load of organic matter 100 mg BOD/-g/day, sludge index 200 - 225 cm^3/g and sludge ash content 33-34 %. The removal of organic matter was very effective and total phosphorus was removed by 40 %.

The concentration of phosphates was practically not changed. Simultaneously effective nitrification took place accompanied by discharge of gas bubbles in secondary clarifiers. The result was an increase of suspended solids concentration in the effluent and frequent discharge of secondary sludge from secondary clarifiers. So the prerequisites of effective biological treatment were established resulting in a sufficiently high degree of purification including nitrification and non stabilized operation of secondary clarifiers.

As soon as the reagent was introduced to the aeration tank the discharge of secondary activated sludge stopped in spite of gas bubbling. At that time the ash content of sludge was up to 39-41 % due to addition of insoluble compounds. Also sludge return flow was increased. The changes of activated sludge properties led to better sedimentation of sludge and the consequent improvement of secondary clarifier operation. In spite of the increased MLSS up to 4 - 5 g/l the active sludge was trapped in the infiltration zone of secondary clarifiers and the whole system of biological treatment operated in a stable manner.

However, turbidity due to small flocks occurred. The presence of created sludge flocks was also revealed by a suspended solids concentration of 20 - 35 mg/l in the effluent which exceeds the permissible level of biological treatment plant effluents. That is why the experimental treatment line was equipped with an additional tank for preparation and metering of polyacrylamide (PAA) flocculant. A 0,5 - 1 mg/l PAA dose simultaneously with a 20 mg/l reagent dose provided a stable 12 - 17 mg/l concentration of suspended matters in the effluent which is in line with the quality requirements of treated water on suspended matters.

Biological-chemical treatment with addition of aluminum sulphate provided a 75 per cent and 90 per cent removal efficiency of phosphates with reagent doses of 9 and 14 mg/l (AL_2O_3) respectively. A dose of 16-17 mg/l increased the removal of phosphates to 95 per cent as the residual phosphate concentrations were reduced to 0,1-0,2 mg/l. Total phosphate removal depends on reagent dose and presence of suspended matter in treated water. The concentration of total phosphorus was reduced by 75-80 per cent with a 16-17 mg/l (AL_2O_3) aluminum sulphate dose and the content of suspended matters in treated water was 12-17 mg/l. Without changing the operation parameters of aeration tanks but with a 30-35 mg/l concentration of suspended matter in the effluent, total phosphorus removal was reduced to 50 per cent.

The modified biological treatment with alternating aerobic and anaerobic conditions in the sludge provides a possibility to reduce the required quantity of reagents or to even eliminate their use completely. One of the possible technologies of effective phosphorus removal is to use traditional biological treatment facilities. Biological sludge from secondary clarifiers is exposed to anaerobic treatment in special tanks. After that the sludge is returned to aeration where it provides effective phosphorus removal from waste water.

Some facilities of the above mentioned technology have been tested in the Municipal Water Supply and Treatment Research Institute including contact and flowing conditions in pilot and full scale plants. /3/. Activated sludges from various modes of biological treatment were tested for their ability to release soluble phosphates. The tests were carried out in 75 mm diameter 1,5 m high glass columns allowing the possibility to take samples along the columns to analysis. The modes of operation were extended aeration, heavily loaded activated sludge process including reduced aeration periods and separation of sludge mixtures by gravity and flotation and thickening and, finally, the nitrification-denitrification process.

The phosphate release intensity was found to vary depending on sludge type. It was connected with different oxygen conditions of waste water treatment process and also with the availability of combined oxygen in nitrates in the system. The most considerable phosphate release was found with sludges of highly loaded treatment with gravity thickening and the smallest with sludges from the nitrification-denitrification process. The increase of phosphate concentration took place only in the sludge compaction zone. The clear water preserves its initial phosphorus contamination. When mixed the phosphate concentration is even in the total volume. During further settling the phosphate release is going on in the sludge compaction zone.

The method of biological waste water treatment with alternating aerobic and aerobic conditions of sludge has been studied in laboratory pilot plants. Preliminary settled sludge mixture was taken from an aeration tank in operation and poured into a laboratory tank. Treated waste water was added to the same tank. The mixture was aerated for 4 hours, then it was allowed to settle for 2 hours. Supernatant was decanted and the sludge was left in peace until it was released. Next morning all consecutive actions were repeated. The aim of the investigations was to reach an elevated phosphorus removal effect. The experiment went on continuously for two weeks.

As a result phosphorus removal increased during the first seven days from 0 to 55 per cent. Then the process became stable and the phosphorus removal remained on the level of 60 per cent.

Technical parameters of aerobic-anaerobic biological treatment of waste water with effective phosphorus removal were investigated also in a small full-scale plant. The plant consisted of a distribution tank providing a possibility to regulate the incoming flow of waste water, an aeration tank and a secondary clarifier and a tank for phosphate release. Sludge was pumped with airlifts. Sludge recycled from the secondary clarifier was directed to the phosphate release tank and then returned back to the aeration tank. The plant was operated on real waste water with the following characteristics: BOD 60-120 mg/l, COD 170-235 mg/l, total phosphorus (PO^{3-}_4) 10-23 mg/l, phosphates PO^{3-}_4 5-22 mg/l, ammonium salt 17-34 mg/l.

Technical evaluation of phosphorus removal was done based on the following parameters characterizing the operation -of single units

Waste water flow 0,6-3,7 m^3/hour
Sludge MLSS in the aeration tank 1,6-6,7 g/l
Sludge load 115-7 13 mg BOD/g sludge a day
Aeration period 1,6-4,6 hours
Sedimentation period in secondary
clarifier, 5-2,0 hours
Release periods of phosphate 2,2-6,5 hours

The results of phosphate release from the sludge in the aerobic zone showed that the efficiency of the process is characterized with two parameters: time of phosphate release and organic load of sludge. The last parameter determines the availability of combined oxygen in the system and controlled degree of treatment on BOD. Within an increased period of phosphate release in studied conditions the efficiency of total phosphorus removal was elevated from 40 to 80 per cent.

Change of period of phosphate release had an influence on the efficiency of ammonification and nitrification processes in the aeration tanks. Within an increased period of sludge detention in the aerobic zone and under similar loads on active sludge, removal of ammonia was poor with consequently smaller formation of nitrates.

With a 6 hour period of phosphate release and with a low load of aeration close to complete oxidation there was no release of phosphate in aerobic conditions and there was practically no phosphate removal in the aeration tank. Total phosphorus removal was not more than 40 per cent.

Relatively stable and higher total phosphorus removal of 72-86 per cent, and phosphates on average of 85 per cent, have been reached with a 6 hour release period with heavily loaded aeration and without nitrates in treated water. However, under these circumstances removal of organic matter was found to be inadequate or even poor compared with traditional biological treatment.

With average loads the quality of effluent was as follows: BOD 10-15 mg/l and COD 35-60 mg/l, content of suspended matters 24-28 mg/l, NO, 0,1 mg/l, NH, 14-17 mg/l. In these conditions a very high quality effluent was produced regarding phosphorus (2,5-4,0 mg/l, total phosphorus removal was about 80 per cent) and the content of phosphates in treated water was 0,2-0,5 mg/l, (removal efficiency 90-97 per cent).

The technical parameters of the experimental plant applying the above mentioned conditions have been adopted as the basic design principles of an experimental full scale plant project in order to carry out further investigations on biological phosphorus removal.

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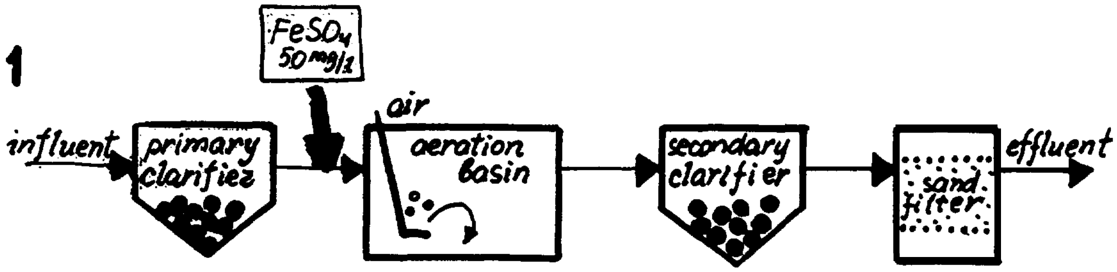
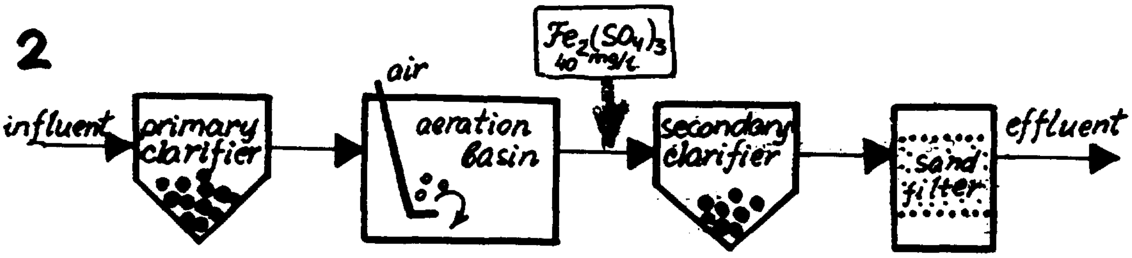
Mineral addition in biological treatment process

1



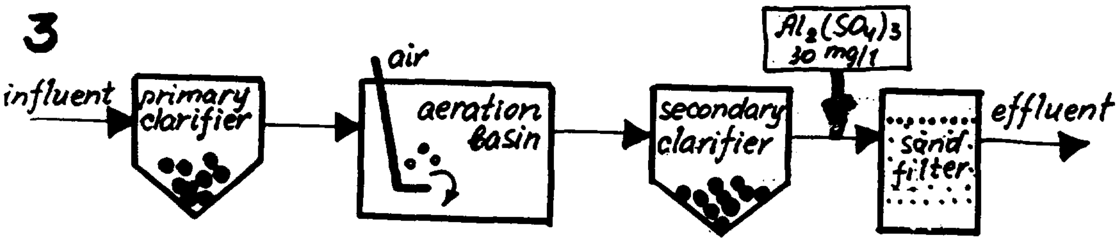
BOD, mg/l	150	10-15	3,5
SS, mg/l	120	10	2,0
Tot P-P, mg/l	6	0,8	0,6
Ortophosphate-P, mg/l	3	0,1	0,1

2



BOD, mg/l	150	10	2,5
SS, mg/l	120	10-20	2,0
Tot P-P, mg/l	6	1,0	0,7
Ortophosphate	3	0,3	0,3

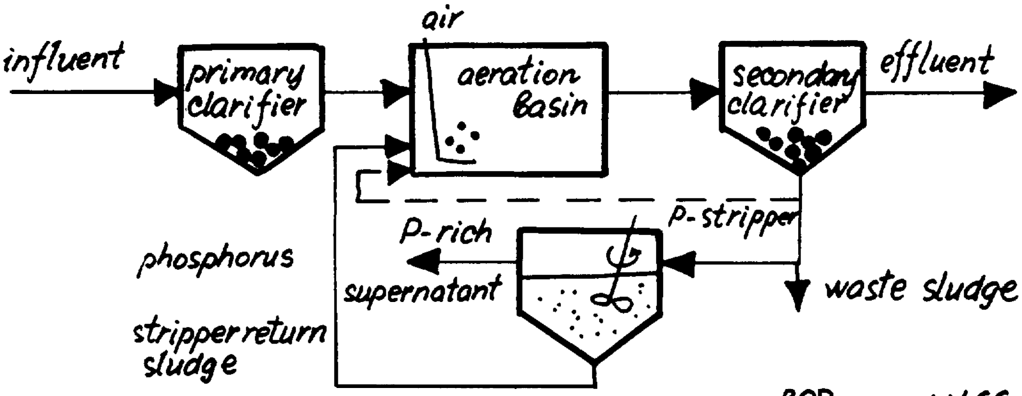
3



BOD, mg/l	150	10	1,0-1,5
SS, mg/l	120	10-15	<10
Tot P-P, mg/l	6	2,5-3	0,5
Ortophosphate, mg/l	3	2	0,2-0,3

Nutrient removal in biological treatment processes

■ Phosphorus removal



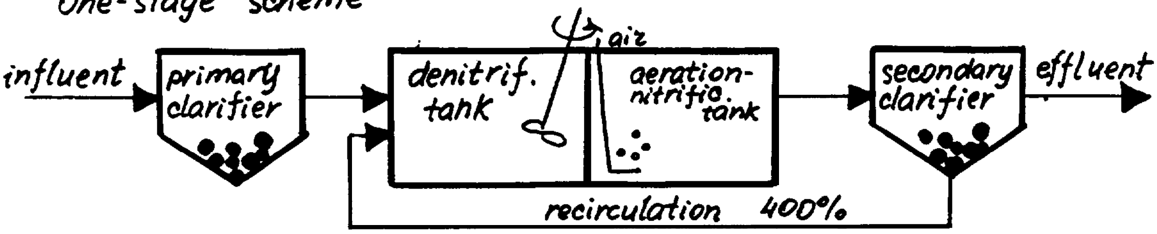
Parameters: P-stripper 6-9 hours, F/M 250 $\frac{mg\ BOD}{g\ MLSS\ day}$, MLSS ~ 3 g/l

Influent BOD 150 mg/l, COD 250 mg/l,
total phosphorus as P 6 mg/l,
ortophosphate as P 2 mg/l

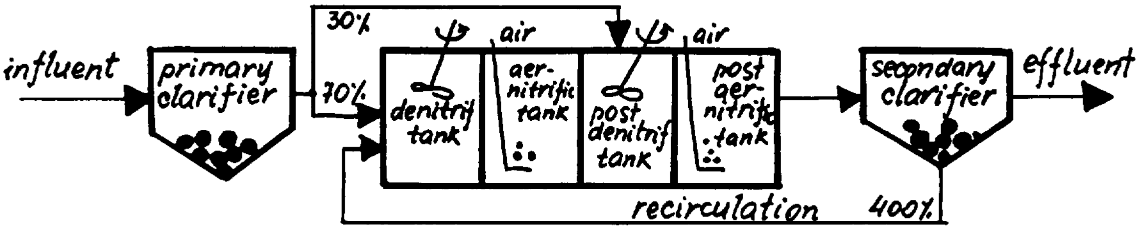
Effluent BOD 12-15 mg/l, COD 35-60 mg/l, total phosphorus 0,8-1,2 mg/l
ortophosphate 0,1-0,2 mg/l

■ Nitrogen removal

One-stage scheme



Combined scheme



Parameters $t_{nitrif} + t_{den} =$ (one-stage scheme)
$t_{nitrif} + t_{den} =$ (combined scheme)

Effluent BOD 10-12,5 mg/l, COD 40-50 mg/l, NH_4^+-N - 2 mg/l
NO_3^--N 8-10 mg/l (one-stage scheme)
NO_3^--N 6 mg/l (combined scheme)

MEASURES USED IN NUTRIENT REMOVAL FROM WASTE WATERS IN ESTONIA

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In the 60ies, certain principles were agreed upon in Estonia for initial measures to be taken concerning the processing of waste waters and their discharge to water bodies. Scientific research was started on the pollution of sea and rivers and their self-purification. A worldwide practice assumes that sea water bodies apparently have huge reception capacity of only partially treated waste waters. This assumption has often been adopted by big enterprises and cities.

In the long run such pollution loads grew, due to big industrial enterprises favored in our country, to such dimensions that they damaged the self-purification ability of water bodies. The importance of nutrients increased inevitably. It has been shown that the main origin of nutrients is agriculture (washed out mineral fertilizers and liquid manure of highly concentrated big farms). All this has caused the critical state of eutrophication of the Gulf of Riga and Pärnu, Vainamere and Peipsi Lake. Big industries have turned several rivers into sewage channels (North-East Estonia).[1]

The first unique and substantial measures to be used in Estonia were, by 1975, two 3 km long sea outfall lines for sewage. At first mechanical treatment was considered sufficient to maintain the self-purification ability of big water bodies (i.e. Pärnu and Tallinn). A third similar sea outfall was put into operation by the end of year 1988 in Kohtla-Järve industrial center where previously a 2-step biological treatment plant had been constructed. Biological treatment has been in operation for 20 years in the town of Narva where waste waters flow into the Gulf of Finland via the big river (earlier important for fishing industry). The plant is overloaded.

The Convention on the Protection of the Marine Environment of the Baltic Sea signed in Helsinki in 1974 considerably enhanced water protection measures in Estonia. From 1976 up to 1986 water protection measures amounted to 156 mil. rubles in Estonia. Over 800 medium size or small treatment units of altogether 1.5 mil. m^3

capacity per day were put in operation in the republic. The intention is to enlarge the existing treatment plants of Tallinn. Kuressaare and Pärnu by chemical-biological stages. The last two ones are subject to specific processing due to meat and dairy industries which cause high nutrient concentrations and loads in the waste water.

At present a new biological treatment plant is under construction in Tartu, our university town, (75 000 m^3/per day), in Kuressaare, Saaremaa's capital, in a district in Viljandi and in the town of Rakvere (in collaboration with the impressive pollution role of the new meat combinate)(Fig. 1). An extension is expected together with an improvement in purification in the treatment equipment of Narva District (up to 140 000 m^3/day) and Kohtla-Järve District's industrial center (up to 110 000 m^3/day) and the biological treatment facilities of Vöru, Pölva, Paide and Haapsalu (each of them up to 10 000 m^3/day) where dairy waste waters are dominating.[8]

In all these locations the waste waters have high nutrient content and nutrient removal is thus envisaged, at the author's initiative, only at 4-5 biggest plants. [1,5]

On the whole, as in Scandinavia, Estonia has dealt with the removal of phosphorus for more than ten years. Reagent methods were introduced with the aid of Moscow in Tallinn in 1985 (when ferrous chloride dosage was 120-150 mg/l) and planned for Tartu, Pärnu and Narva and by our Finnish colleagues (by turn-key delivery) to Rakvere. Ferrous chloride dosage has been envisaged after biological treatment as post-coagulation with a dosage up to 15 mg/l. Scientists at Tallinn Technical University have introduced a biological method of phosphorus removal (anaerobic zone) which has proved very promising. Besides, since the phosphate concentration is relatively low in Tallinn, one should consider replacing the use of reagents by other methods.181

Scientists have shown that water eutrophication cannot be completely avoided by removal of phosphates from waste waters (even up to 0.5 - 1.0 mg/l). It is also necessary to reduce nitrogen compounds which is very expensive. [2] Total nitrogen removal should according to HELCOM recommendations be achieved with special treatment down to the level of 15 mg/l and scientific studies made during three years to find out the practical possibilities of nitrogen removal down to the level of 12 or 8 mg/l. On the author's initiative, such a goal has been set in the uppgraded treatment plants in Parnu (since 1984, 30 000 m^3/day)(Fig. 2) and Kuressaare (since 1989, 6 000 m^3/day, Fig. 3). In the new treatment plant in Narva it is planned (to reach 140 000) to be constructed in 1990. The Moscow Communal Academy is engaged in this research. Several scientists and the author of this paper drafted recently regulations for settling the water treatment plant issue in Kohtla-Jarve (50 % is made up by urban waste water). The proposal envisages biological treatment of industrial waste water, where local phenol removal has been carried out, in parallel with a municipal water treatment line. Both lines should have nitrogen removal by nitrification-denitrification. The latter will test this method in the near future in the 1st section (Fig. 4)(in Parnu in full scale).

Successful application of the above mentioned method makes use of mechanical mixing equipment. As such equipment is not manufactured in our country, we drafted in 1988 an agreement on joint collaboration with the Swedish company "Flygt" for testing unique submersible mixers and for more extensive deliveries to the first objects (in Parnu, Kuressaare, Kohtla-Jarve etc.). The Estonian SSR Ministry of Communal Services signed this agreement. The applicability of the given method and mixers to remove nitrogen and phosphorus was tested in a model state farm named after J. Gagarin and in EKSEKO pig farm's liquid manure handling plant, where the author tried to introduce this method for the first time in the USSR (taking as an example the urban waste water treatment). Later on the contribution of VODGEO scientists helped to achieve even better results. After manure decanting by reagent method and one-stage primary anoxic zone with the Menzel circulation system the content of ammonia in aeration tanks was reduced from 1500 mg/l to 10-20 mg/l.(Fig. 5). Yet the final content of nitrates stayed over 50-100 mg/l in denitrification because of insufficient organic matter, Ten submersible mixers of the company "Flygt" were used, with a pitch diameter of 60 cm ($N = 13{,}5$ kW). The results can be considered fairly good since it is so difficult to treat such waste waters.

While expanding treatment equipment in Narva and Kohtla-Järve, we are planning to introduce analogous Menchel-type circulation aeration tank where the water flow (velocity being 0.4-0.5 m/s) will be created by the company's "Flygt" multidimensional and low-gear pitch flow makers.(Fig. 6). It helps to save electrical energy to a great extent which is a must at that locality. Here the anoxic zone with a low oxygen content environment will be created in the reactor's inner circular channel which receives raw water together with recycling activated sludge from final sedimentation basin. The first such reactor tank will be constructed for this purpose in the town of Rakvere for their water treatment complex (20 000 m^3/day). Additional savings of electrical energy will be achieved by recirculation from the outer circular corridor into the inner one which will noticeably reduce the pumping energy via the final sedimentation basin. I think that in such a way the existing aeration tanks, when being reconstructed, should be applicable in the new treatment process (extensive experience in Sweden), but using the Flygt low head PP-mixers for inner recirculation.

As far as small types of treatment plants are concerned, the Tallinn Technical University has tried to test the anoxic-aerobic method (using the example of Denmark).[7]. The system seems to have reached perfection, thanks also to the consulting company "VIAK" in Sweden. We would very much welcome joint collaboration with this company!

Collaboration on a consultation basis has started with the Danish company “Kruger” for the adjustment of the real “Danish invention”, on the author's initiative, in Pärnu sewerage works and in EKSEKO plant (treating pig manure, were denitrification was solved by me more economically) (Fig. 5).

We hope that this joint venture will also form a foundation for manufacturing some equipment jointly (cap aerators, jet aerators, submersible mixers). This would make it possible first of all to deliver such equipment to Estonia and other Baltic countries in order to guarantee the necessary treatment measures for the protection of the Baltic Sea (nitrogen removal has become increasingly important). The companies "Flygt", "VIAK" (prefers jet aerators and SB reactors) and "Seikone OY" (using bio-rotors technology) have proposed scientific-technical and manufacturing cooperation to enhance modern waste water treatment in small Estonian treatment plants. As far as dewatered sludge handling is concerned, one Finnish company has proposed an idea (of Japanese origin) of joint manufacturing of cornposting mixers. We also have technical cooperation with the company “Humboldt” in the field of centrifuges (a. ACM), started 10 years ago.

The above mentioned joint ventures will assist us in reaching the environmental protection goals to be introduced in our IME ("Self-supporting Estonia” -program). At the same time we hope to guarantee, in collaboration with others states, protection of the Baltic Sea from anthropogenic violence. With the described measures Estonia can by 1995 contribute in reducing the pollution load of industries and municipalities to the Baltic Sea. Thus the Estonian share of the entire load might be as follows: organic - 13 %: nitrogen-12 %; phosphorus - 9-10 %. These figures are significant when we consider the fact that we are a very small republic with the population of a million.

The author’s opinion is that the attitudes towards consideration of “sewage treatment plant or deep-sea outfalls” have changed also due to technical-economical motivations. Therefore we should always abandon the idea of erecting expensive sea outfalls. Instead, resources should be directed to effective waste water treatment in order to protect eutrophication of the coastal areas of the sea and to avoid overloading of the sea with nutrients.(Fig. 7).

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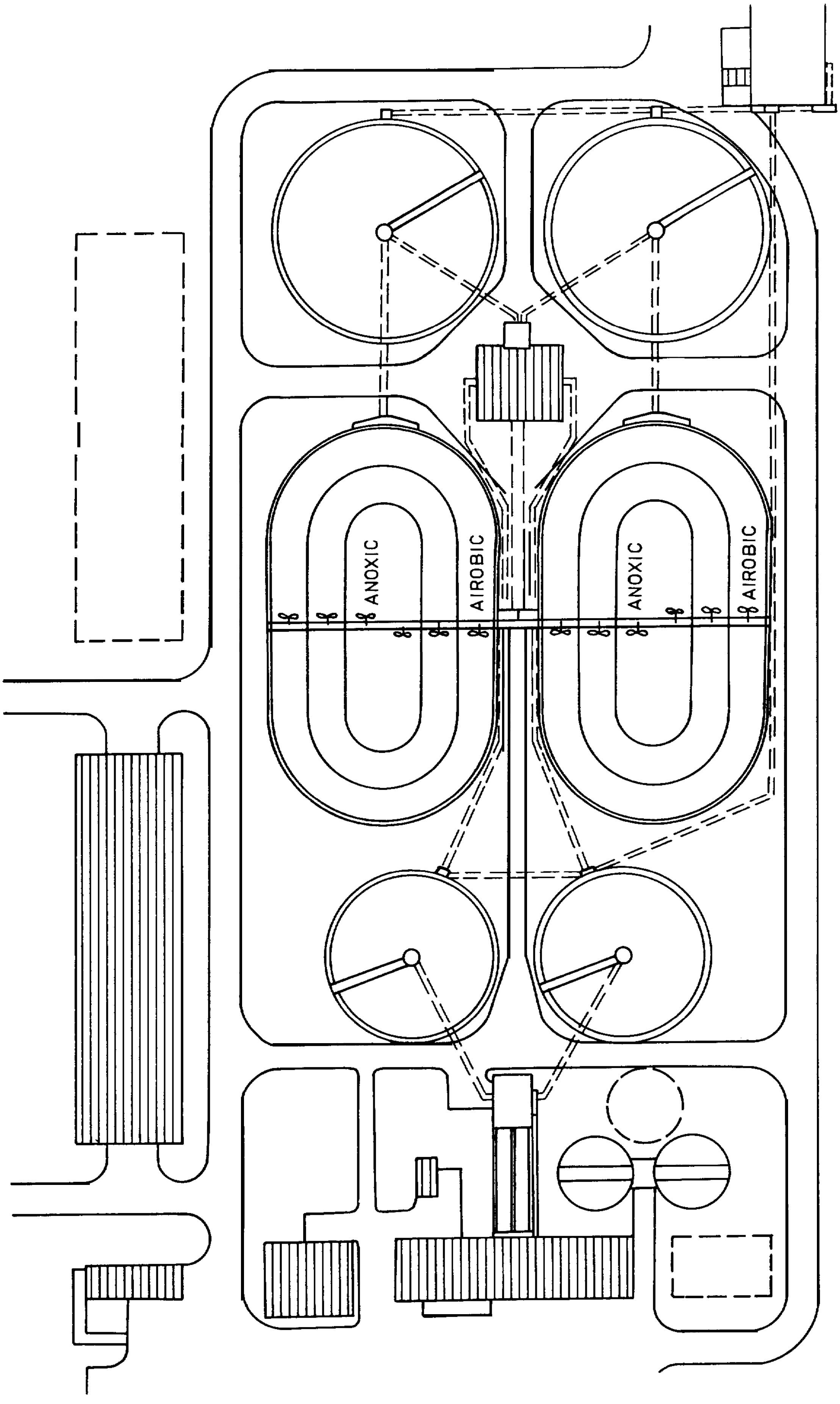


Fig.1 MENZEL AEROTANKS IN RAKVEREPLANT

2-STEP BARDENFO OR BIO-DENITRO PROCESS

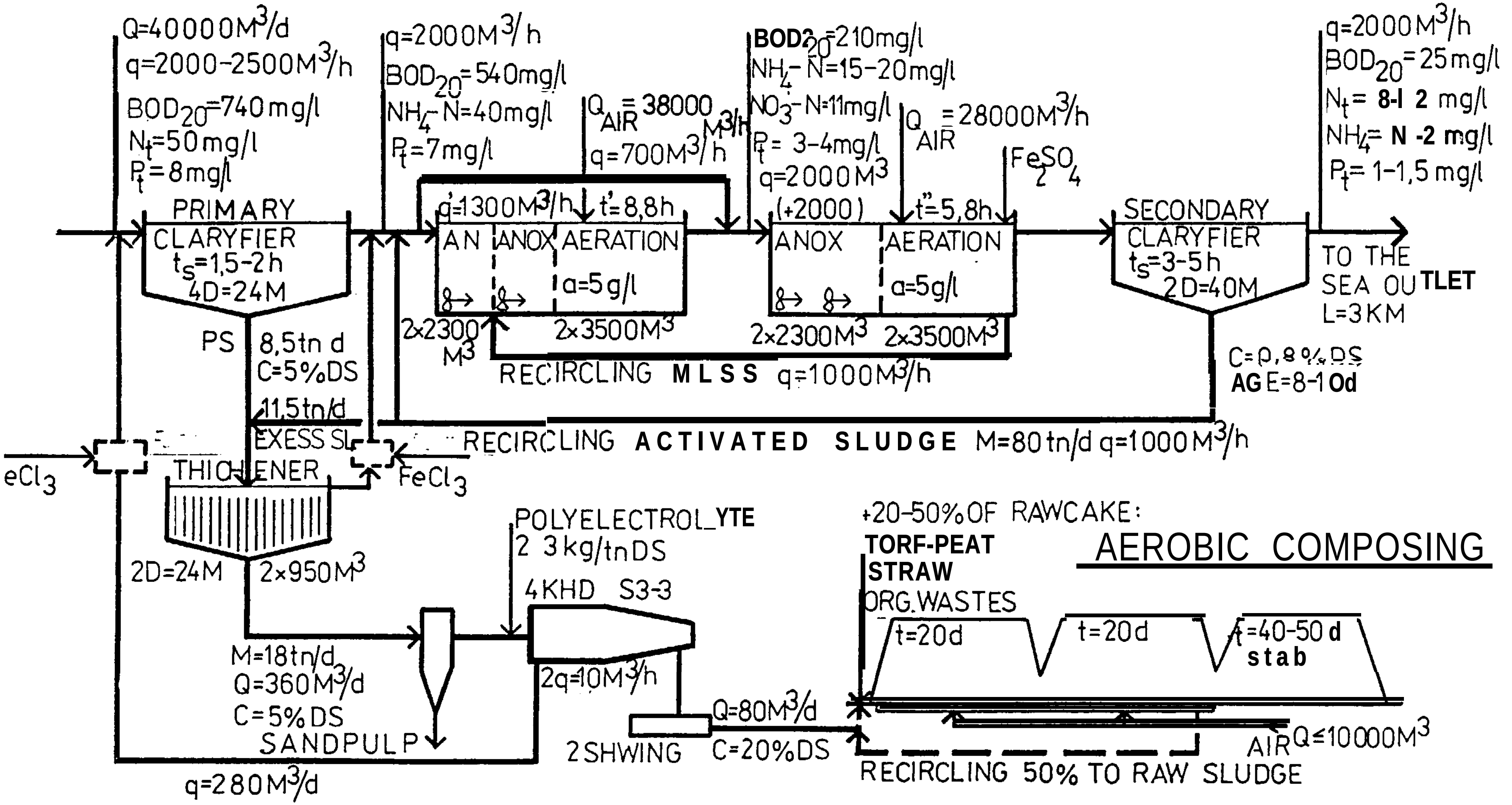


FIG.2 THE BALANCE SCHEME OF BIOPROCESSES IN PÄRNU PLANT

SS=18tn/d BOD_5=22,8tnO_2/d B_R=0,60kg BOD_5/M^3d B_a=0,30kgBOD_5/kgMLSSd B_N=0,023kgN/kgd

(TO TOTAL VOLUM) (TO AERATED VOLUM 14000M^3)

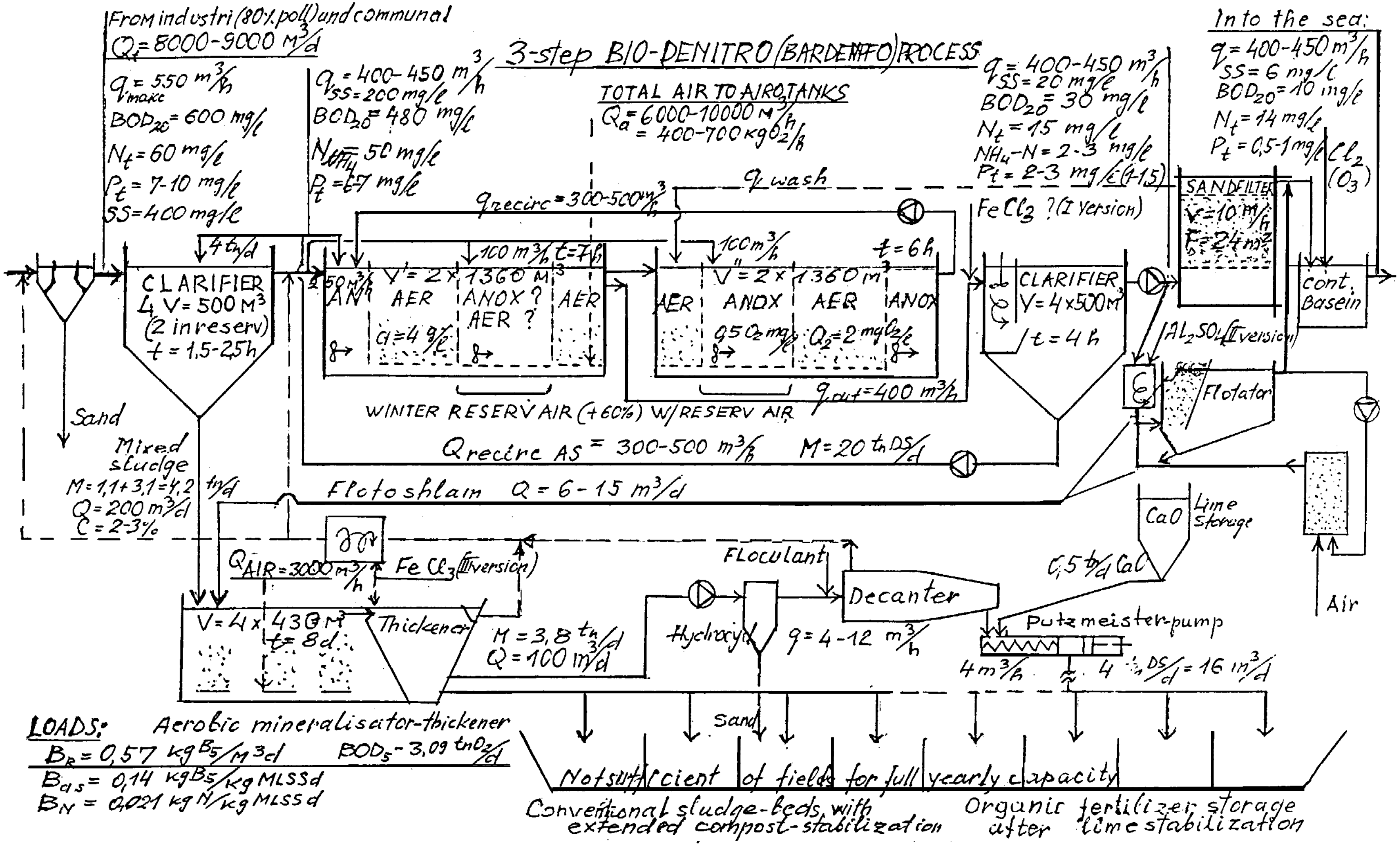


FIG.3 THE BALANCE SCHEME OF WASTE WATER HANDLING IN KURESSAARE PLANT

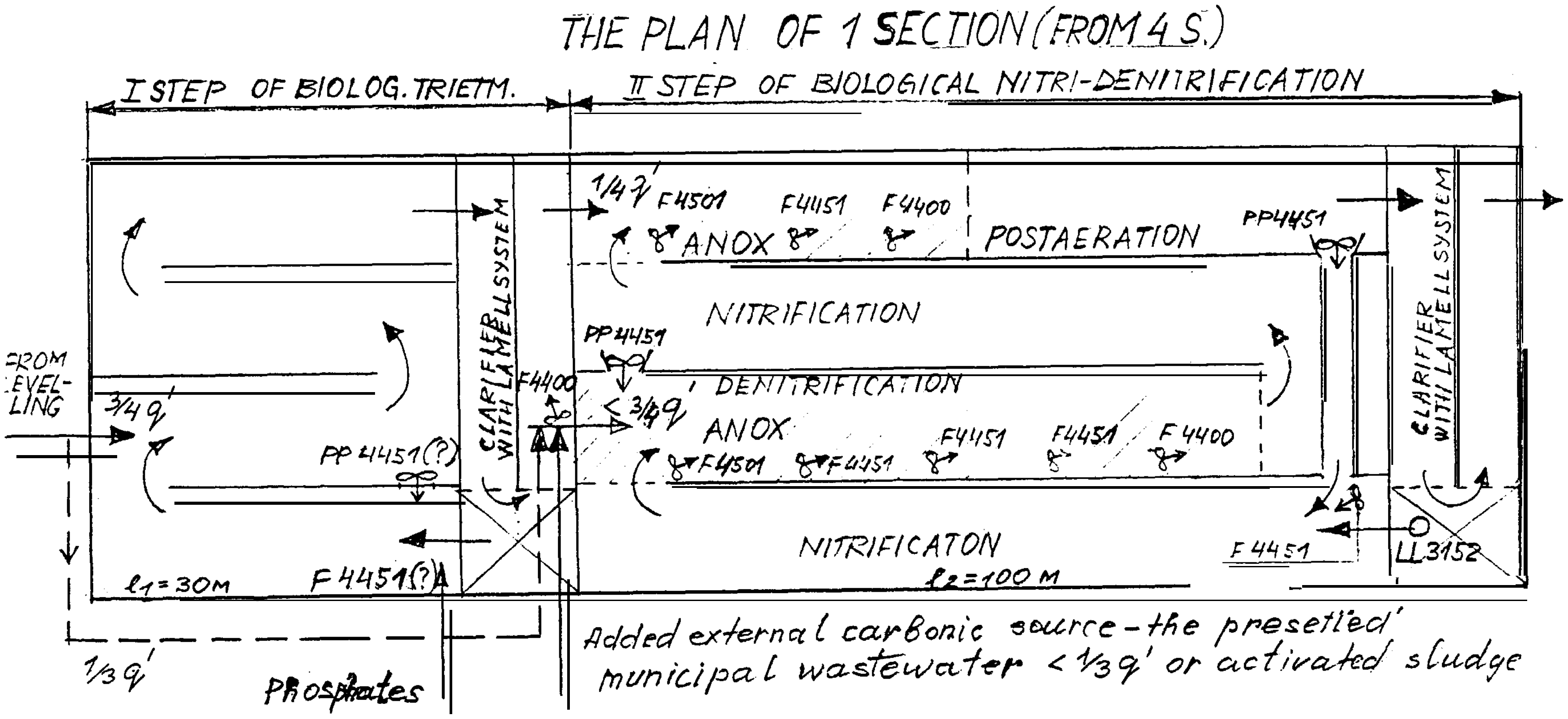


Fig.4. THE SCHEME OF RECONSTRUCTION KOHTLA-JÄRVE INDUSTRIAL WASTEWATERS TRIETMENT PLANT FOR NITRI-DENITRIFICATION RESEARCH

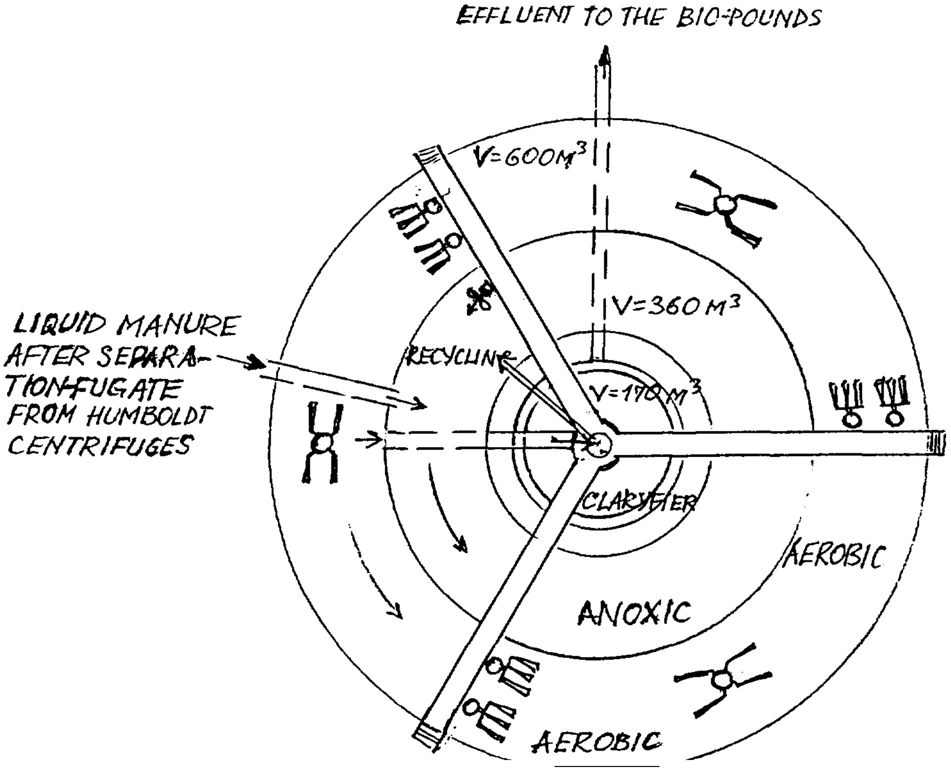


FIG.5 MENZEL-TYPE CIRCULATION AEROTANK IN EKSEKO

$D = 24\,м \quad H = 2{,}5\,м \quad V_a = 960\,м^3$

$Q_{ww}^{max} = 8{,}5\,м^3/h \quad Q_{aer}^{O_2} = 100\,kgO_2/h$ (solved)

$\Sigma N = 9 \times 15 + 13{,}5 = 148{,}0$ kW („KISHOR" KDS 20 DN 150)
„FLYGT MIXER H500

Results :

	INFLUENT	EFFLUENT
BOD total	> 5000 mgO_2/l	25-40 mgO_2/l
N_t	> 1500 mgN/l	100-200 mgN/l
NH_4-N	> 1300 mgN/l	10-20 mg/l

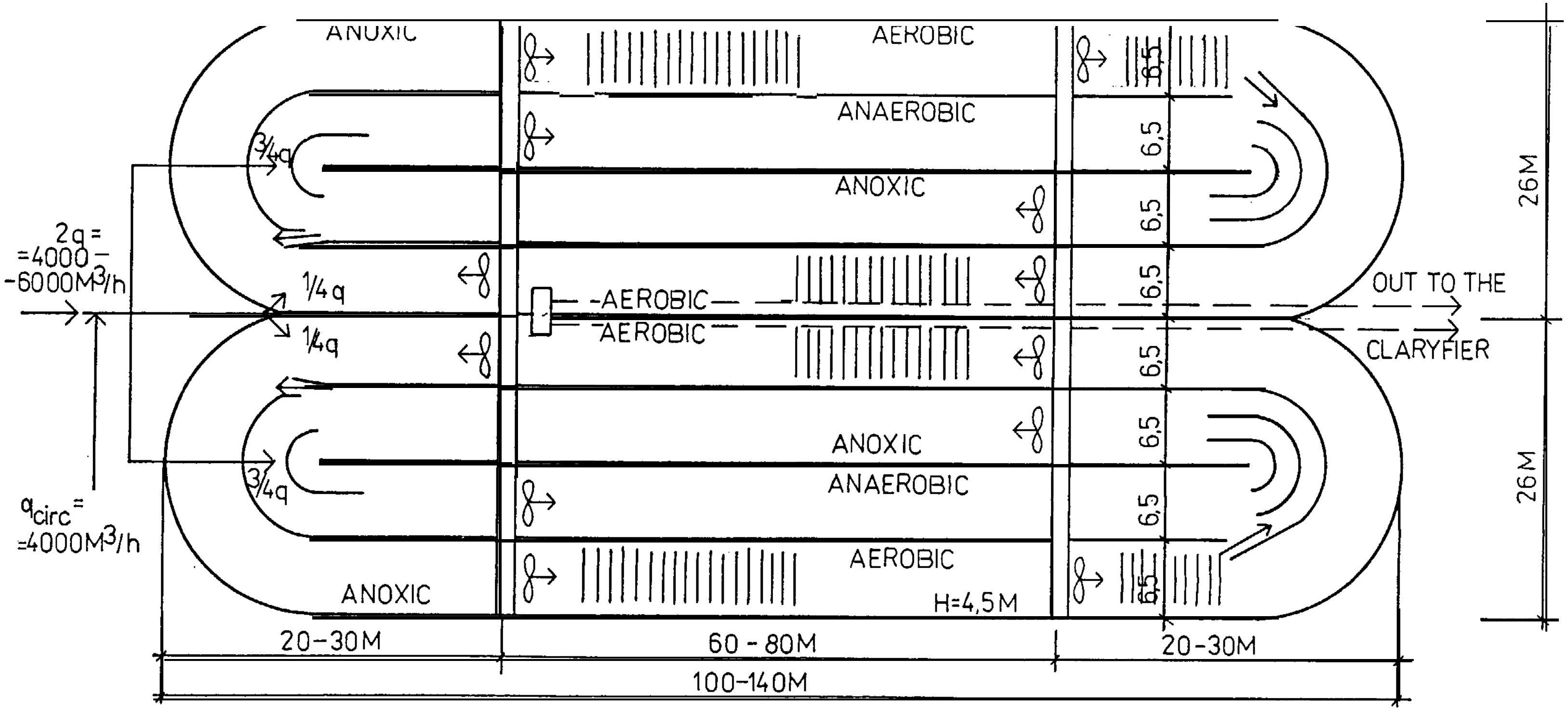
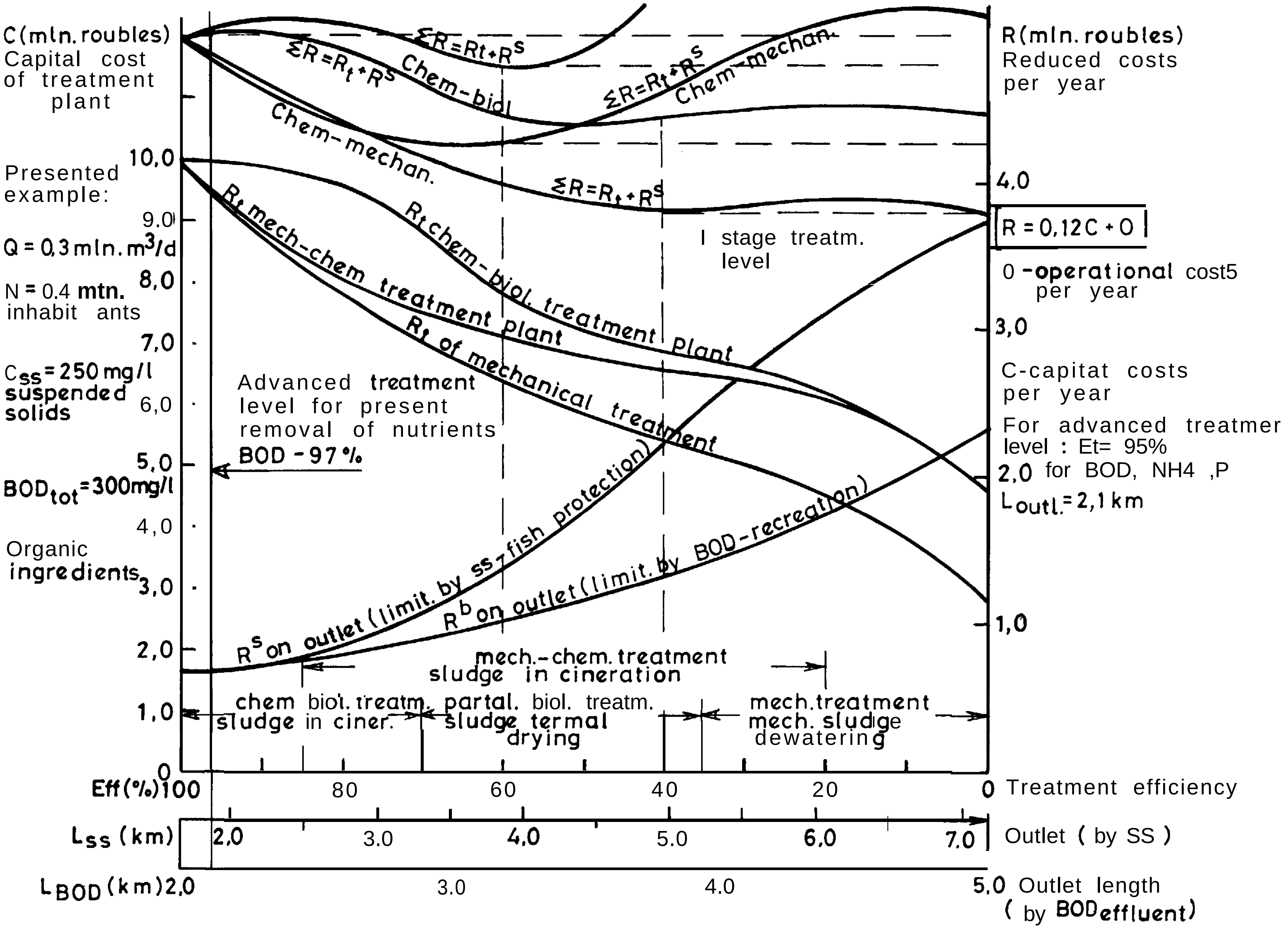


FIG.6 MENZEL-SYSTEM AEROTANK FOR NITRI-DENITRIFICATION IN DESIGNED PLANTS -FOR TOWNS TALLINN, NARVA, KOHTLA-JÄRVE AND KAUNAS.

Fig. 7 MINIMIZING REDUCED COSTS OF PLANT



ACTIVITIES OF THE HELSINKI COMMISSION ON MATTERS RELATED TO NUTRIENT DISCHARGES FROM URBAN AREAS

Vassili Rodionov
Technological Secretary
Baltic Marine Environment Protection Commission
- Helsinki Commission -

First of all, I wish to convey to all participants the most cordial greetings of the Executive Secretary of the Commission, Commander Fleming Otzen, and his wishes for a successful meeting.

In the strategy adopted by the Commission the value of seminars dealing with technical advance in the Baltic Sea Area is stressed and the Baltic Sea States are encouraged to host seminars in the field of technology. Such seminars convened on a regular basis under the umbrella of the Helsinki Commission make valuable practical contribution to further development of cooperation and promote fruitful exchange of information.

The Convention on the Protection of the Marine Environment of the Baltic Sea area (Helsinki Convention), concluded in 1974 and in force since 1980 is the basic foundation of cooperation among the Baltic coastal states. This Convention is the first international instrument to deal with all different sources of pollution in respect of a given maritime region.

The great importance and need for further steps to reduce the substances most harmful to the ecosystem of the Baltic Sea was underlined in the Declaration on the Protection of the Marine Environment of the Baltic Sea Area adopted and signed during the ninth meeting of HELCOM in February 1988 by the Ministers of the Baltic Sea States responsible for the environmental protection. In this environmental-political document the ministers declared, inter alia, their firm determination to reduce substantially heavy metals, toxic or persistent organic substances and nutrients in the order of 50 % out of the total discharges of each of them as soon as possible but not later than 1995. Taking into account this serious goal, consideration of all available and possible technical means is quite necessary.

Therefore, the exchange of information and knowledge on environmental technologies including preferential treatment is emphasized in the Declaration.

In the framework of the Commission the problems of reduction of nutrient discharges are dealt with on the branch-oriented basis and comprise:

- municipalities
- agriculture
- industry
- fish farming.

The aim of this presentation is to outline the activities of the Commission in the area of nutrient problems in urban areas, i would like to show how these items have been dealt within the whole scope of reduction of land-based pollution.

The principles and obligations in the work concerning land-based pollution are formulated in Article 6 of the Convention, the first paragraph of which is very simple and clear:

"The Contracting Parties shall take all appropriate measures to control and minimize land-based pollution of the marine environment of the Baltic Sea Area."

Goals, criteria and measures concerning the prevention of land-based pollution are specified in Annex III to the Convention:

"In accordance with the provisions of Article 6 of the present Convention the Contracting Parties shall endeavour to attain the goals and apply the criteria and measures enumerated in this Annex in order to control and minimize land-based pollution of the marine environment of the Baltic Sea Area.

1. Municipal sewage shall be treated in an appropriate way so that the amount of organic matter does not cause harmful changes in the oxygen content of the Baltic Sea Area and the amount of nutrients does not cause harmful eutrophication of the Baltic Sea Area.

2. Municipal sewage shall also be treated in an appropriate way to ensure that the hygienic quality, and in particular epidemiological and toxicological safety, of the receiving sea area is maintained at a level which does not cause harm to human health, and in a way that under the given composition of the sewage no significant amount of such harmful substances as are listed in Annexes I and II of the present Convention is formed.

3. The polluting load of industrial wastes shall be minimized in an appropriate way in order to reduce the amount of harmful substances, organic matter and nutrients.

4. The means referred to in Paragraph 3 of this Annex shall in particular include minimization of production of wastes by processing techniques, re-circulation and re-use of processing water, developing of water economy and improvement of qualifications for water treatment. In the treatment of waste water mechanical, chemical, biological and other measures, according to the quality of the waste water, and as required to maintain or improve the quality of the recipient water, shall be applied.

5. The discharge of cooling water from nuclear power plants or other kinds of industries using large amounts of water shall be effected in a way which minimizes the pollution of the marine environment of the Baltic Sea Area.

6. The Commission will define pollution control criteria, objectives for reduction of pollution and objectives concerning measures, including processing techniques and waste treatment, to reduce pollution of the Baltic Sea Area.”

The Commission, already at its interim stage established a working group, under the Scientific-Technological Working Group (STWG) and later on the STC, to consider various aspects and to make relevant proposals, which might be necessary to fulfill the obligations of Article 6 of the Convention. This group is known as the WGS (Working Group on Criteria and Standards for Discharges of Harmful Substances into the Baltic Sea Area).

During 1980-1985 the Commision adopted more than 10 Recommendations concerning hazardous and noxious substances listed in Annexes I and II of the Convention.

The First Periodic Assessment of the State of the Marine Environment of the Baltic Sea, covering the five-year period from 1980 to 1985 (BSEP No. 17), showed that there had been progress in the state of the marine environment compared with the state of the Baltic evaluated in 1980 (BSEP No. 5). Concentrations of toxic substances like DDT, PCBs and mercury in living organizms and seawater were decreased. Unfortunately, the trends of nutrient content in the Baltic Sea and the oxygen conditions in its deep basins turned to be still discouraging. Investigations made revealed an urgent need to take all appropriate measures to treat municipal sewage and industrial wastewater with special emphasis on the reduction of discharges of nutrients.

In the Medium-Term Plan adopted in 1984 as HELCOM Resolution 5/A, the Commission gave high priority, inter alia, to evaluation of effects and elaboration of proposals for appropriate action against discharges of nutrients and oxygen-consuming substances into the marine environment. Special emphasis was made on improvement of technologies for reduction of nitrogen compounds. At the same time it was pointed out that branch-wise approach should be established for elaboration on criteria and standards taking into account the varying need for reduction measures within the different branches. As a first step HELCOM Recommendation 6/7 was adopted by the Commission in March 1985. It was declared that:

a) appropriate criteria and measures be applied to sewage discharges in order to control and minimize land-based pollution and eutrophication of the marine environment of the baltic Sea Area. In the treatment of the wastewater mechanical, chemical, biological and other measures, according to the quality of the wastewater, and as required to maintain or improve the quality of the recipient water, shall be applied;

b) where nutrient removal is of primary concern appropriate treatment should be carried out, for example, by replacing or combining biological treatment with chemical precipitation or other methods of equal efficiency; and

c) where nitrogen removal is found more necessary than phosphorus removal, the treatment described above should be replaced by or combined with nitrogen removal methods.

First branch-oriented projects were established in late 1985. One of them was the project for matters related to discharges from urban areas, Sweden as Lead Country. The main task of the project was to promote the development of methods for collection and treatment of sewage and stormwater from urban areas.

The project worked successfully during its initiative stage resulting in recommendations adopted by the Commission in 1986 (HELCOM Recommendations 7/3, 7/4 and 7/5). According to HELCOM Recommendation 7/3 the sewerage systems should be renewed in such a way that infiltration and exfiltration be minimized, a separated or a semi-separated sewerage system should be selected for new developments. HELCOM Recommendation 7/4 invisaged that those parts of urban wastewater which are of industrial origin and contain heavy metals or other harmful substances which cannot be reduced in a central treatment plant to the environmentally acceptable level, should be pretreated on the spot of their formation, i.e. before entering the sewerage system. Recommendation 7/5 concerning reduction of discharges from urban areas by the treatment of stormwater, indicated that measures should be taken already at the source and the first flush of stormwater especially from heavily polluted industrialized urban areas be purified. (The Recommendation was later superseded by Recommendation 9/9 containing specific limits for overflows).

Since the tasks given for the project were fulfilled, in 1986 a new project on urban areas was established to deal with:

- combined sewer overflows;
- pretreatment of industrial wastes before discharge into municipal sewerage systems;
- control programmes;
- implementation of nitrogen reduction in municipal wastewater treatment.

To stress again the importance of seminars it is fair to recall that the activity of the project was favoured by the ideas provided by the Visby Seminars 1986 and 1987.

The work of the project resulted in a draft Recommendation concerning measures aimed at the reduction of discharges from urban areas by the use of effective methods in wastewater treatment. It was discussed and adopted by the Commission in two steps: in 1987 (HELCOM Recommendation 8/3) and in 1988 (HELCOM Recommendation 9/2). It was declared that:

a) urban wastewater deriving from households or industrial enterprises should be collected and treated before being discharged into water bodies; by-passes may only be used in emergency cases;

b) domestic sewage or wastewater of similar type which is collected in a central sewerage system and treated in wastewater treatment plants, loaded with more than 10 000 person equivalents, should be treated as soon as possible and not later than 1998 by biological methods or other methods giving equivalent results, so that the treatment should result in:

- at least 90 % reduction of BOD,; and
- at most a concentration BOD, in the effluent of the treatment plant of 15 mg/l;
- annual average values of total phosphorus below 1,5 mg P/l.

Since no consensus could be reached upon an effluent concentration of nitrogen, it was decided that, as a start, each Contracting Party should start research and evaluation projects with a purpose to give a basis for further recommendations for nitrogen removal within three years. The projects should, inter alia, include studies of process technology and costs for nitrogen removal to reach the targets:

(i) 12 mg total nitrogen/l in the effluent water or 50 % reduction of total incoming nitrogen;

(ii) 8 mg total nitrogen/l in the effluent water of 75 % reduction of total incoming nitrogen.

The results of the research and evaluation projects should be reported at annual seminars held within the auspices of the Helsinki Commission.

The first specialist meeting of this series was the Fourth Karlskrona Conference on the Health of the Seas (7-9 June 1988), which concluded, inter alia, that:

- the development and application of more efficient and cost-effective techniques to reduce the load of nutrients should be encouraged;

- research on microbial and other processes governing nutrient removal in industrial and municipal wastewater treatment plants should be encouraged with the aim of developing reliable design and operation strategies, e.g. as regards nitrogen removal techniques;

- measures should be taken to substantially reduce discharges from industrial point sources by means of best available technology;

- measures should be taken to connect all urban areas to sewage treatment plants utilizing advanced techniques for nitrogen and phosphorus removal. For example, precipitation could be applied rapidly at all major sewage treatment plants, which at present have only mechanical or biological treatment, in the catchment area of the North Sea and the Baltic Sea.

This Tampere seminar is expected to be an important step in the exchange of relevant information among the experts, and implementation of the decision of the Commission. It would be of great value if the seminar could agree upon certain actions that might be taken to facilitate the formulation of future HELCOM Recommendations.

The adoption of more stringent Recommendations is not the aim in itself. Protection measures recommended should lead to improvement of the marine environment. In this respect the prerequisite for future decisions by the Commission is the better knowledge of the state and changes in the marine environment. The results of the evaluation are important tools for decision-making. Comprehensive monitoring programmes and assessments play a key role in the work of the Commission. The IIId stage of the Baltic Monitoring Programme (BMP) started from 1 January 1989. The preparation of the IInd Periodic Assessment is in its final stage. In January 1990 the data collecting for the IInd Pollution Load Compilation will begin according to the Guidelines adopted by HELCOM 10.

Special emphasis is given to the follow-up on implementation of HELCOM Recommendation and the Ministerial Declaration by the each Contracting Party. The Commission has initiated the work aimed to collect, in harmonized way, information on action taken and results achieved by each country on the basis of the adopted decisions. The information collected at regular intervals (each 3 years) will be considered by the Commission with a view to preparation of new Recommendations, revision of existing ones or any other action necessary. The new reporting system was established by HELCOM 10 for this purpose.

Successful work of the Commission requires not only multinational cooperation but bilateral and individual efforts as well. There is a positive trend that environmental aspects are also now involving cooperation between twin-cities, universities, enterprises around the Baltic.

Since the problems in the Baltic Sea Area have much in common with those appearing in other sea areas, e.g. the North Sea, strengthening of cooperation with other international organizations, primarily with the Paris Commission is essential. In the HELCOM strategy such cooperation is stressed as an important item, because it not only generates new ideas for the work but also is of benefit in harmonizing activities and goals in specific questions.

To complete, I would like to wish once again all success to the Seminar and its participants.

SIMULTANEOUS PRECIPITATION

Mr. Risto Saarinen

The Water Protection Association of the Vantaa River and Helsinki District

INTRODUCTION

Simultaneous precipitation is a major concept in municipal wastewater treatment plants in Finland. In the end of 1987 75 % of the water was treated by simultaneous precipitation process ferrous sulphate being the chemical used for phosphorus removal. This paper covers recent data and the experiences we have gained in Finland using ferrous sulphate for two decades.

FERROUS SULPHATE - POTENTIAL FOR PHOSPHORUS REMOVAL

Ferrous sulphate is a by-product of titanium dioxide production. Roughly when you get a kg of TiO_2 you also get 3-4 kg of $FeSO_4$ $x7H_2O$. Titanium dioxide production in Europe is rather high and ferrous sulphate is easily available. Also other by products such as pickling waste liquor can be used for phosphorus precipitation.

Annual ferrous sulphate amount from TiO_2 production in Europe is roughly 1,6 million tonnes per year. Assumed that the product includes 18 % iron the production equals phosphorus amount of 300 000 kg/d with molar ratio 1,5 mol Fe/l mol P. This means that existing TiO_2 plants could serve treatment plant of 100 000 000 p.e. if we assume a 3 g P/person/day load. The hypothetic calculations above don’t include the acid solution of TiO_2 production nor the pickling liquor from metal industry.

Ferrous sulphate is available in Finland as heptahydrate, a product which reminds wet snow. Drier forms of the chemical are also produced. Tetrahydrate and even more monohydrate are free flowing and are available. Drying of the product is an economical matter not a technological problem.

Table 1. Ferrous sulphate production in Europe

Methods of use and disposal of wastes from titanium dioxide production in selected ECE member countries (Replies to ECE questionnaire)

(Thousands of tonnes per year)

	Disposal and utilisation of acid solutions		
	Discharge to sea or river	Recycling or other uses	Neutralization
Belgium (E)	140		-
Czechoslovakia		25,0	-
Finland	90	90	-
France	317 0	-	53,0
Fed.Rep. of Germany	272: 15	99	-
Italy	100,5	4,0	27,5
Netherlands	119		-
Norway	37,3		-
Poland		35	10
Spain	67+9,8	22,83	-
United Kingdom (E)	220		-

	Disposal and utilization of ferrous sulphate			
	Water treatment	Pigment production	Discharge to sea	Storage
Belgium (E)			-	-
Czechoslovakia	25	81	-	48
Finland	60		96,6	263,4
France	74,7		-	10,0
Fed.Rep. of Germany	374,5	28,0	-	-
Italy	7	7	26	-
Netherlands			14,64	-
Norway	65	27	42,8	-
Poland	8	4	-	139
Spain			172,55	-
United Kingdom (E)	-	-	-	-

E = estimated values

REACTIONS OF IRON AND PHOSPHORUS

Iron if ferrous sulphate is in bivalentic form **(Fe^{2+}).** Phosphorus in wastewater is detected mainly as ortho-, poly- and other phosphates and organic phosphoric compounds. Roughly one half of the phosphorus is in the form of orthophosphate and the rest of it tends to be degraded to ortophosphate by hydrolysis during the activated sludge process.

The following, simplified reactions take part in the process:

$Fe^{2+} \; \underline{\qquad} \; Fe^{3+} + e^-$ [1]
$Fe^{2+} + 2\,OH^- \; \underline{\qquad} \; Fe(OH)_2$ [2]
$Fe^{3+} + 3\,OH^- \; \underline{\qquad} \; Fe(OH)_3$ [3]
$3\,Fe^{2+} + 2PO_4^{3-} \; \underline{\qquad} \; Fe_3(PO_4)_2$ [4]
$Fe^{3+} + PO_4^{3-} \; \underline{\qquad} \;$ Fe PO, [5]

The speed of oxydation of ferrous iron to ferric iron [1] is favoured by higher pH and oxygen concentration and presence of activated sludge.

Ferrous hydroxyde and ferrous phosphate formations [2][4] are slow reactions and the stability of the products is very low. Only in very narrow pH range ferrous iron stays in the precipitated form. Thus the main reactions are ferrous iron oxydation [1] and ferric hydroxyde and phosphate precipitation reactions [3][5].

Theoretically 1 mol (56 g) iron is needed for the precipitation of 1 mol (31 g) phosphorus. The iron consumption in practise is increased by side reactions (hydroxydes etc.), redissolving of phosphorus, load from sludge treatment and the lack of the load vs. dosage control. The consumption is decreased by adsorption to the activated sludge and the precipitation caused by the iron, aluminium and calsium in the raw wastewater. The evaluation of these factors hasn’t been done thoroughly. A molar ratio (Fe/P) of 1,5 -2,0 has shown good results.

Based on the theory above ferrous sulphate can be added in one point, but it’s more economical to use two or sometimes even three adding points.

Ferrous sulphate is generally dosed according to the flow changes or on a steady chemical flow basis. Even once-a-day adding is used. Iron is bound to the activated sludge floc and can build a storage of chemical. However, most accurate and economical results are reached if the feeding follows the phosphorus load.

FULL SCALE EXPERIENCES

In the following some results are given of the Finnish simultaneous precipitation plants and three plants are described more detailed.

Whole country

In the end of 1987 there were 578 municipal wastewater treatment plants in Finland. 392 of them had simultaneous precipitation as the treatment concept. 42 of these plants had a load of 10 000 p.e. or more. The results of these plants are shown in pictures la -ld. The plants are put in order according to the phosphorus mass flow to the plant. The average phosphorus concentrations (stressed with the flow) of the influent and effluent were 7,4 and 0,69 mg/l. Phosphorus reduction in these plants was 91 %.

The concentration limits set by the authority varied between 0,8 and 1,5 mg/l. Reduction efficiency limits varied between 80 and 90 %. These conditions were met in most cases. Some exceptions existed, but clear solutions to the problems can usually be found: 1) Soluble phosphorus concentration could easily be reduced till the level of 0,1 - 0,3 by using 10 - 30 % more ferrous sulphate. In addition, the chemical is advised to be dosed in two points, for instance 80 % to the pre-aeration and 20 to the end of the aeration basin. 2) Suspended solids concentration can also be reduced to one half by adding polyelectrolytes to the outlet of the aeration basin. Polyelectrolytes help as well plants with high as plants with low solids concentration. The dosage varies mostly between 0,1-

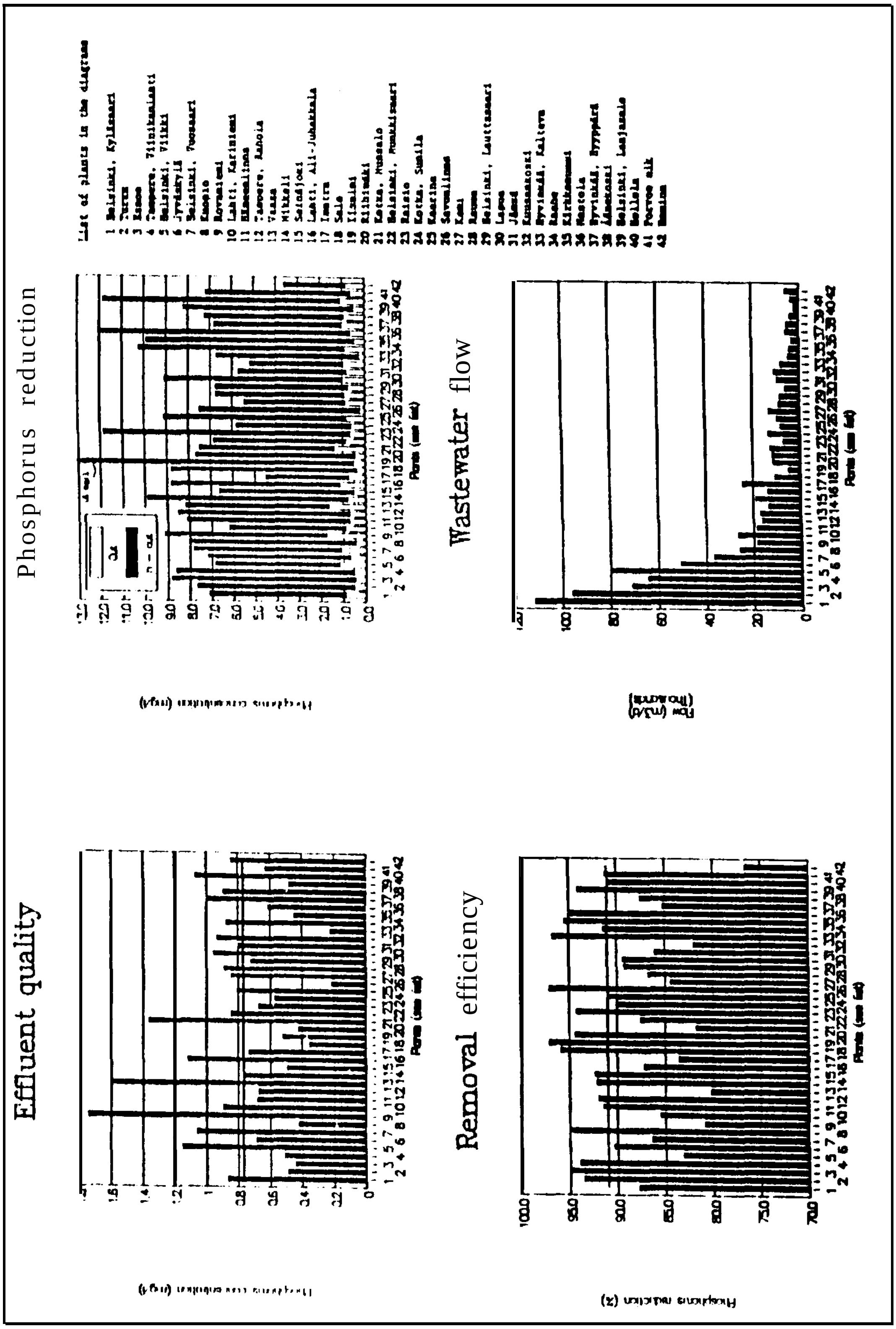
1,0 g/m^3 wastewater. Usually the consumption is between one to two thirds of the amount used in sludge conditioning.

Some problems in phosphorus removal have occured in plants with nitrification need. Due to the cold climate sludge age has to be even 20 - 25 days which causes problems in capturing the solids in the final clarifier. Denitrification in the clarifier and lack of alkalinity in some cases have shown to make the problem even worse. However, if the plant is well designed and operated, a good result should be obtained by simultaneous precipitation.

Detail examples

The operation conditions and results of one small and two medium size treatment plants are shown in table 2 and picture 2.

Tuusula plant is a small and simple plant treating 3 500 p.e. load. It consists of screen, aeration and sedimentation. The sludge is thickened with lime and transported to be treated elsewhere. Hyvinkää plant treats 19 600 p.e. load. It consists of screen, pre-aeration, primary clarification, aeration with anoxic part of 40 % and secondary clarification. The sludge is thickened with lime and dried with belt filter presses. Riihimäki plant treats 22 300 p.e. load. It consists of screen, pre-aeration, primary clarification, two Carrousel type aeration basins and two secondary clarifiers. Diary wastewater (5 - 10 % of the inflow) is pre-aerated separately and led directly to the aeration basins. The sludge is thickened, digested anaerobically, dried with belt filter press or centrifuge and composted.



Picture 1. The phosphorus removal results of municipals simultaneous precipitation plants treating min. 10.000 p.e. load in 1987.

Table 2. Operation conditions in Tuusula, Hyvinkää and Riihimäki plants in 1988.

	Ferrous sulphate ($FeSO_4x7H_2O$)				Lime ($Ca(OH)_2$)		
	Process				Process		Sludge tr.
	t/a	g/m3	gFe/gP	molFe/molP	t/a	g/m3	t/a
TUU	40	200	4,7	2,6	0	0	11
HYV	455	150	4,2	2,3	54	17	180
RII	484	110	2,7	1,5	+	+	0

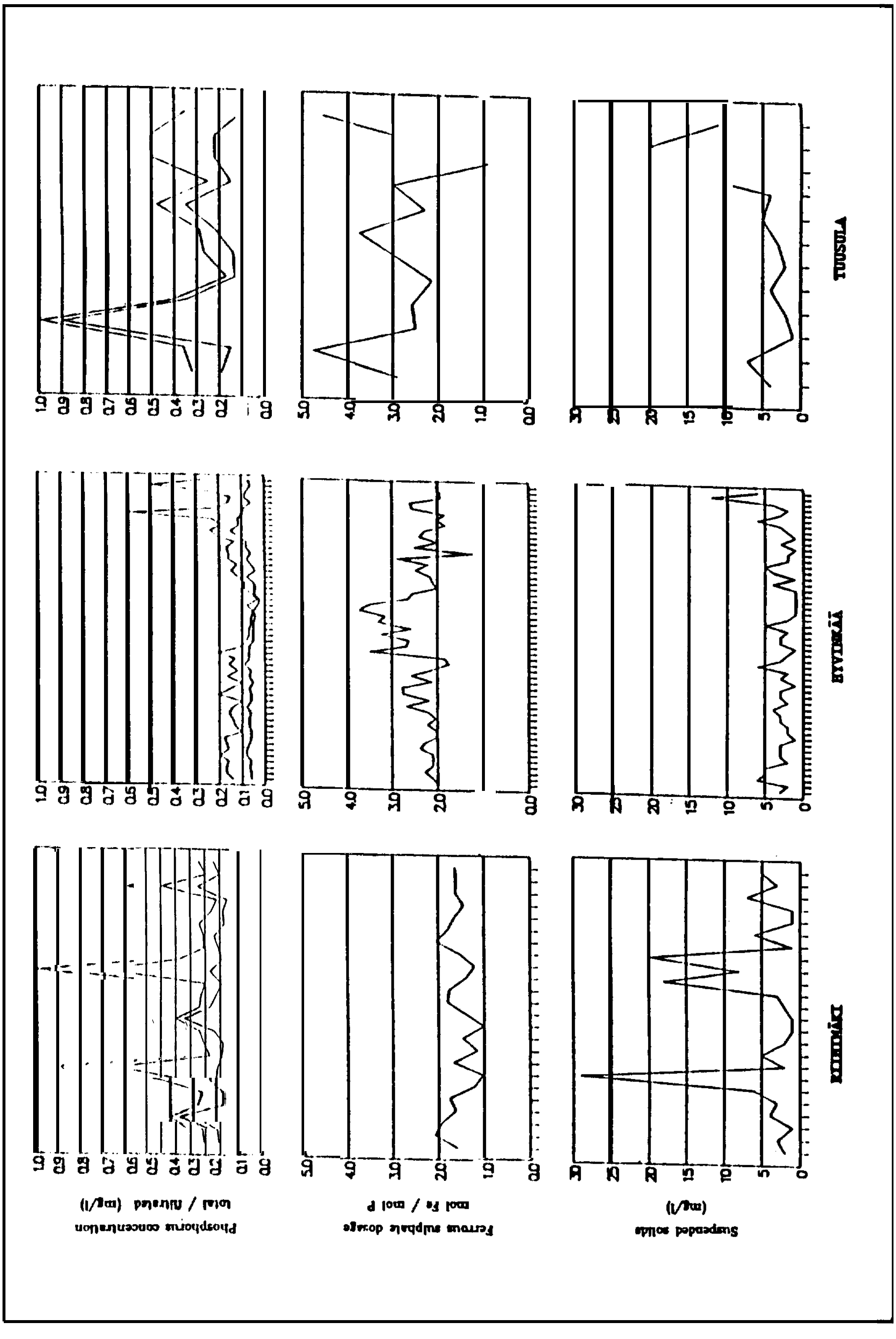
	Polyelektrolyte			
	Process		Sludge treatment	
	kg/a	g/m3	kg/a	kg/kg TS
TUU	0	0	0	0
HYV	1040	0,3	2100	2,3
RII	0	0	3200	4,6

	Mean flow
	m3/d
TUU	570
HYV	8700
RII	12240

	Energy			
	MWh/a	kWh/m3	kWh/BODi	kWh/BODr
TUU	170	0,30	6,3	6,8
HYV	1190	0,37	3,4	3,4
RII	1850	0,41	1,8	1,8

Plants: TUU = Tuusula HYV = Hyvinkää RII = Riihimäki

BODi = BOD in the plant
BODr = BOD removed in the whole process



Picture 2. Phosphorus removal results in Tuurula, Hyvinkää and Riihimäki plantr in 1988

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FLOTATION-FILTRATION - A METHOD OF UPGRADING PHOSPHORUS REMOVAL

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INTRODUCTION

Simultaneous precipitation has proved to be a serviceable method for phosphorus removal in waste water treatment. In Finland, for instance, it is widely used, and nowadays the values of total phosphorus P_{tot} = 0.5 - 0.8 mg/l treated water are easily met when simultaneous precipitation is applied in an activated sludge plant.

When an extremely low content of phosphorus is required, say P_{tot} = 0.1 - 0.3 mg/l, combined to BOD_7-value less than 10 mg/l or even 5 mg/l, a conventional solution throughout the world has been to have a tertiary stage with filtration in a treatment plant.

Using flotation filters instead of plain filters in the tertiary stage is a new process combination in advanced waste water treatment. Over five years' full-scale experience with a medium-size activated sludge plant with simultaneous precipitation in Savonlinna, Finland which is fitted with tertiary flotation filters shows that really good operational results including total phosphorus $P_{tot} < 0{,}3$ mg/l can be continuously achieved in this way with a lower overall cost than by using plain filters in tertiary treatment.

FLOTATION FILTER - A MONOLITHIC COMPOSITION OF TWO UNIT OPERATIONS

The standard model of flotation filter containing a conventional downflow sand filter and an inlet shaft fitted with dispersion equipment for flotation, which is carried out in the head above the filter bed (fig. 1), was developed in Sweden in the 1960's and patented in most western countries. During the last 25 years flotation filters, which save a lot of construction cost, have become very popular for water treatment plants in Finland, where in fact it has never been patented.

Combining flotation and filtration in the same tank is possible because of the equal hydraulic capacities of those unit operations for removal of suspended solids. The innovation in tertiary waste water treatment is that, in a flotation filter, flotation can be used as a supplementary removal operation between secondary clarification (which is carried out by sedimentation) and filtration when it is needed and not to be used when it is not necessary.

This simple fact is the key to the advantage of tertiary waste water treatment which can be achieved using flotation filters instead of plain filters.

OPERATIONAL ALTERNATIVES

Mechanical tertiary treatment

Plain mechanical treatment is the basic or normal way of operation with tertiary flotation filters, when simultaneous precipitation is applied in the activated sludge process and the target in phosphorus removal is $P_{tot} < 0.3$ mg/l. This means that filtration is operated continuously and flotation is operated only when settling in the secondary clarifiers does not succeed well enough, and the load of suspended solids would be too high for the proper operation of filters.

The operation of flotation can be automatically controlled, i.e. be started and stopped, according to the turbidity of secondary settled water. The disturbances in secondary clarification because of hydraulic overloading or because of poor sludge settleability can be totally handled by flotation which has a good load-bearing capacity both for flow and for suspended solids (fig. 2).

This means that the filters are always operated in proper conditions and the degree of removal of suspended solids is continuously very high. The removal of phosphorus then totally depends on the way, in which the simultaneous precipitation of aqueous phosphorus succeeds in the activated sludge process.

Experience shows (Table 1) that when simultaneous precipitation is operated properly (PO,-P $\leq$ 0.1 mg/l, the value of total phosphorus P_{tot} less than 0.3 mg/l in treated water can be continuously achieved.

Table 1 Pihlajaniemi Waste Water Treatment Plant
(Savonlinna, Finland)
Operational results as monthly averages
(analysis from 24 hrs collection samples)

Month/year		BOD_7 mg/l	P_{tot} mg/l	NH_4-N mg/l	SS mg/l
June	1988	5	0.34	0.1	3
July	"	3	0.26	0.1	5
August	"	4	0.21	0.8	4
September	"	3	0.15	0.1	2
October	"	3	0.16	0.1	3
November	"	4	0.10	0.4	1
December	"	5	0.30	0.5	2
January	1989	4	0.17	0.4	2
February	"	3	0.14	0.1	2
March	"	2	0.14	0.7	2
April	"	9	0.37	1.0	5
May	"	9	0.36	0.4	5

The operational reliability of the treatment plant is clearly seen from the values of suspended solids in the table. The monthly averages are from 24 hrs collection samples taken daily.

A good total load-bearing capacity of the flotation filter tertiary stage given by flotation also means that the whole process can be well controlled in all circumstances and no bypassings of the secondary stage will happen when snow melts or in rainy weather.

When the bypass arrangements of the unit operations are adequate and a crossover between the secondary clarifiers and the flotation filters is possible, the secondary clarifiers and the flotation filters can even be operated side by side. This doubles the hydraulic capacity of the treatment plant and the total treatment standard will still be moderately maintained even when exceptional high flows of waste water have to be treated.

Because of a good load-bearing capacity of the whole process, the treatment plant and all unit operations can optimally be dimensioned. This means that the construction cost of a waste water treatment plant fitted with tertiary flotation filters is very reasonable (Fig. 3).

The operating cost of a treatment plant fitted with tertiary flotation filters is also moderate when plain mechanical treatment with flotations filters is applied. The operating cost of flotation filters is very low, because flotation is effectively used only when needed, and filtration can be operated in optimal conditions, which means long filter runs and a low consumption of backwash water. One must remember that a conventional single-medium filter with coarse sand (grain size ø 2-3 mm) is correct for tertiary flotation filters in order to achieve an equally low content of suspended solids in treated water with tertiary multi-media filters.

Contact filtration

When really low values of total phophorus, say $P_{tot} \approx 0.1$ mg/l, are required in treated waste water, the precipitation of aqueous phosphorus can be boosted by introducing with a minute dosage of trivalent iron or aluminium ($Me^{3+}/PO_4\text{-}P \leq 1.5$ -2.5) into the secondary settled water.

This means that filtration in the flotation filters is operated so called “contact filtration” which is a widely used method with tertiary filters in Switzerland, for instance. However, the operational principle of the flotation filters is still the same as it is in mechanical tertiary treatment. Full-scale trials in Savonlinna have shown that contact filtration can easily be applied with tertiary flotation filters. Results in phosphorus removal have been fully comparable to those achieved in Switzerland with tertiary filters.

The amount of chemical sludge in contact filtration coming from filters into the backwash water is so little that it does not cause any problem in the activated sludge process or in sludge dewatering when the backwash water with possible flotation sludge is returned in the primary clarification and taken out of the water process together with primary sludge.

Together with a small amount of coagulant, this means that the operating cost of the tertiary treatment with flotation filters applying contact filtration is only a slightly higher than when mechanical treatment is applied.

Post-precipitation

In order to ensure the best possible operational results, post-precipitation is also easily applied in tertiary treatment with flotation filters. The dosage of aluminium or ferric sulphate into the secondary settled water must then be quite large, 80 - 120 g/m^3. No flocculation tanks are needed, because a flocculation sufficient for flotation can easily be carried out in the inlet chamber connecting the flotation filters.

Flotation must be operated continuosly in post-precipitation to remove the flocs created by chemical precipitation so that only the smallest ones (ø 10 urn) can reach the filter bed and be removed by filtration. The huge amount of chemical sludge removed from water by flotation cannot be returned to the primary clarification with the filter backwash water. It must be separately taken off from the surface of the flotation filters and individually treated for waste disposal.

Experience from full-scale trials in Savonlinna has shown that results in phosphorus removal with tertiary flotation filters are not significantly better in post-precipitation than in contact filtration. The average value of total phosphorus has been about $P_{tot} \approx 0.1$ mg/l. It has also been found out that in post-precipitation almost the whole reduction of phosphorus as well as other impurities occurs in flotation, and the significance of filtration as the last removal operation is negligible.

Because the operating cost of the tertiary treatment with flotation filters applying post-precipitation is many times higher than by applying mechanical treatment or contact filtration, post-precipitation is not a reasonable operational variation when the activated sludge process is working normally.

The possibility to apply post-precipitation in tertiary treatment with flotation filters is important, because it can be brought into use when there are bad operational disturbances in the biological activity of the activated sludge process or when it is totally out of operation. In these situations, which are not unusual in practice, tertiary treatment with flotation filters will preserve the treatment standard when post-precipitation is applied.

SUMMARY

Adding a tertiary treatment with flotation filters to a waste water treatment plant using the activated sludge process fitted with simultaneous precipitation is a very effective method to carry out a highgrade phosphorus removal with reasonable cost.

It is just the coexistence of flotation, the possibility to use flotation between the secondary clarifiers and tertiary filters, which results in flotation filters being much more efficient than plain filters in tertiary treatment.

As a removal operation for suspended solids which has a good load-bearing capacity both for flow and for suspended solids, flotation ensures the proper operation of the treatment plant in all circumstances. Phosphorus removal can be boosted either by a light chemical treatment, socalled “contact filtration”, or when need arises by a full chemical treatment, post-prepicitation.

The flexibility of operation reached by using flotation filters in the tertiary stage is such an important advantage that it can only be realized by a person who has operated or been in operational

response of such a plant in difficult circumstances caused, for instance, by great variations in hydraulic and BOD-loading.

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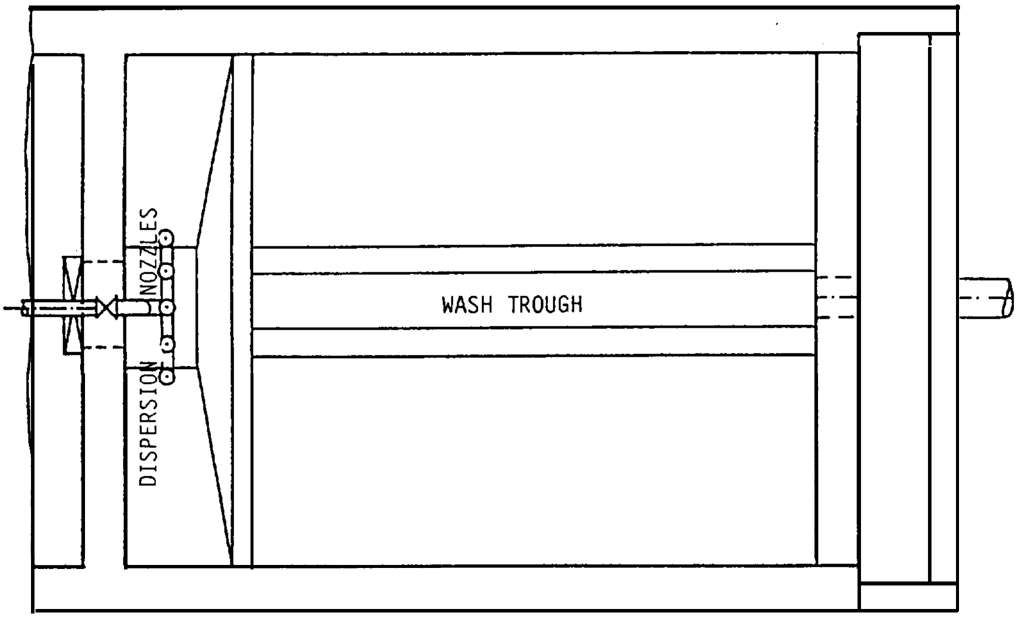
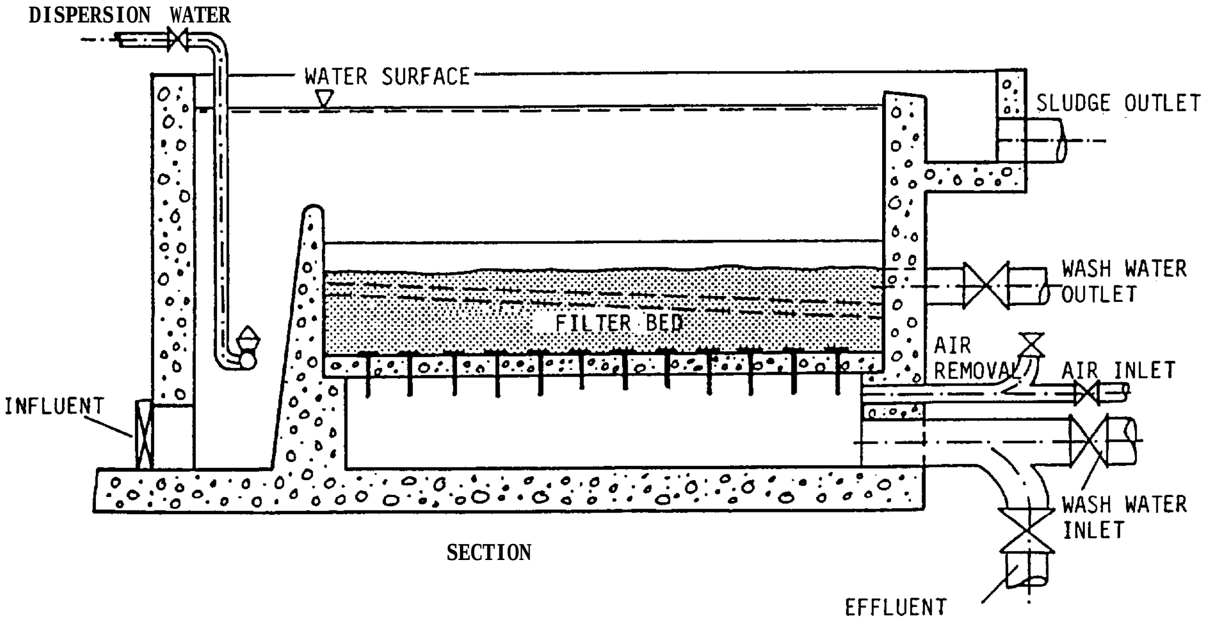
Fig. 1 FLOTATION FILTER



PLANE



SECTION

NUTRIENTS REMOVAL IN MUNICIPAL WASTEWATER RECLAMATION SYSTEM

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INTRODUCTION

A new approach to water management, already implemented in several countries, involves reclaiming water from municipal sewage for industrial and commercial reuse.

Wastewater reclamation has multiple benefits including water conservation and supplementing available water resources. This would also result in a significant improvement of water quality in the receiving streams.

The scarcity of the usable water in some regions of Poland makes it necessary to search for such unconventional sources of water as municipal sewage. Water reuse should become an important element of the water management system, especially in the southern Poland: Silesia and the Cracow region.

To solve an acute water shortage in the Upper Silesian industrial region, water reuse technology has been studied since 1975. The water reuse system that has been developed for this region includes 19 wastewater reclamation plants with a total capacity of 9 m^3/s. The implementation of these plants is included in future central water planning [5].

The most commmon planned application of reclaimed water for industrial purposes is to supply cooling systems. This amounts to about 78 % of reclaimed water reuse; the others are: boiler make-up water, washing of industrial products and water as a direct products of manufactured products.

Nitrogen and phosphorus compounds are among the most important constituents of municipal wastewater contamination. Both these substances are obviously the main nutrients controlling biological growth in the aquatic environment. Besides, the presence of an excess nutrients results also in a poor water quality making water unsuitable for the prospective municipal and industrial users.

The latter becomes particularly significant in the industrialized regions of the Southern Poland where the wastewater reclamation systems are planned. Both nutrients: nitrogen and phosphorus are the parameters limiting water quality with respect to application of reclaimed wastewater as an industrial water almost in all branches of industry, particularly in industrial cooling systems. Therefore, the nutrients removal technology is an important part of wastewater reclamation systems. It has also some unique features as a result of interrelation of nitrogen and phosphorus removal and other tertiary processes involved in complex wastewater reclamation technology [3].

QUALITY REQUIREMENTS FOR NUTRIENTS IN RECLAIMED WATER

Both nutrients considered: nitrogen and phosphorus are not decisive factors of water usefulness for industrial purposes in case of using natural water resources. River or lake water intakes are commonly characterized by a low concentration of nutrients; usually much below the level which is harmful for the industrial processes. For that reason some industries did not even include nutrients into their water quality requirements [7]. The problem of nutrients as quality parameters is growing bigger when the reclaimed wastewater is considered as an industrial water source. Therefore, the permissible concentration of nutrients and degree of their removal needed to be established separately for some industries.

Table i comprises the maximum recommended concentrations of nutrients determined for the industrial users of reclaimed wastewater in the South Poland. Values given for a cooling system refer to the concentration of the circulating water; a level of nutrients in the make-up water should be two times less then for the circulating water [2].

Table 1. Maximum required concetrations of nutrients for industrial reuse of reclaimed wastewater [5, 71

Reclaimed water users	**NH,-N** gN/m^3	**NO,-N** gN/m^3	**PO,** g/m^3
Metallurgy - surface cooling circulating water with heat load:			
10^6 kJ/m^2.h	1.0-3.0^x		4
10^5 "	0.5-0.8^x		4
10^4 "	3.5-6.0^x		4
Steel melting shop and rolling millsurface cooling, with water alkalinity:			
0.8 - 1.5 meq/dm^3	1.4-2.6		4
1.5 - 2.0 "	2.6-3.5		4
4.0 "	7.0		4
Foundry - moulding mass production	10.0		
Machinery industry - plating and heat treatment of metals	2.0	2	5
Power plant - cooling cycle	3-5		
- heating cycle	3		
Ceramic industry	3	12	2.5
Petrochemical industry	40	8	

^{x}higher numbers refer to short term deterioration

DEGREE OF TREATMENT

The degree to which wastewater is renovated is determined by the selection, combination and operation of unit processes. The selection of advanced treatment processes to be used in wastewater reclamation plant depends on the type and strength of wastewater available and the quality requirements of the uses considered for renovated water.

All wastewater classes' effluents coming from the conventional secondary treatment plants operating in the South Poland have been divided into both types and classes. The two types differentiate wastewater according to their inorganic content; within every type of effluent two classes were established with different levels of **organics,** suspended solids and nutrients (Table 2).

Table 2. Two classes of wastewater used for selection of wastewater reclamation processes [5]

Parameter	Maximum **values, g/m^3**	
	class 1 **/full treatment/**	**class** 2 **/highrate treatment/**
Suspended solids	**20**	**50**
COD	**40**	**100**
BOD,	20	50
NH,-N	10	40
Total N	20	60
Phosphates	5	10

Assigning the effluent to either class helps to choose a proper wastewater reclamation technology.

Water users category

Since different types of industrial plants employ the same or similar process technologies, the process water required in those manufacturing departments has the same water quality standards. It will result in applying the similar water reclamation processes for certain groups of process water which have been defined as follows [5].

Group I - high quality demineralized water used as boiler make-up water or process and rinsing water in electroplating plants

Group II - cooling water used for surface cooling systems working at high and medium heat load in steel plants

Group III - cooling water used in power plants for surface cooling. This group also includes cooling water for surface cooling at low heat load in steel plants and coke plants

Group IV - water for blast-furnace gas cooling, process water in building industry, rinsing water in paint shops

Group V - water of the poorest quality used for slag granulation hydraulic transport of slag and cinders in steel and coke plants and foundry.

To meet the quality requirements in the first three groups of uses, removal of nutrients is needed. Degree of treatment for ammonia nitrogen is within the range of 50 % to 90 %. Group I reguires ammonia concentration in reclaimed water to be less than 0,5 g N/m^3, which is practically very difficult to maintain on a continuous basis; also a high degree of denitrification is essential in this group of reclaimed water uses.

Phosphorus, another important nutrient which limits biological growth in closed cooling water systems, should also be controlled by proper, advanced wastewater treatment. A degree of phosphorus removal for reclaimed wastewater required to prevent the development of algae and slime producing organisms in cooling water circulating through cooling towers is not attainable in the conventional biological treatment processes; it requires more effective biological or chemical methods [6].

PROCESS CONFIGURATION

A specific character of nutrients removal technology, being a part of wastewater reclamation systems, results from: interrelation of other tertiary treatment processes involved, complexity of the objectives to be accomplished in the course of reclamation and importance of reclaimed water quality for its users.

Particular features that distinguish the nutrients removal processes in a wastewater reclamation system compared to those aimed at natural waters protection are:

- higher reliability and consistency of nutrients removal imposed by the importance of industrial production requirements; as a result of it double, two-stage or complementary processes are often designed.

- possibility of utilization of nutrients removal potential existing in other types of wastewater renovation processes provided to control another refractory contaminants; it improves technical and economical feasibility as well as the removal efficiency of the whole treatment system.

- operation of whole or at least a final part of the wastewater reclamation processes, under constant flow conditions.

- equalization of diurnal variation of nutrients in a final effluent since reclaimed water is usually stored for a day before pumping it to the users.

Process configuration for nitrogen and phosphorus removal, based on updated practical experiences might be applied as three options:

a) three-stage, physical-chemical processes based on lime treatment result in phosphates precipitation and rise of pH in the 1st stage and removal of ammonia gas in a stripping process applied in the 2nd stage. Break-point chlorination at the end of a technological scheme may operate as a complementary process for residual ammonia removal

b) biological nitrogen removal combined with enhanced removal of phosphorus in a multiphase biological reactor. This treatment technology, although implemented in full scale plants, is not yet reliable enough for wastewater reclamation for industrial systems.

c) combined biological and chemical process configuration. It consists of chemical precipitation as a 2nd stage of phosphorus removal following biological treatment in a multiphase reactor as in option b). Filtration and final chlorination, usually applied for other reasons at the final part of the technological scheme, may be utilized as the complementary processes to improve removal efficiency of both nutrients. The treatment option **c)** has been estimated as the most feasible technology for implementation in the South Poland [4].

EXAMPLES OF MUNICIPAL WASTEWATER RECLAMATION VENTURES IN SOUTH POLAND COMPRISING NUTRIENTS REMOVAL

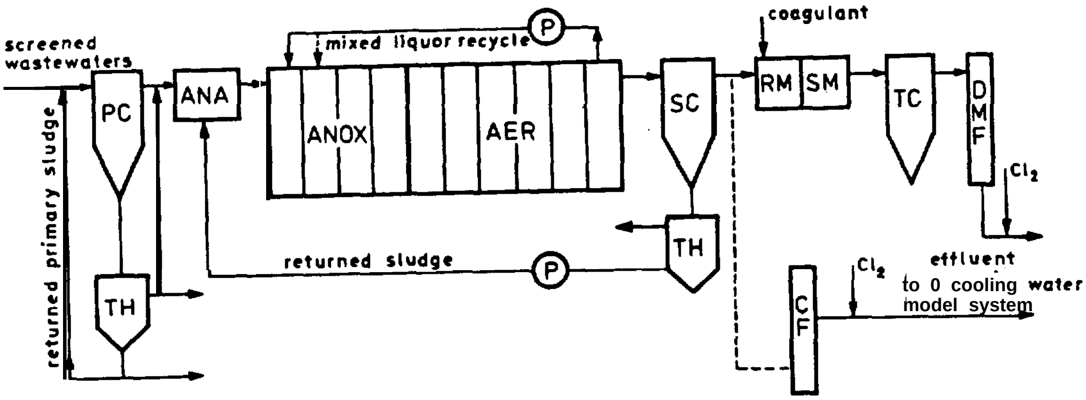
The idea of municipal wastewater reclamation for industrial reuse has emerged in Krakow in 1985 because of high salinity of Vistula river water unsuitable for supplying the industrial cooling systems. The research works that have been started in 1987 are aimed at the selection of wastewater reclamation technogies and developing the design criteria. The total capacity of the full scale plant is planned to reach 2.3 m^3/s.

The technology of the experimental pilot-scale units (Fig.1) at existing municipal wastewater treatment plant has been developed based on the experiences of the other countries, local wastewater characteristics and required water quality with respect to the cooling system requirements.

The unit processes comprise: biological nutrients removal supplemented by coagulation with alum, ferrous sulphite or lime alternatively tested, filtration and chlorination.

The efficient removal of nutrients takes place in consecutive, complementary biological-chemical and physical unit processes.

An example of a wastewater renovation plant projected within the Silesian system of water reclamation with fully developed pilot-scale technology experiments and design work is located at Tychy [2]. The existing conventional activated sludge facility has a capacity of 39 000 m^3/d. The advanced multistage process designed for wastewater reclamation is expected to obtain 15 000 m^3/d of water for mashinery industry supply. The optimum flow diagram of this plant is shown in Fig.2.



PC-primary clarifier
TH- thickener
ANA-onocrobic zone
ANOX- anoxic zone
AER- aerobic zone
SC-sccondory clarifier

SM-slow miring took
RM- ropid miring tank
TC- tertiary clarifier
DMF-dual medio filter bed
CF-contact filtration
P- pump

FIG. 1. SCHEME OF THE EXPERIMENTAL PILOT UNITS FOR CRACOW WASTEWATER RECLAMATION.

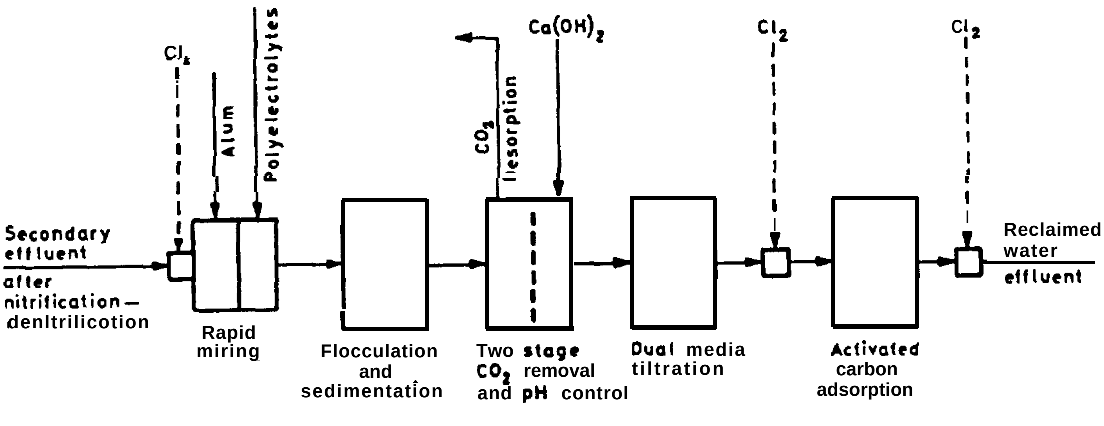


FIG. 2. OPTIMUM FLOW DIAGRAM OF WASTEWATER RECLAMATION SYSTEM SELECTEO FOR FULL SCALE PLANT AT TYCHY.

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PHOSPHORUS REMOVAL IN SMALL TREATMENT UNITS

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INTRODUCTION

The primary goal for chemical treatment is to remove phosphorus from the wastewater. Chemical treatment has mostly been used as a supplement to the biological process (simultaneous or post precipitation). However several treatment plants with only chemical precipitation are in operation. This paper covers results and operational experiences with regard to phosphorus removal in small wastewater treatment plants in Norway.

In this paper "small treatment unit" is defined as treatment plants with a design capacity equal or less than 1000 pe. Treatment plants serving one single house or a group of houses are named "mini-plants". The mini-plants are normally owned and operated by the residents. The small treatment plants are owned by municipalities and privat institutions e.g. hotels or nursing homes. In the municipalities, the plants serve small neighbourhoods. Usually the influent flow and composition of wastewater fluctuate widely. Usually the plants are placed inside buildings, concequently they are very compact. The final result is a very small and sensitive treatment system. These plants require high professional quality of the operators and the supervisors. The main operating costs for these plants are salaries for the operators, energy costs for heatling and ventilation of the buildings and costs for transport of sludge to the dewatering plants (Johansen, 1982).

For a municipality it is very expensive to have a permanent staff of process experts. To solve this problem, several publicly owned operating companies have been established. These companies employ the necessary process experts, and support the local owners of the plants.

REMOVAL OF SOLUBLE PHOSPHORUS

At the small chemical treatment plants aluminium sulphate, ferric chloride or slaked lime, are the most common flocculants. The reactions between Al”’ or Fe**+ and soluble phosphorus are briefly described by the following equations:

$$Al_2(SO_4)_3\ 18H_2O + 2PO_4^{3-} \qquad 2AlPO_4\ t\ 3SO_4^{2-}\ t\ 18H_2O \qquad 1)$$

$$Al_2(SO_4)_3\ 18H_2O\ t\ 6HCO_3^- \qquad 2Al(OH)_3\ t\ 6CO_2 + 3SO_4^{2-} + 18H_2O \qquad 2)$$

$$FeCl_3\ 6H_2O\ t\ PO_4 \qquad FePO_4\ t\ 3Cl^- + 6H_2O \qquad 3)$$

$$FeCl_3\ 6H_2O + 3HCO_3^- \qquad Fe(OH)_3\ t\ 3CO_2\ t\ 3Cl^-\ t\ 6H_2O \qquad 4)$$

Equations 1) ans 3) show that 1 mol of Me (Al or Fe) combines with 1 mol of PO, to form 1 mol of $MePO_4$. Equations 2) and 4) show that the flocculants also neutralize the alkalinity in the wastewater to form $Me(OH)_3$ and CO,. Equations 1), 2), 3) and 4) are simplified The actual reaction process is a combination of precipitation, adsorption and ion exchange.

Two criteria have to be met in the operation of small chemical wastewater plants that use Al- or Fe-salts as flocculants.

1. Addition of flocculants to achieve a molar ratio, $\frac{Me}{P} \geq 1$
2. Addition of flocculants to lower the pH value to the range where the solubility of the PO,-complex is at a minimum (figure 1).

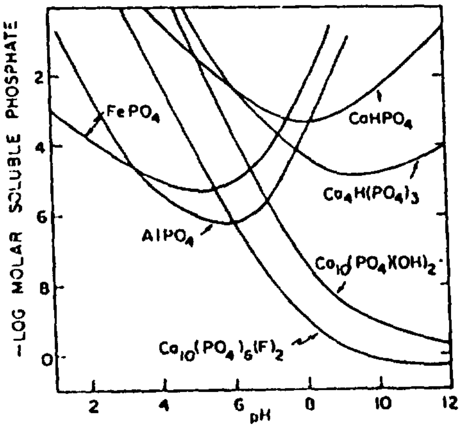

Figure 1 Solubility diagrams for solid phosphate phases (Leckie and Stumm, 1970)

Equation 5) describes the reaction between lime ($Ca(OH)_2$) and PO,. Equation 6) describes the reaction between lime and the alkalinity.

$5Ca^{2+} + 4OH^- + 3HPO_4^{2-} Ca_5OH(PO_4)_3 + 3H_2O$ 5)
$Ca^{2+} + HCO, + OH^-CaCO_3 + H_2$ 6)

Figure 1 shows that at pH values higher than 9.5, all of the calcium phosphate complexes have reached the solubility minimum. The complexes have poor settling properties. To improve the settling characteristics the pH value has to be raised to 11.0 or higher to form $CaCO_3$ and $Mg(OH)_2$. Magnesium hydroxide has a gelatinous character that improves the flocculation process.

For operation of chemical treatment plants that use lime $Ca(OH)_2$ as flocculant, one criterion has to be met:

1. Addition of $Ca(OH)_2$ to reach a pH value higher than 11.0.

If the Mg-concentration in increased by addition of seawater, the target pH value is in the range 9.5-10.0. Table 1 shows pH ranges for optimal precipitation.

Table 1 Typical pH Ranges for Otimat Precipitation (Ødegaard, 1988)

Flocculant	Practical pH range
Aluminium sulphate	5.5-6.5
Ferric chloride	5.0-6.0
Lime	11.0-12.0

For simultaneous precipitation plants the optimal pH range is 6.5-7.5. The drinking water in Norway is mainly supplied from lakes, consequently the alkalinity in the municipal wastewater is low, typically 2-3 meq/l. When nitrification occurs in the biological treatment step, the alkalinity in the wastewater is consumed. The addition of coagulants consumes the alkalinity too; as a result the pH in the chemical treatment step drops too low to obtain satisfactory precipitation of phosphorus. To counteract this reaction sodium bicarbonate ($NaHCO_3$) or lime ($CaOH_2$) are added to the biological treatment step on many plants.

FLOCULANT DOSING CONTROL SYSTEMS

At plants that are uning Al or Fe salts, pH is the most important process parameter. Normally the dosing of congulants are controlled by one of three methods.

1. Flow- proprotional control

The flocculant is added on a constant rate according to the flow through the plant. The quality of the wastewater is regarded as constant. Practical experience shows that this is not true. In periods with rain and snowmelting the alkalinity changes and the pH becomes too low to obtain optimal precipitation of phosphorus.

2. Flow - proportional control combined with pH feed - back control

The pH is monitored after addition of coagulants. If the pH value differs from the optimal value, a regulator changes the dose of coagulants added. Practical experience shows that it is difficult to adjust the regulator, resulting in pH fluctuations. This is aspecially true on small wastewater treatment plants.

3. Flow proportional control combined with alkalinity feed - foreward control.

At many plants there is a linear relationship between alkalinity and conductivity. This relationship is used to control the flocculant addition. The conductivity in the wastewater prior to the addition of flocculants is monitored. If the alkalinity in the wastewater decreases, the conductivity decreases too. The necessary dose of flocculant to reach the optimal pH range has to be roducod. So far the practical experiences with this control system are very good.

PROCESS LAY-OUT ON MINIPLANTS FOR PHOSPHORUS REMOVAL

Phosphorus removal in plants that are serving one single house is uncommon. However in some areas in NOrway for instance, the Pollution Control Authorities require phosphorus removal on the mini-plants as well. Figure 2 shows a miniplant for chemical treatment.

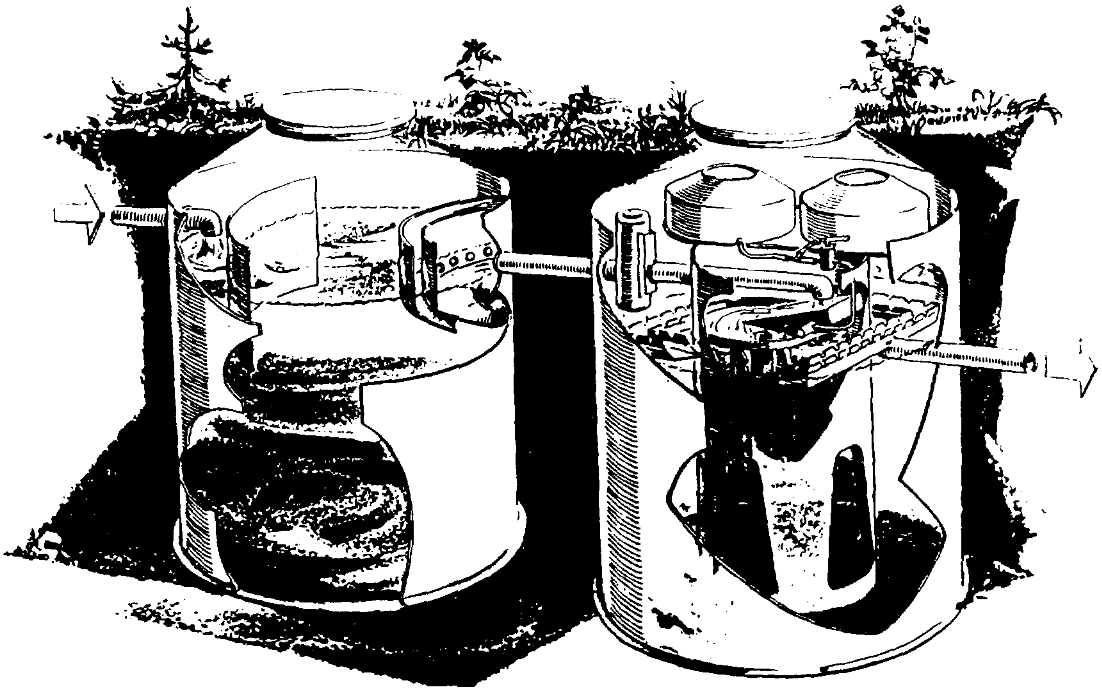

Figure 2 Mini-plant (WALLAX) for chemical treatment

This plant consists of a septic tank and a chemical treatment tank. From the septic tank settled sewage is discharged through a box which is emptied automatically by means of the balancing weight principle. This box also activates a valve, and aluminium sulfate is dosed and mixed with the wastewater. Chemical sludge i stored in the settling tank and has to be removed 4 to 5 times a year.

Figure 3 shows an example of a miniplant for biological and chemical treatment.

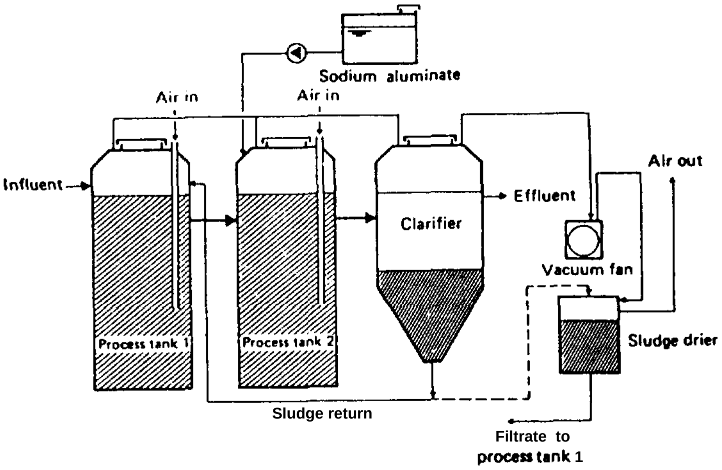

Figure 3 Mini-plant (BIOVAC) for biological and chemical treatment plant.

In the two process tanks the wastewater is biologically treated in a activated sludge system. A vacuum fan suchs air into the process tanks, keeps the sludge in suspension and recycles the sludge from the clarifier. Liquid sodium aluminate is used as the precipitant. It is added to process tank 2 intermittently.

PROCESS LAY-OUT FOR SMALL CHEMICAL AND BIOLOGICAL-CHEMICAL TREATMENT PLANTS

Figure 4 and 5 shows common process layouts for small biological and biological-chemical treatment plants.

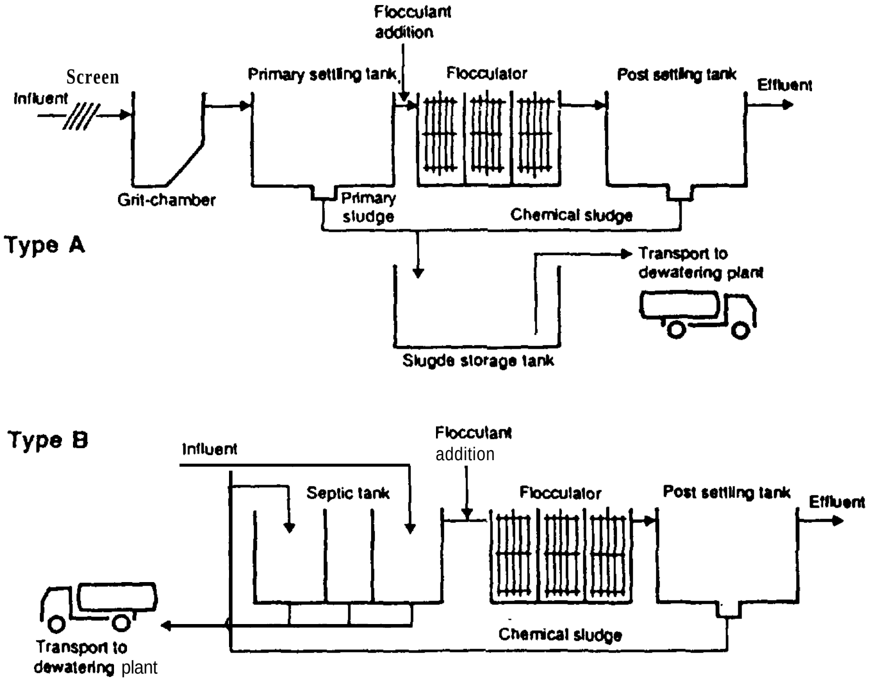

Figure 4 Process layout small chemical treatment plant.

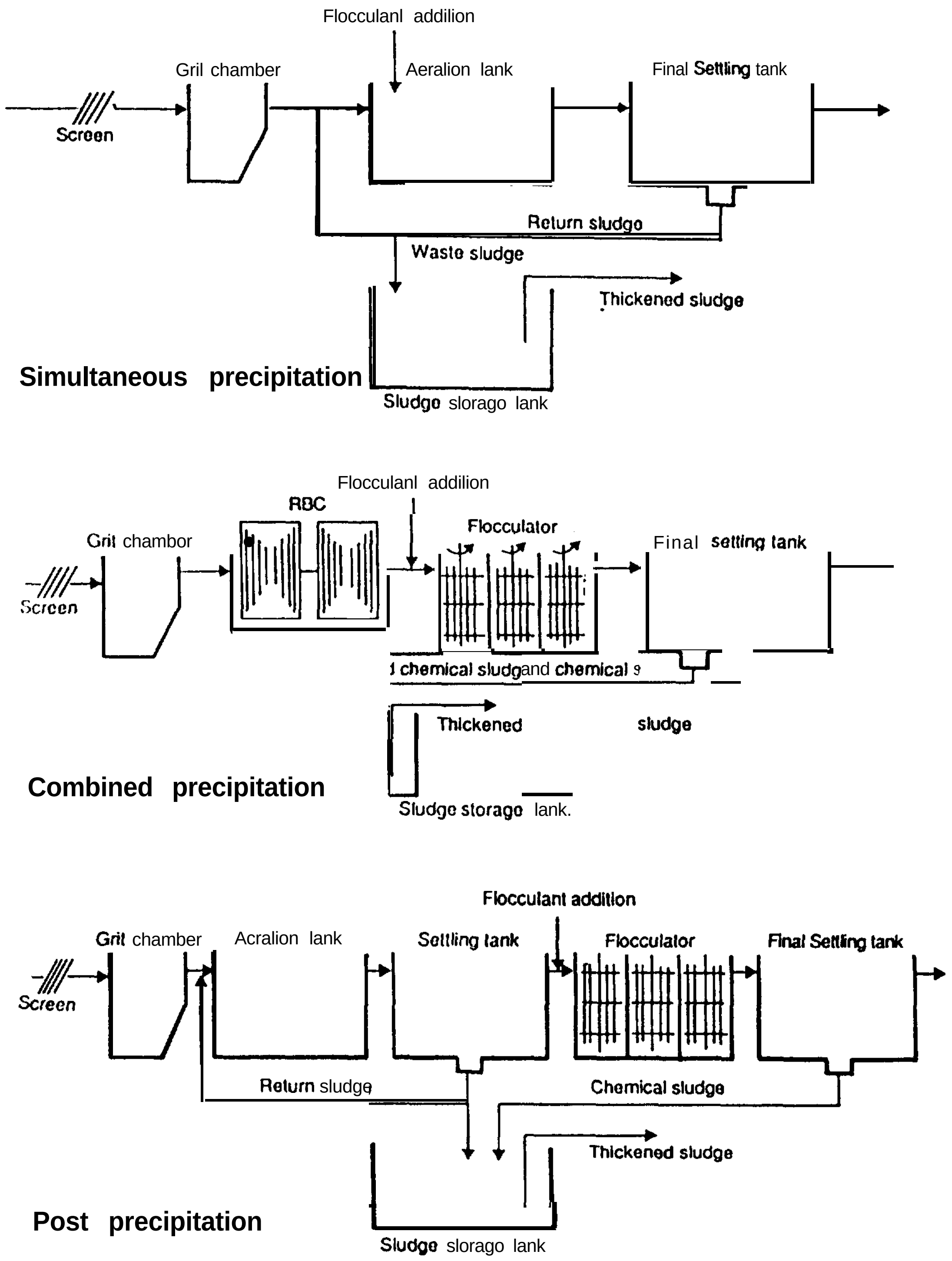

Figure 5 Process combination for biological and chemical treatment

The pretreatment of the wastewater consists of a bar screen and grit chamber, or a septic tank. The septic tank is used as a combination of pretreatment unit and sludge storage tank.

The flocculants are added by a dosing pump or a dry feeder to a continuously operating dissolving unit. The flocculator is divided into 2 or 3 separate chambers with vertical paddlers. Sludge from the settling tanks is pumped to a separate sludge storage tank or to a septic tank. From the storage tanks, the sludge is transported to a larger plant for dewatering.

Table 2 Effluent Standards for Small Treatment Plants

Process	Annual average (g/m^3)	
	tot-P	BOD7
Mini-plants:		
Chemical	1.5	
Biological chemical	1.0	20
Chemical treatment	0.5	60
Simultaneous precipitation	1.0	30
Combined precipitation and post precipitation	0.5	15

Undoubtedly all process combinations are available to meet the effluent standards. However, an number of factors influence the performance stability of the plants.

TREATMENT RESULTS

It is of great importance to have reliable information concerning the performance of the treatment plants, because the investment and operating costs are considerable, and the plants play an important role in the protection of the inland waters.

Mini-plants

Treatment results from the mini-plants are very scarce. In Norway all mini-plants have to pass an approval system. In this system the plants are tested for half a year.

The treatment plants that are shown in figure 4 (WALLAX) have been tested. For three plants the average effluent concentration for tot-P was 0.8 mgP/l. Minimum and maximum values were 0.4 and 1.9 mg P/l.

Two BIOVAC plants (figuro 4) have been tested and the average effluent concentration for tot-P was 0.6 mg P/l. Minimum and maximum values were 0.1 and 2 mg P/l.

A signed service contract is required in order to get permission to install a mini-plant. The operating experience shows that the service contract is the most important factor to obtain reliable treatment results.

Chemical treatment plants

The treatment process is normally monitored by frequent analyses of PO_4-P in the effluent and measurements of the pH value and secchi depth. This is done by the operator. The pollution control authorities sample for discharge control 4-6 times per year. Normally, flow proportional one day composite samples are taken. Table 3 gives some basic information on 17 small chemical treatment plants in Norway and Sweden.

Table 3 Basic Information on 17 small Chemical Treatment Plants

Name of the plant	No	Design Pe	Actual Pe	Average flow (m^3/day)	Type of floccu- lant	Average dose (g/m^3)	Type of wastewater
Østby	1	700	30	72	Al-sulphate	247	Municipal
Strandlykkja	2	160	varies	9	Al-sulphate	177	Municipal
Sjusjøen	3	1000	-	173	Al-sulphate	245	Recr.area
Fagerfjell	4			59	Al-sul./Fe-cl.	-	Hotel
Flesberg	5	600	230	89	Al-sulphate	150	Municipal
Sollihøgda	6	100	varies	-	Al-sulphate	140	Municipal
Mykingården	87	-	-	49	Al-sulphate	200	Nurs.home
	9				Fe-chloride	-	Hotel
Hyggen				25			
Døvika	10	400 220	400	73	Al-sulphate Al-sulphate	230 170	Municipal Municipal
Vrangfoss	11	600	60	170	Al-sulphate	133	Municipal
Svenseid	12	380		173	Al-sulphate	275	Municipal
Akkerhaugen	13	900	500		Al-sulphate	81	Municipal
Ualand	14	400	100	-	Lime	500	Municipal
Drangsen	15	190	100	20	Lime	820	Municipal
Köinge	16	360	210	249	Lime	284	Municipal
Fagered	17	300	40	29	Lime	486	Municipal

Ortho-P in the influent is not a routine analysis, but based on previous experience (Eikum et al., 1979) the soluble phosphorus corresponds to 60 % of the total phosphorus. The molar ratio Al or Fe is in the range 3 to 4. This is due to high ***alkalinity*** in the wastewater and less than optimum utilization of flocculants.

The annual average influent and effluent concentrations for total P from 17 small chemical treatment plants are computed and shown in figure 6.

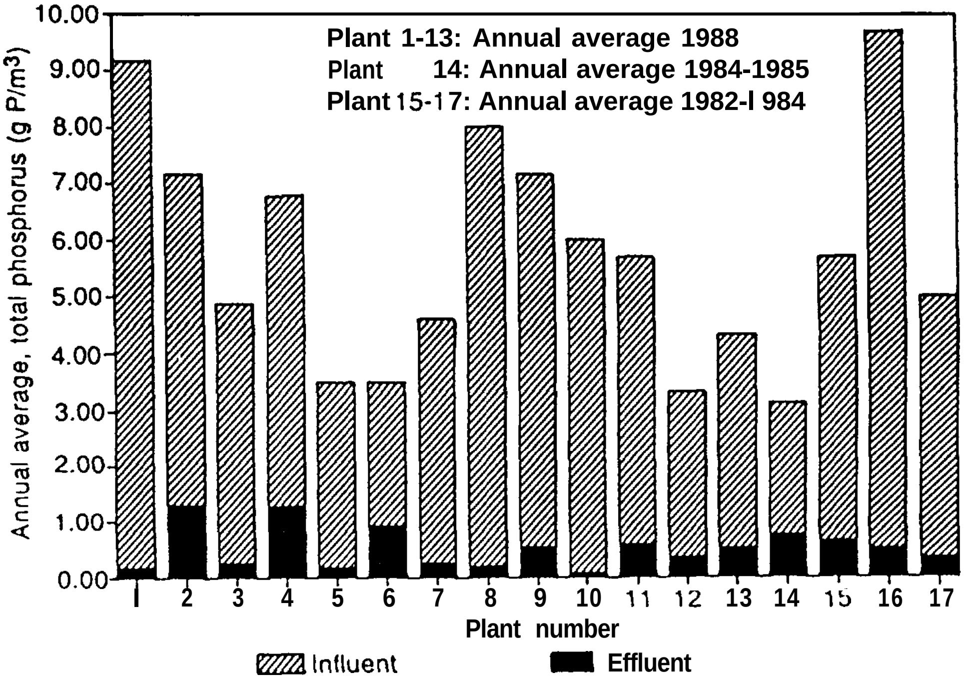

Figure 6 Annual averages for **influent** and effluent concentrations of tot-p from 17 chemical treatment plants.

Biological-chemical treatment plants

In 1985 an investigation of the effluent concentrations from all treatment plants in Norway was conducted. The investigation includes information about 174 small (design capacity 50 to 1000 pe) biological-chemical treatment plants. The most important characteristics for the process combinations are shown in table 4.

Table 4 Background Data for the Treatment Plants Included in the Survey

Process	Number of plants	Median			Total number of samples			Average number of samples		
		Design cap. (PE)	Actual load %	Years in operation (years)	totP	BOD7	SS	totP	BOD7	SS
Simultaneous precipitation										
Activated sludge	88	300	62	8	403	349	239	4.58	3.97	2.72
Combined precipitation										
RBC	36	400	50	6	163	149	26	4.52	4.14	0.72
Poet precipitation										
Activated sludge	49	500	48	6	234	165	152	4.77	3.37	3.10

Table 4 shows that simultaneous precipitation plants are the largest group. Fifty percent of the plants have a design capacity equal or less than 300 PE. The simultaneous precipitation plants have been in operation for a longer period of time compared to the combined and post precipitation plants. This is due to the fact that many of the simultaneous precipitation plants are former biological treatment plants. Consequently the plants are not designed for phosphorus removal.

Suspended solids (SS) is normally not a part of the discharge permit, consequently the number of SS data is small compared to the number of tot-P and BOD, data.

For each plant the annual average (1985) was computed for tot-P, BOD, and SS. The annual averages for the plants are shown in cumulative frequency plots in figure 7 and figure 8. Table 5 shows average and median concentration, and average removal efficiency for each process combination.

Table 5 Average and Median Effluent Concentrations, and Average Removal Efficiencies

Process	Average concentr. (g/m^3)			Median concentr. (g/m^3)			Average removal efficiency (%)	
	tot-P	BOD_7	SS	tot-P	BOD_7	SS	tot-P	BOD7
Simultaneous precipitation								
Activated sludge	1.75	45	40	1.2	18	36	82	85
Combined precipitation								
Biological contactor	1.47	25	30	0.8	10	27	82	85
Post precipitation								
Activated sludge	1.0	15	17	0.54	11	14	92	93

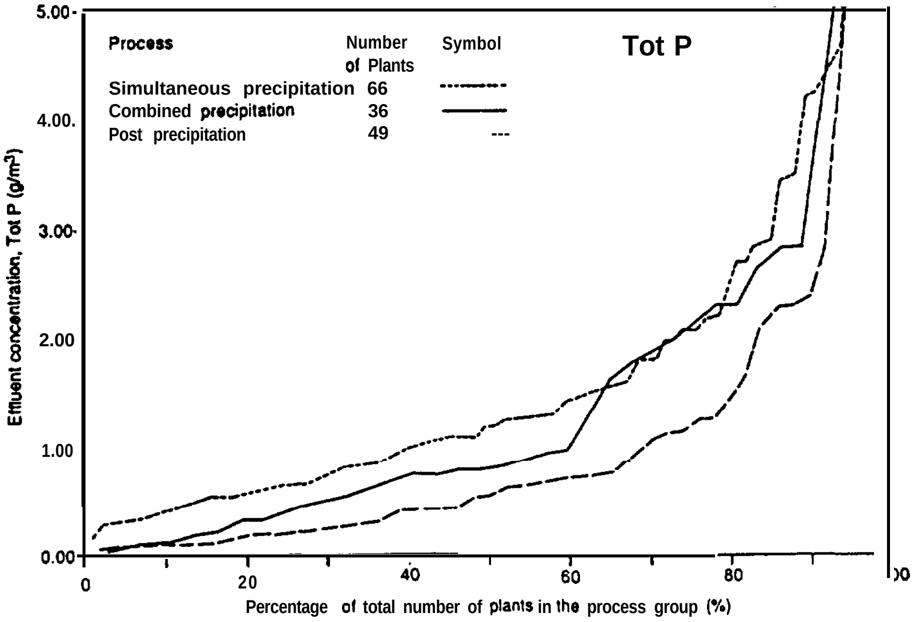

Fig. 7. Cumulative frequency plots of annual averages for tot-P.

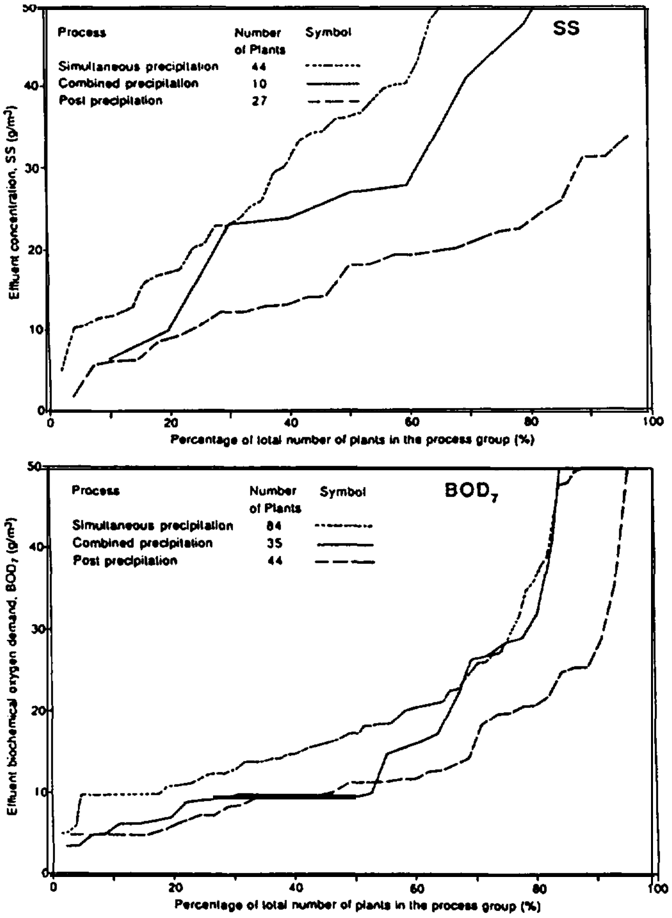

Fig. 8. Cumulative frequency plots of annual averages for SS and BOD$_7$.

Figure 7, figure 8 and table 5 clearly show that the process combinations have different levels of performance. Simultaneous precipitation has the highest concentrations for tot-P, BOD, and SS. Fifty percent of the post precipitation plants meet the effluent standard for phosphorous removal and 70 % meet the effluent standard for removal of BOD,. Thirty percent of the combined precipitation plants meet the effluent standard for phosporous removal and 60 % meet the standard for removal of BOD,. Forty percent of the simultaneous preicipitation plants meet the standard for phosporous removal and 75 % meet the standard for removal of BOD,.

The frequency plots for SS (figure 8) show that the difference in effluent concentrations between the process combinations is partly due to the variation in the removal of particles. The separate settling tank for biological sludge on the post precipitation plants is very favorable. Consequently the chemical treatment step acts as a trap for biological sludge that escapes from the biological settling tank. In most instances flocculation prior to floc separation will improve separation on fine particles (Ødegaard, 1987). The difference in effluent concentrations between simultaneous precipitation and combined precipitation supports this observation, Combined precipitation and simultaneous precipitation shows the same removal efficiency. This is partly due to higher influent concentrations on the simultaneous precipitation plants. Many of the simultaneous precipitation plants do not use automatic sampling units for the influent samples. The influent concentrations are consequently based on grab samples.

FACTORS THAT HAVE INFLUENCE ON THE TREATMENT PLANT PERFORMANCE

There are many factors that influence the effluent concentration at treatment plants apart from the basic differences in process. Table 6 shows the factors that were judged by the local water authorities and plant owners in the investigation in 1985 as the most important critical factors.

Table 6 Factors that Negatively Influence Treatment Plant Performance

Factor	Simultaneous precipitation %	Combined precipitation %	Post precipitation %	Total (all groups) %
Lou quality of the sewer system	33	42	27	33
Unsatisfactory design of the plant	38	22	4	25
Low hydraulic and organic loading	7	11	10	9
High hydraulic and organic loading	9	17	6	10
Bad maintenance	7	8	4	6
Equipment breakdown	13	19	6	12
Organizational problems	25	22	8	20
Industrial effluents	6	14	0	6
Miscellaneous	8	17	6	9

Usually more than one factor is regarded as responsible for the problems on the plants that do not meet the effluent standards, consequently the columns in the table add up to more than 100 %.

In most cases it is a combination of several factors that cause the problems. Table 4 shows that several factors are regarded as very important. These are:

Low quality of the sewer system

Precipitation and snowmelting cause the influent flow to increase considerably owing to leakage into the sewer system. This is especially important for the simultaneous precipitation plants, because sludge is lost in the effluent.

Unsatisfactory design of the treatment plants

Many of the simultaneous precipitation plants were not originally designed for phosphorus removal. The area of the final settling tank is too small, censequently the hydraulic surface load is too high. Mechanical problems with the RBC units are important factors causing many of the combined precipitation plants to exceed the effluent standards. Some of the problems are due to overloading of the first step of the RBC unit, causing excessive growth and problems with the bearings and shaft as a consequence (Ødegaard, 1983).

Organizational problems

The small treatment plants are owned by local communities or private institutions. Generally the operators are well trained to do the daily routine tasks. However, supervisors at the next level in the community do not always seem to give treatment plant operation high priority. This is primarily due to lack of understanding regardling treatment plants operation. Managing of treatment plant operation is only a minor part of the supervisors daily work, consequently other tasks got a higher priority.

Table 6 shows that the remaining factors that negatively influence the treatment plant performance are regarded as almost equally important.

CONCLUSIONS

1: Low quality of the sewer system, unsatisfactory design of the plants and organizational problems are the main factors that cause small wastewater treatment plants not to meet the effluent standards.

2: Better flow equalization and particle separation are the basic demands to achieve lower effluent concentrations of tot P and BOD,.

3: To meet the goals of our effort in pollution control, operational management is just as important as the design and qualityof each individual plant. Advanced treatment systems should mainly be used for larger treatment facilities where the necessary operational knowledge exists.

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PRE- AND POST PRECIPITATION

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Kemira Kemi Ab - Water Treatment

INTRODUCTION

In Sweden we have had considerable experience of chemical precipitation as phosphorus reduction demands were introduced in the country some 15-20 years ago. Fig 1 shows treatment developments in Sweden up to the present day.

For phosphorus reduction the mechanical and biological treatment processes have mostly been supplemented by the addition of a third stage - a chemical post-precipitation stage - which has made it possible to achieve total phosphorus effluent values of 0.5 mg/l and below. Biological phosphorus removal has had not great success in Sweden because it is difficult to achieve total values below 2 mg of phosphorus per litre of water. On the other hand, chemical post-precipitation has not achieved great success outside the Scandinavian countries because of the high investment cost it involves. Simultaneous precipitation processes are not common in Sweden without a complementary reduction stage.

Post precipitation is often combined with two points dosing or return sludge pumping of the chemical sludge to the primary or secondary treatment stage.

POST PRECIPITATION

Post precipitation is a method when very strict phosphorus demands, below **0,3** mg P_{tot} per litre, has to be obtained. It gives very stable results even at different hydraulic loads.

The post precipitation process gives very low concentrations of dissolved phosphorus and is of course depending on an efficient separation stage, which can be sedimentation, flotation or filtration.

For an efficient precipitation and flocculation effect the pH is important. Different precipitants show different pH optimum. (Fig 2)

To reach the optimal pH age excess of the metal salt can be dosed.

100 mg/l of Kemira AVR or 150 g of Kemira JKL consumes 0,6 mekv/l of the alcalinity. This method to regulate the pH is simple but the sludge production increases.

Another way is to dose an acid for example H_2SO_4. 30 mg/l of H_2SO_4 consumes 0,6 mekv alcalinity. Sulphuric acid gives no sludge but it is necessary to use two chemicals.

A third way to reach an optimal pH is to produce the H^+ by nitrification. Oxidation of 4,5 mg/l N decreases the alcalinity 0,6 mekv/l.

From an economical point of view the cost for 100 g AVR is about 6 Finnish pennies. For 30 g H_2SO_4 about 1,5 pennies and for nitrification the energy cost only about 0,5 pennies.

A new generation of chemicals the poly-metal salts, for instance Kemira PAX, are less sensitive for pH. A good floc formation and separation is possible at a higher pH.

The precipitation of phosphorus requires about 1,5 mol Me^{3+} to react with 1 mol HPO_4^{2-}. That is 15 g Kemira AVR per gram P. In practice a higher dosage is necessary when the precipitated phosphorus floc is very small and difficult to separate. The fluffy hydroxid floc gives through sweep coagulation and a bigger floc good separation possibilities. If a filter is used for separation, the floc formation is not that important.

The post precipitation process is also very efficient in removal of suspended solids. It serves as a very good complement to a high loaded biological stage.

Chemical treatment removes particles down to 0,1 µm. This means that bacteria and virus are removed almost totally. (Fig 3)

The third stage can also serve as a guard for hydraulic peaks and pick up loss of MLSS. The sludge age and nitrification can be saved. An industrial discharge can inhibit the biological activity, the post precipitation stage can protect the recipient.

In many cases it is very favourable to pump the chemical sludge back to the influent and take it out together with the mechanical sludge or the biological excess sludge. It improves the thickening and dewatering process at the plant but it also reduces the phosphorus content in the biological effluent before the chemical post precipitation step. (Fig 4)

This pre-reduction of phosphorus results in a lower concentration of phosphorus in the sludge from the chemical stage, if the same dosage is used with and without sludge pumping. The effluent is then less sensitive to suspended solids. A two point dosing has the same influence.

For pre-precipitation and simultaneous precipitation processes without a third stage the concentration of phosphorus in the suspended solids in the effluent is very important for the total removal efficiency.

If simultaneous precipitation is used compared to pre-precipitation shows that 20 mg SS in the effluent gives 1 and 0,44 mg respectively P per litre only as suspended phosphorus (Fig 5). Total phosphorus in these examples will be higher.

PRE-PRECIPITATION

It is generally known that trivalent metal salts are good at removing suspended solids from a turbid water. In the process used to treat surface water, to produce potable water, aluminum salts are often used to destabilize and flocculate the pollutants. Some times, highly charged metal ion complexes such as polyaluminum sulphate or polyaluminum chloride is used because it is more effective in this process than a salt with a lower valence.

The organic matter in sewage water not removed by the gravity over primary tank is in stable suspension, consisting of particles smaller than 0.1 mm. This stable suspension may be destabilized by using the low molecular, highly charged metal salts mentioned earlier. These salts are also able to form fluffy hydroxide flocs that can arrest the destabilized particles through general sweep coagulation. Large aggregates capable of being sedimentated are formed. Dissolved compounds like phosphorus are precipitated at the same time. Fig 6 shows that with an effective precipitant and with good initial mixing and flock formation, particles down to 0.1µ may be destabilized, coagulated and removed from the waste water.

Measured in terms of organic substance these correspond to a total reduction of some 75 % or even more for normal municipal sewage. Phosphorus reduction then often exceeds 90 %.

The size distribution of particles between 0.6 to 9 µ in sewage water has been studied in our laboratory.

The volume of the particles was measured in 13 different size ranges.

The sewage water then was precipitated with different chemicals at different dosages. A maximum peak of particles was found in the size range 0,5 - 1,5 µ. (Fig 7)

The percent removal for particles down to about 2 µ was very effective by chemical treatment, about 90 % was removed.

The smaller particles, size about 1 µ, the removal efficiency was related to the chemical dosage. This removal differs between 50-80 %. (Fig 8)

A good example of a direct precipitation plant is the large VEAS treatment plant outside Oslo, see fig 3, which has been designed to handle about 400 000 m^3 a day. (Fig 9)

The retention time in this plant is only 3 hours. In Norway with direct precipitation more than 50 sewage plants show a reduction efficiency of more than 75 % for BOD and more than 90 % for total phosphorus. (Fig 10)

NITRIFICATION

In Scandinavia we are now facing a new situation concerning nitrogen. Our coast line waters in northern Europe show very serious problems with algae blooms and anaerobic bottom conditions. We must decrease the discharge of nitrogen to our sea waters. For our sewage plants this is a problem because most of them have too small biological volumes and retention times to achieve nitrification and denitrification in existing volumes. We have to increase the volumes according to today's technical knowledge. Here chemical pre-treatment and unloading with pre-precipitating technique is very favourable. To build up a nitrifying system it is necessary to increase the sludge age high enough to let the slow growing autotrophics not be washed out from the biological system. Especially during winter with our low water temperatures, often below 10°C, it is necessary to have a high sludge age. The rate of nitrification is very low at low water temperatures.

With an increasing sludge age it is possible to maintain the same degree of nitrification even at low water temperatures.

In a trickling filter the nitrifiers start to grow when most of the organic matter is consumed and the number of the fast growing hetrotrophics start to decrease. Big volumes and surface are necessary if the BOD/N-ratio is high. The lower BOD/N-ratio, the smaller surface in the trickling filter to achieve nitrification. (Fig 11)

For an activated sludge process the sludge age is one of the most important parameters for nitrification. For cool water a very high sludge age is necessary.

An increased removal of organic matter and suspended solids over the primary tank with 100 %, which can be expected when pre-precipitation is introduced, will also double the sludge age if the same tank volume and sludge concentration is used. Of course simultaneous precipitation decreases the sludge age because of the sludge production of the chemical in the biological stage. (Fig 12)

Sewage water from chemical treatment contains normally just about 25 % of the original organic content. The organic matter is mainly in a dissolved readily degradable form. Next figure 13 shows the chemical oxidation rate of different fractions of the sewage water. (Fig 13)

The remaining part after chemical treatment shows the highest oxidation rate, about four times higher compared to some part of the effluent from primary treatment.

To use the chemical treated water in a compact biological process with a biological fixed film system can be of a great interest, as this combination can be volume saving.

When sewage water passes the fixed biological film soluble organic and nutrients diffuse into the biofilm together with oxygen. In this oxidation process it is an advantage if the organic matter is in a soluble form, because it can penetrate the bacterial membrane directly.

Organic matter in collodial and in bigger particulate form are adsorbed on the biofilm’s surface and solubilized by enzymatic activity before it can penetrate the bacterial membrane and serve as an electron donor.

The pre-precipitation gives a water with a very low content of particles which should be an advantage in combination with a fixed film biosystem. The possibility to increase the sludge content together with a high oxidation rate of the organic matter is volume saving and sludge age increasing compared to conventional biological treatment.

Pilot plant tests to study fixed film system with and without pre-precipitation have been carried out at Helsingborg’s waste water plant.

With pre-precipitation it was possible to operate the plant with 100 % nitrification at twice the hydraulic load compared to the presettled line. For simultaneous precipitation the retention time was four times longer compared to the pre-precipitated.

DENITRIFICATION

Denitrification may be carried out using either one or two main principles: pre-denitrification or post-denitrification. The latter process takes place downstream of the nitrification stage, the former upstreams. To utilize the nitrate the environment must be anoxic, i.e. without dissolved oxygen. A degradable carbon source is also required, unless endogenous respiration is used, which requires very long retention times. Methanol is a conceivable source of carbon that provides a high rate of oxidation but it costs about FIM 0.06 per gram reduced nitrogen. Thus, the methanol cost of total nitrogen reduction in a denitrification process is about FIM 24 per person per year. This high expense and the toxicity problems of methanol makes it important to use a cheap carbon sources, e.g. industrial waste products or internal carbon sources. The use of primary sludge is possible, but the oxidation rate is low for unprocessed sludge, in addition to which, the quantity in conventional treatment is barely enough. To remove BOD upstream of a nitrification stadge and then return the BOD to the denitrification stage as a source of carbon is an interesting process alternative. The quantity of organic substance precipitated consists of particles down towards 0.1 µ. The biological oxidation rate of the fraction added through pre-precipitation is higher than that of normally primary sludge, and it is also possible to hydrolyse the sludge to increase further the availability. The higher oxidation rate the carbon source shows, the smaller denitrification volume is necessary.

BOD influent = 200 g BOD, primary effluent is 130 measured as BOD and 70 g BOD per m^3 primary sludge is produced. If 5 g BOD is required per gram reduced nitrogen and all primary sludge can be used, it is sufficient to reduce 14 g of nitrogen. It is very doubtful whatever this will work as a large part of this BOD is difficult to degrade. With normal pre-precipitation 75 % of the influent BOD is removed over the primary tanks, which involves a fraction of

BOD that is readily degradable compared to the normal primary sludge. The amount 150 g BOD should be enough for a reduction of 30 g of nitrogen.

If the anoxic zone upstream of the nitrification stage is constructed, the influent waste water may serve as a source of carbon. The nitrate is returned by the return sludge and possibly by a separate return operation. Pre-precipitation has the advantage that only the most readily degradable part of the BOD is present. The anoxic zone can be utilized in terms of volume and retention time. For the best efficiency an utilization of the waste water's internal carbon sources, pre- and post-denitrification should be combined.

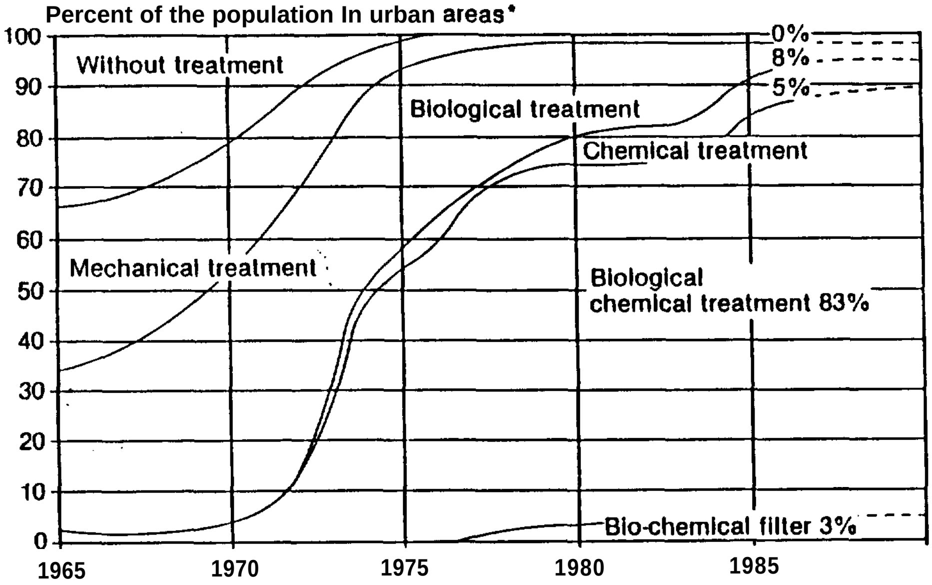
ECONOMICAL ASPECTS

The Swedish Water Work's Association (VAV) has made an economical study for a Swedish sewage plants to reach 75 % of nitrogen removal. The size of the plant is 100 000 pe and the flow 40 000 m^3/day. The retention time in the activated stage has to be increased, aeration and anoxic zones, to 12 hours. The total cost to build 1 m^3 of aeration tank volume is estimated to FIM 2040. The capital cost, 12 % rate of interest, depreciation 20 years buildings, 10 years machinery, gives FIM 0.44 per m^3 of treated water for 12 hours retention time in the aeration tank. With pre-precipitation it is possible to double the sludge age without tank expansion. For denitrification the volume saving is more difficult to predict, when both pre- and post-denitrification is used. The difference in the systems is the distribution of particles between 100 micron and 1 micron which have a low oxidation rate, see fig 13.

In the pre-precipitation process this organic matter is extracted over the primary tanks, hydrolyzed and used in the post- or pre-denitrification process. In the conventional system this organic part is not used in the pre-denitrification stage if the volume is not very big because the retention time is too short. It is oxidized in the aerobic stage. This organic matter, about 25 % of the influent, represents for a municipal sewage water a value of FIM 0.06 per m^3 if it substitutes methanol or FIM 10 per pe and year. This will pay for the precipitant in the pre-precipitation, which normally costs about the same.

The volume savings for nitrification can be halved. Also for denitrification with hydrolysed sludge some volume savings can be expected compared to a system with internal carbon source. With a volume saving of 4 hours' retention time, the capital cost is decreased in the mentioned example with more than 20 FIM per pe and year.

Sewage treatment *in* Sweden 1965-1986



• Urban areas, > 200 inhabitants and < 200 m distance between buildings. ~ 85% of total population.

Fig. 1

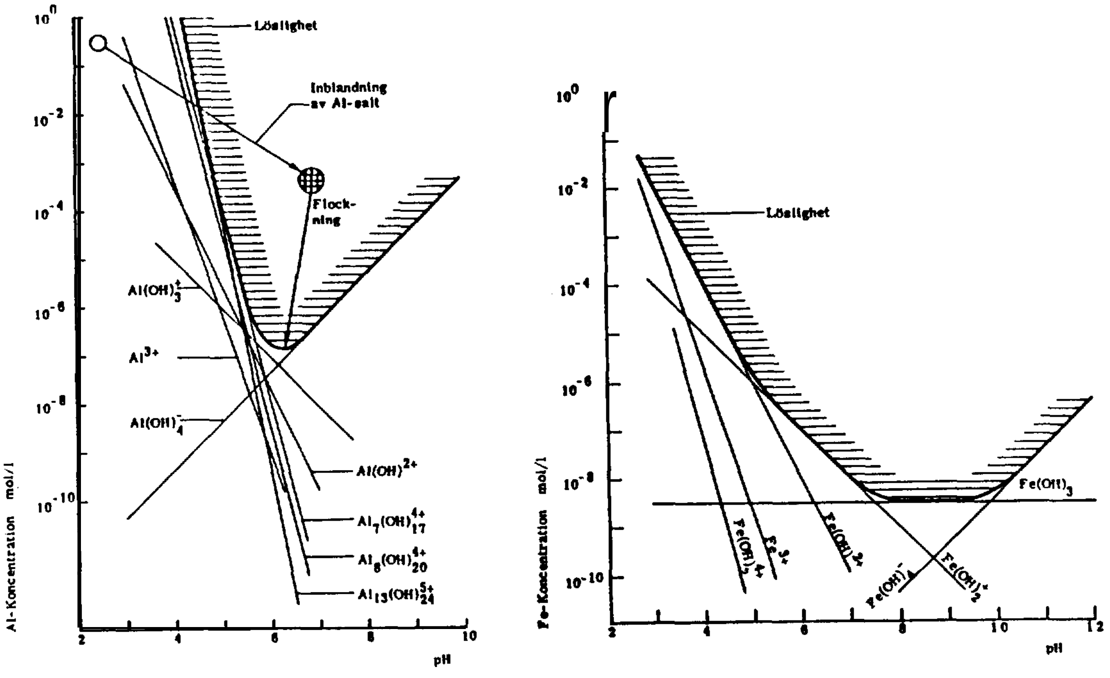


Fig. 2

Virusremoval by chemical coagulation

(M. Chaudhuri, R. Engelbrecht)

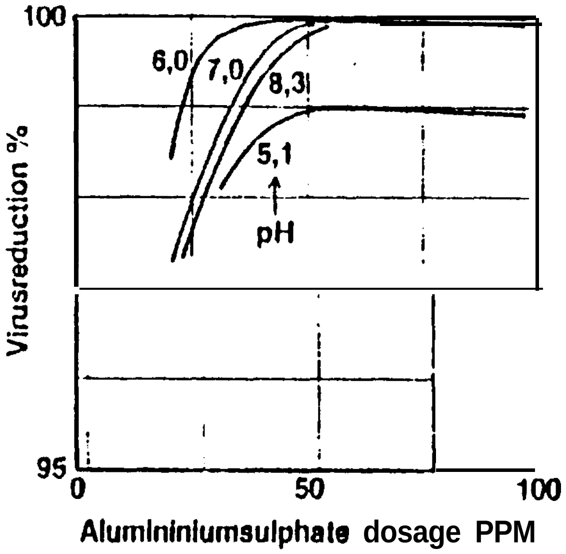


Fig. 3

Bengt Hultman
Fosforreduktion vid kommunala reningsverk

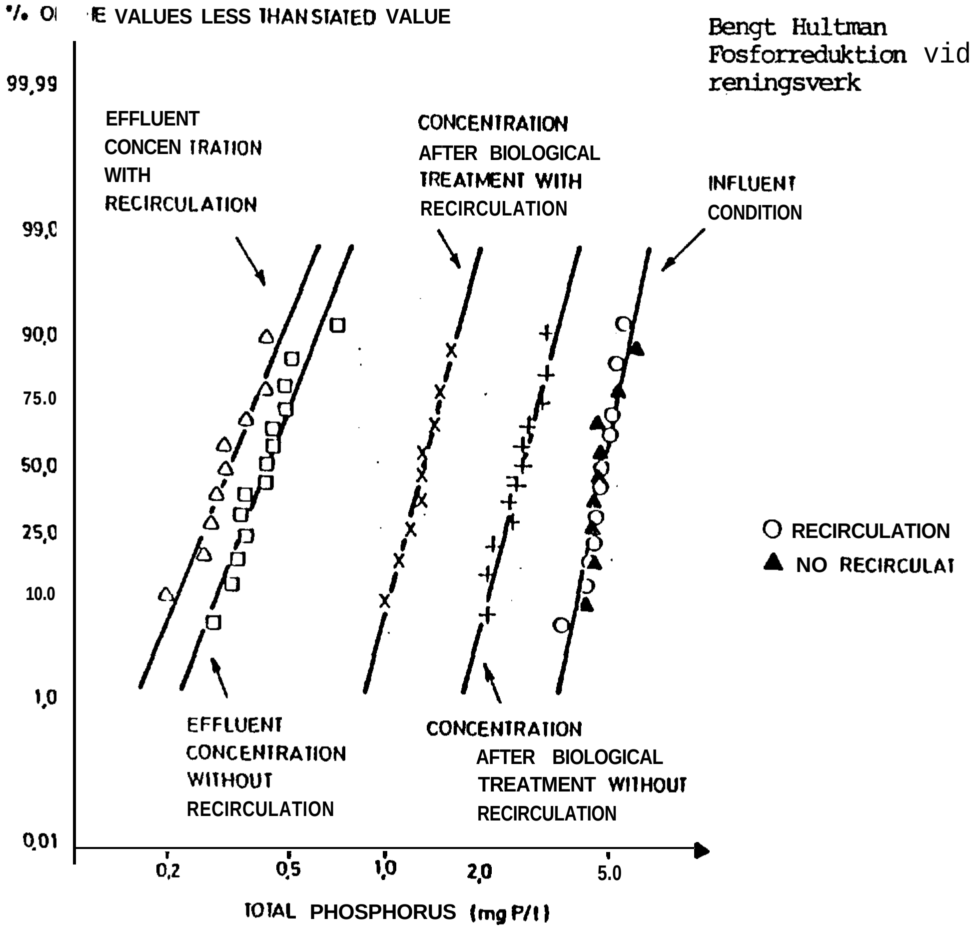


Fig. 4

PRECIPITATION

Chemical Dosage 320 mmol

SIMULTANEOUS

Influent	**Primary** effluent	Secondary effluent	
BOO: 200	140	10	
P: 8	6		
Biosludge:		10	% P **in sludge: 5%**
Chemical sludge:		50	
			SS = 20 gives 1 **ppm** P

PRE

800: 200	80	10	
P: 8	1		
Biosludge:		40	% P in sludge: **2,2%**
Chemical sludge:	45	5	
			ss = 20 **gives 0,44 ppm** P

Fig. 5

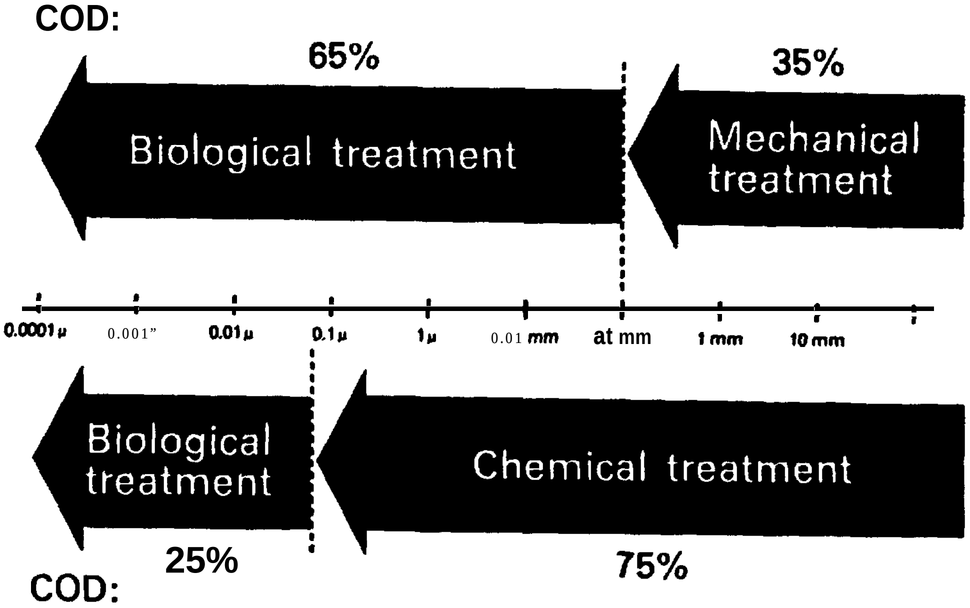


Fig. 6

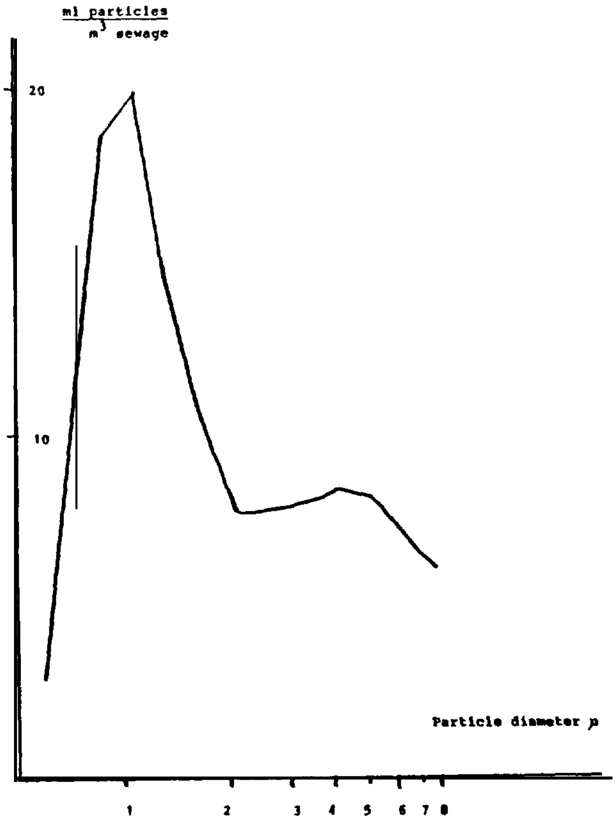

ml particles / m3 sewage
20
10
Particle diameter μ
1
2
3
4
5
6
7
8

Fig. 7

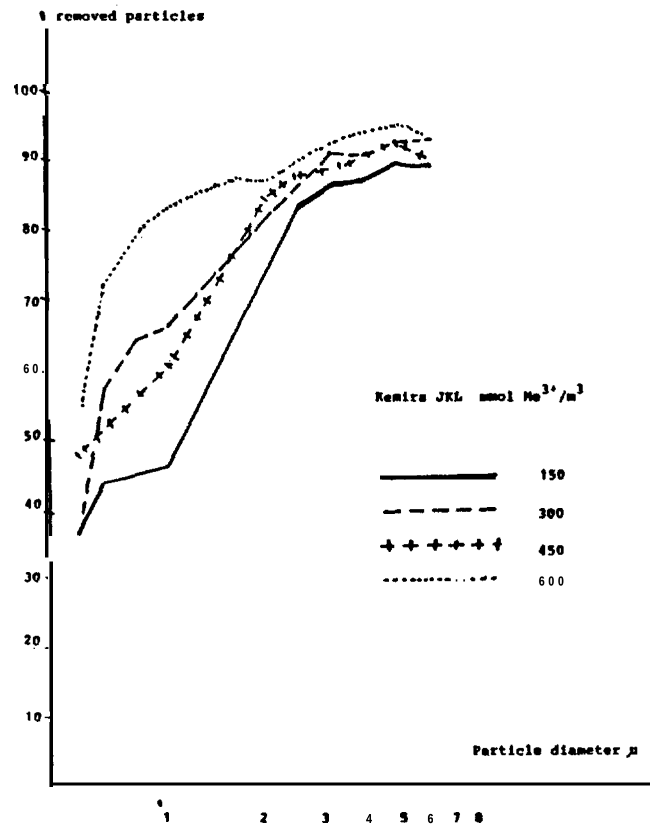
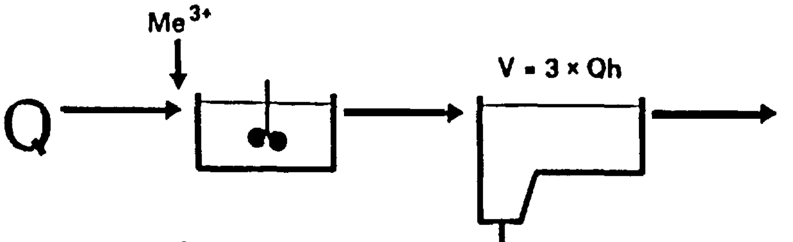

% removed particles
100
90
80
70
60
50
40
30
20
10
Kemira JKL mmol Me3+/m3
150
300
450
600
Particle diameter μ
1
2
3
4
5
6
7
8

Fig. 8

Direct Precipitation

VEAS



Q = 300.000 m^3/d
Dosage:
430 m mol Me^{3+}/m^3

		Influent mg/l	Effluent mg/l
BOD		140	30
SS		110	10
P	tot	3.5	0.2
N	tot	15	11

Fig. 9

Process	Number of plants	SS			BOD			COD			TOT.P		
		In	out	%	in	out	%	In	out	%	In	out	%
PP	23	172	27	04.3	216	42	80.6	313	82	70.6	5.5	0.54	W.2
SP	33	218	22	09.9	238	38	84.9	404	74	81.6	7.1	0.50	83.0
PP & SP	56	387	24	87.6	229	39	83.0	350	83	70.9	6.2	0.52	91.6

1985 yearly average treatment results obtained in 56 chemical, non- biological treatment plants in Norway, ranging in size from 2.000 - 750.000 PE.

Fig. 10

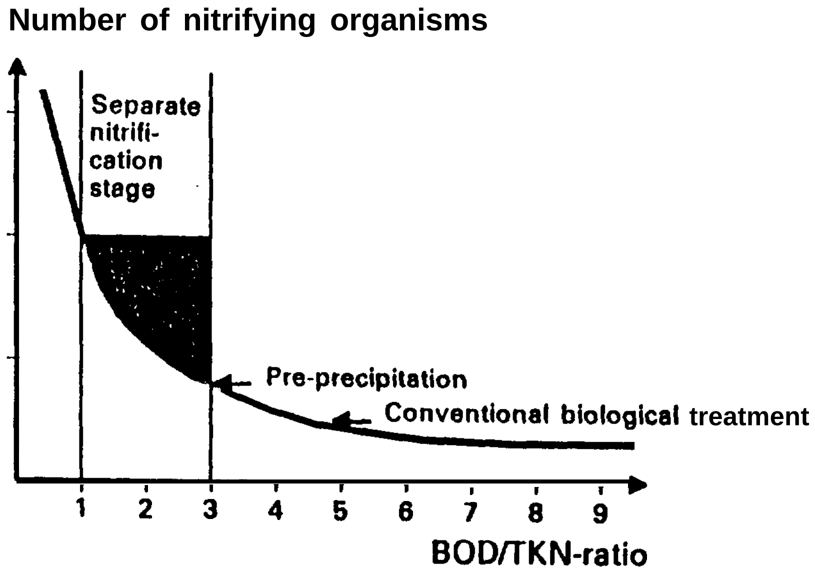


Fig. 11

Sludge age

		$\frac{\text{Sludge quantity in the process}}{\text{production of sludge}}$
Conventional biological treatment	BOD × 0.7 200 × 0.7 = 140	$\frac{1000}{140} = 7$
Simultaneous precipitation	BOD × 0.7+chem.sludge 200 × 0.7+50 = 190	$\frac{1000}{190} = 5$
Pre-precipitation	$\frac{\text{BOD} \times 0.7}{2}$ $\frac{200 \times 0.7}{2} = 70$	$\frac{1000}{70} = 14$

Fig. 12

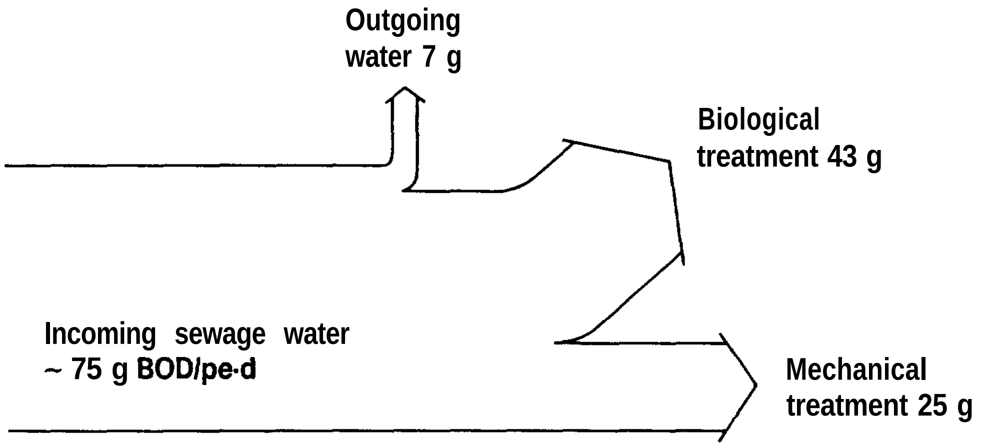
Table 1
Composition of Organic Materials in Wastewater[a]

Item	Classification			
	Soluble	Colloidal	Supracolloidal	Settleable
Size range (µm)	<0.08	0.08 - 1.0	1-100	>100
COO (% of total)	25	15	26	34
TOC (% of total)	51	14	24	31
Organic constituents (% of total solids)				
Grease	12	51	[illegible]	19
Protein	4	25	45	25
Carbohydrates	4	7	11	2b
Biochemical oxidation rate, k, d^{-1} (base 10)	0.39	0.22	0.09	0.08

a Adapted in part from Reference 2,10,18.

Fig. 13

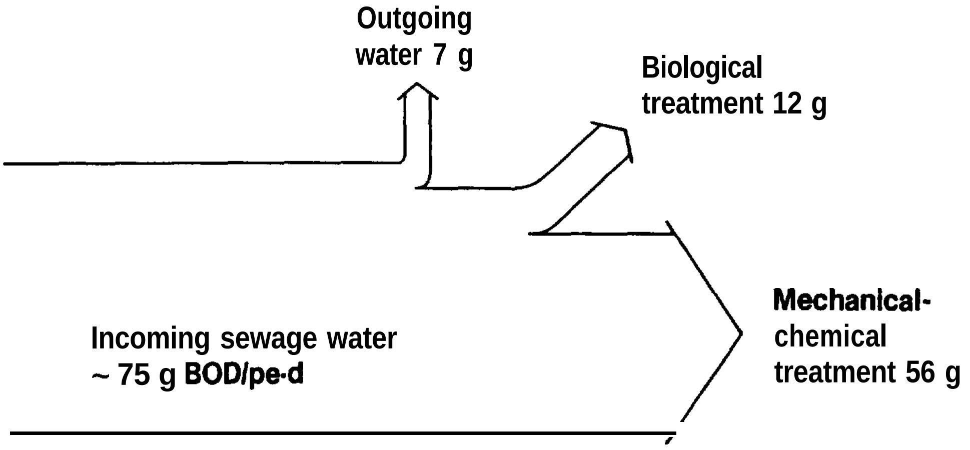
Separation of organic matter in a conventional biological treatment



Energy consumption for biological treatment
1 kg BOD = 1.3 kWh
43gBOD = 0.056 kWh/pe ~ 20 kWh/pe·annum

Fig. 14

Separation of organic matter in an optimal pre-precr’pitation



Energy consumption for biological treatment
1 kg BOD = 1.3 kWh
0.02 kWh/pe·d ~ 7 kWh/pe·annum (-75%)

Fig. 15

METHANOL ~ *2 FIM/KG*

-3 g per gram reduced N

for 100.000 pe (40.000 m^3)

1 g N	87.600 FIM/year
15 g N	1.314.000 FIM/year

3 g methanol ≈ 3 g hydrolyzed "BOD"

PRE-PRECIPITATION

200 g BOD

↓ 75%

150 g BOD

↓ 35% is hydrolyzed

53 g BOD is worth

1.545.000 FIM as C-source

NITRIFICATION - DENITRIFICATION

100.000 pe PLANT **(40.000 m^3/d)**

CONVENTIONAL		*PRE-PRECIPITATION*
VOLUME		
Nitrification	8 h	$\sim$4 h
Denitrification	4 h	$\lesssim$4 h
* 0,44 FIM per m^3		0,29 FIM per m^3
-64 FIM per pe year		$\sim$42 FIM per pe year

Δ 22 FIM

Organic matter $\sim$(0,1 μ - 100 μ) $\approx$ 25%
= 50 g BOD

1 g methanol = 1 g BOD = $\frac{2}{1000}$ FIM

Value 14 FIM per pe and year

* 1 $m^3 \approx$ 2000 FIM 12% rate of interest

Depreciation
- 10 years machinery
- 20 years building

TUBE FLOCCULATION - CHEAP AND EFFECTIVE METHOD FOR PHOSPHORUS REMOVAL

Mr. Arto Latvala
National Board of Waters and the Environment

INTRODUCTION

In many areas of the world there are increasing problems in protecting e.g. the lakes and seas against pollution. The polluting loads may be still growing because of the lack of money for environmental protection purposes. This year we have heard alarming news from the coastal Mediterranean tourist areas. E.g. in Italy there has been reported mass appearance of algae. The time may not be far away when we have similar problems in coastal areas of the Baltic. The intention of this paper is to discuss a cheap and effective phosphorus, suspended solids and particulate biochemical oxygen demand removal method, that can be used in different phases of the implementation of wastewater treatment plant systems.

SMALL SEWAGE WORKS

As a first example the system used for small sewage works should be mentioned. In Finland there are now more than twenty plants of this type (fig. 1). They are mostly situated near the Arctic circle in Lapland. Some of the plants are renewed from conventional types and some are totally new. The size of these plants are from a few dozen to a few hundred as person equivalents.

The treatment process is as follows:

- primary sedimentation that is also working as an equalizing basin
- feeding of chemicals by the chemical pump to the suction openings of the wastewater pump
- pumping the wastewater and the chemical solution together by the wastewater pump, that also functions at the same time as the rapid mixing equipment of the chemical solution
- flocculation in pipes that have been built under the ground floor inside the wastewater treatment building

- secondary sedimentation so that the same basin is working as sludge blanket clarification, and also as sludge storage at the same time.

In the last phase the wastewater is directed to the bottom of the secondary sedimentation basin via a settling pipe, from where it flows through the sludge blanket. By this method it is possible also to retain very small particles from the wastewater, due to the filtering effect of the sludge blanket.

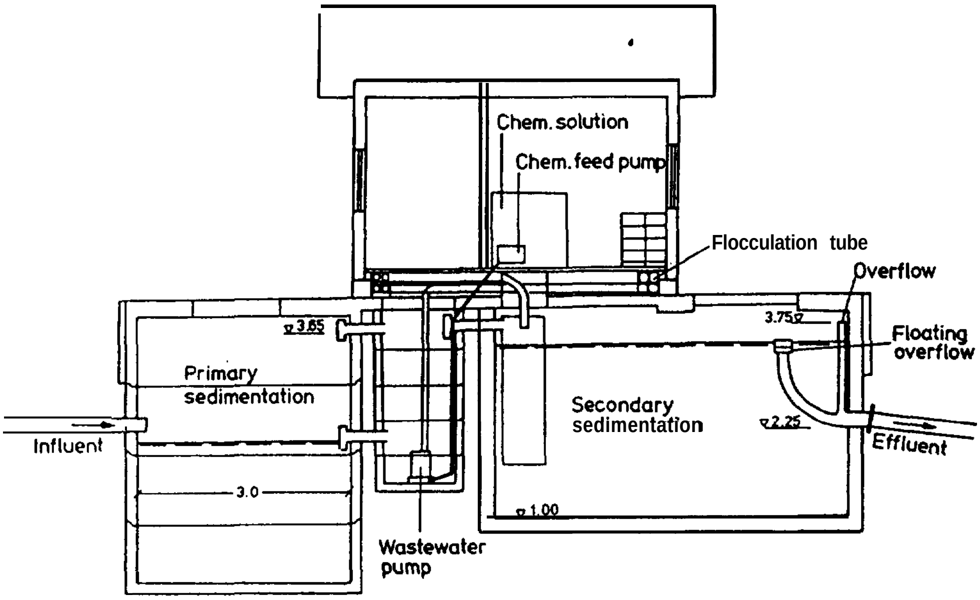


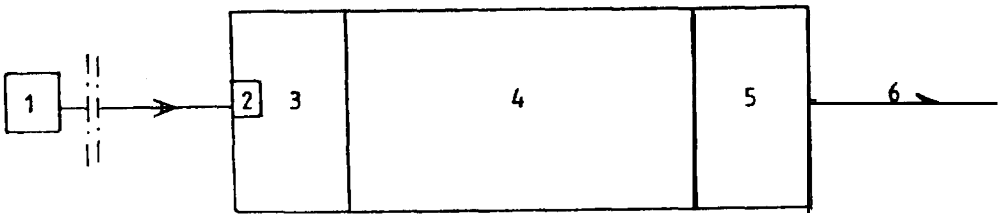
Fig. 1. The chemical tube flocculation wastewater treatment plant of the Saarenketo type.

The results of this kind of plant and experiment have been earlier reported (Latvala 1989). To summarize them briefly it may be stated that by this method it has been possible to obtain 70 % reduction in BOD,, 99 % reduction in particulate BOD, and 94 % reduction in total phosphorus with a molar ratio of 2.6 mol/mol of coagulating Me and phosphorus. Compared with conventional chemical sewage treatment systems the implentation costs of this system have been about one half less. The maintenance of the plants is also quite simple because the machinery consists only of chemical feeding and wastewater pumping.

UPGRADING THE EXISTING SEWAGE WORKS

In order to obtain better performance and better results at existing sewage works the processes may be changed. As a case, for example, sewage treatment at Luhanka, south of Jyväskylä, is discussed.

At Luhanka the sewage of about 160 people is conducted via a pressure pipe in Lake Päijänne to the wastewater treatment plant. The treatment of sewage has been effected by the activated sludge-simultaneous precipitation method (fig. 2) up to April 1988, when the process was changed to direct chemical precipitation with flocculation in a pipe (fig. 3).



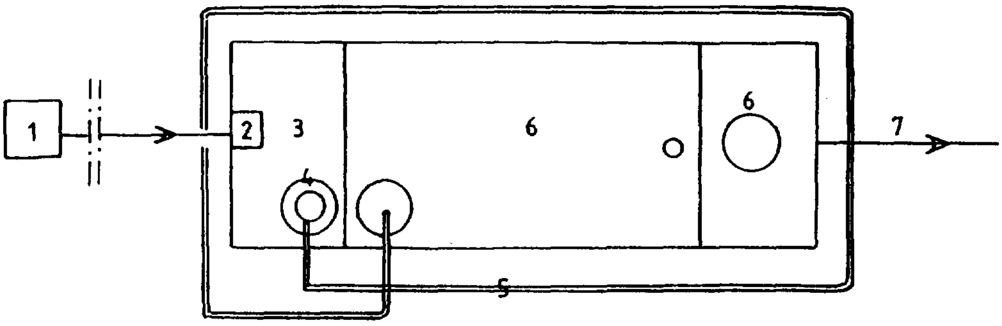
1. Pumping station
2. Grid
3. Primary sedimentation
4 Aeration
5. Secondary sedimentation
6. Effluent

Fig. 2. The Luhanka sewage treatment plant process during the period 1979 - 1988.

When considering the purification results (fig. 4) we can recognize that the BOD,-values of the treated wastewater have decreased by the some amount, about 25 %, and the effluent phosphorus values have decreased substantially by about 87 %; compared to the effluents before process change (table 1).

Table 1. Effluent mean values of BOD, and phosphorus calculated from fig. 4 before and after the process change.

Effluent	Biological-chemical process	Chem. process with tube flocculation
BOD$_7$, mg l^{-1}	65,8	48,4
P mg l^{-1}	7,13	0,92



1. Pumping station
2. Grid
3. Primary sedimentation
4. Pumping with chemical feeding
5. Flocculation pipe
6. Secondary sedimentations
7. Effluent

Fig. 3. The Luhanka sewage treatment plant process after alteration n April 8th 1988.

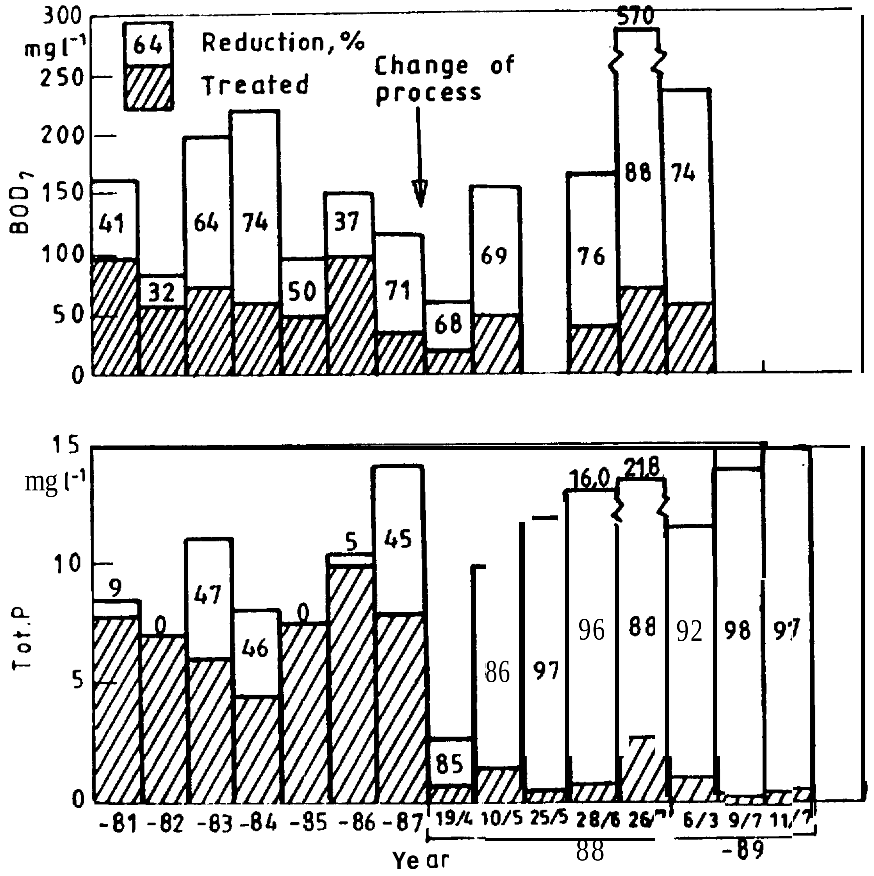


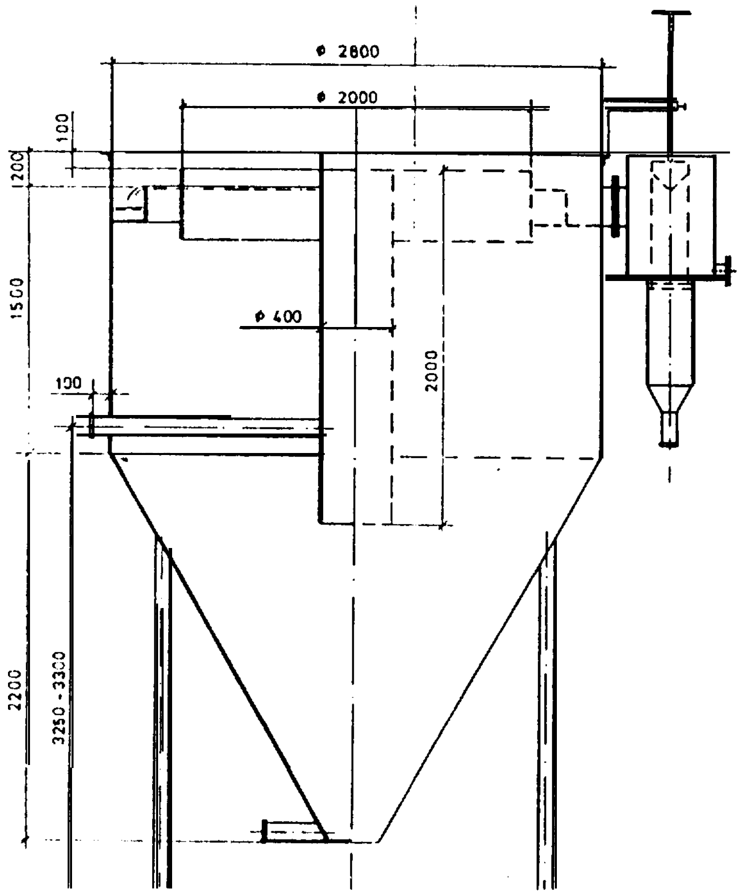
Fig. 4. The purification results of BOD, and phosphorus at Luhanka before and after the process change.

It may be surprising to some, that a chemical process has given better BOD_7-results than the activated sludge-simultaneous precipitation process. There are some good reasons for this in this case. One of them is the considerable increase in the area of secondary sedimentation and an other is the fact that activated sludge process does not work properly on a small scale without e.g. equalizing the sewage flow. A third good reason might be the tube flocculation method itself as discussed earlier in this paper. The length of the flocculation tube is 45 m and the diameter of it is 100 mm. The area of secondary sedimentation was increased from 1.7 m2 to 5.1 m^2 plus 1.7 m2.

When we look at the phosphorus results we can see the very poor operation of the old process, but the new process has been working satisfactorily.

THE FIRST PHASE OF THE NEW TREATMENT SYSTEM

In 1987 there were conducted some experiments at the Suomenoja watewater research station in Espoo. The treatment process for Espoo sewage was as follows: the feeding of the chemical, pumping, flocculation in tubes and sedimentation. For the sedimentation there was used a round sedimentation basin (fig. 5). The daily amounts of the treated wastewater by this system and sedimentation basin have been up to 400 m^3. This means a maximum surface load of about 2.75 $m^3 m^{-2} h^{-1}$. In practice the surface loads should be of that amount only exceptionally. The results of the experiments are shown in fig. 6 and 7 (Latvala 1989).



When we look at the phosphorus results we can see the very poor operation of the old process, but the new process has been working satisfactorily.

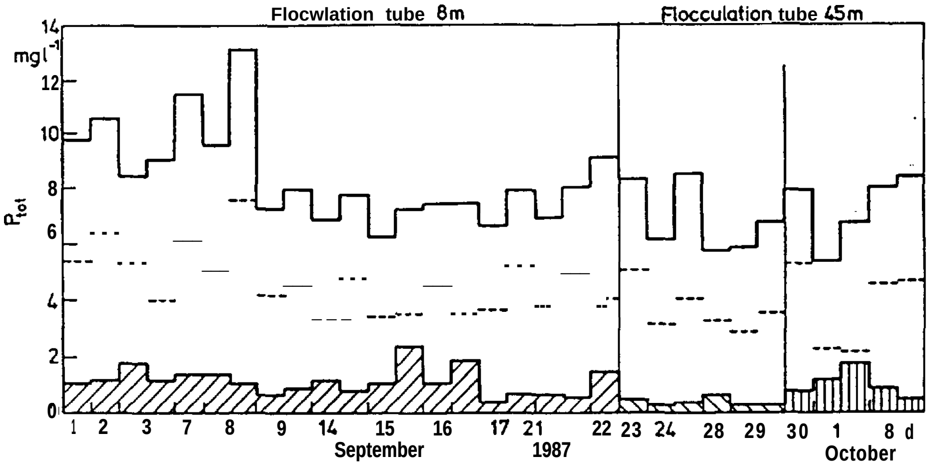


Fig. 6. The total phosphorus before and after treatment by the flocculation tube length of 8 m and 45 m.
--- suspended phosphorus before treatment.

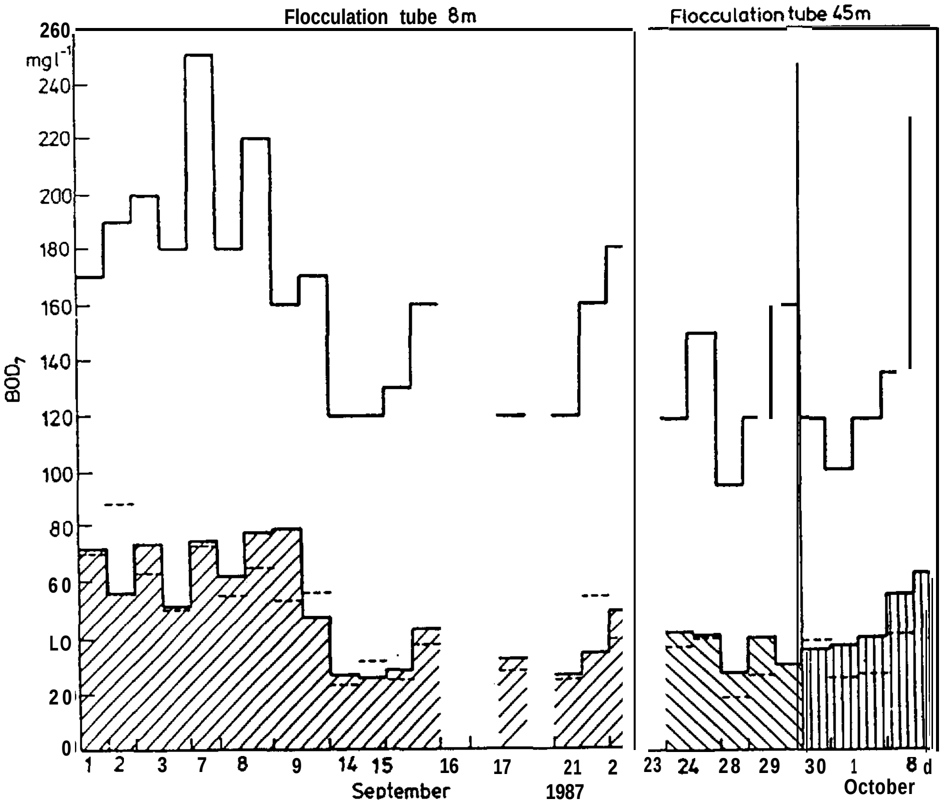


Fig. 7. The biochemical oxygen demand BOD, before and after treatment by the flocculation tube lengths of 8 m and 45 m.
--- soluble BOD, before treatment.

DISCUSSION

Most engineers agree that in sewage treatment we should have both biological and chemical phases. In Finland we mostly have simultaneous precipitation with ferrous iron associated with an activated sludge method. In small sewage works we know in practice that the results have been poor with all the methods.

In the case of Luhanka the change to chemical tube flocculation method improved the results e.g. in respect to total phosphorus and biochemical oxygen demand. In the Suomenoja experiments it has also been possible to obtain good phosphorus and particulate BOD, results with tube flocculation and sedimentation.

This method is cheap to build, because only chemical feeding, wastewater pumping, flocculation in tubes and sedimentation are needed. The sedimentation basins may be those intended later on for primary sedimentation, when the treatment process will be effected in a biological phase.

With the technical advance of chemical sewage treatment by tube flocculation methods the times of better and cheaper sewage treatment are drawing - I hope - a little nearer.

CONCLUSION

The chemical tube flocculation method is an effective and profitable first phase wastewater treatment system that might later on be accompanied by some biological treatment e.g. for nitrogen oxidation.

REFERENCES

Latvala, A. 1989. Advanced chemical treatment with flocculation in pipes. International Specialized Conference on Design and Operation of Small Wastewater Treatment Plants. Trondheim, Norway 26 - 28 June 1989. Preprints p. 211 - 218.

TEMPERATURE EFFECTS ON BIOLOGICAL NITROGEN REMOVAL

- Nitrification under Danish Climate Conditions

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Water Quality Institute

INTRODUCTION

In 1987 the Danish Parliament passed legislation requiring all existing wastewater treatment plants larger than 15 000 PE and all new plants greater than 5 000 PE to establish extended nitrogen removal.

The general requirement concerning the nitrogen concentration in the effluent is a maximum of 8 g N/m^3. It is however possible to set up more stringent effluent requirements for discharge to sensitive waters such as long fjords and lakes. The effluent requirements concerning ammonia are determined by the local county authorities and are in most cases put at 2 g NH,-N/m^3 in the summer and 4 gNH_4/m^3 in the winter months (Jansen, 1989b). The difference in the requirements concerning the NH, effluent concentration between summer and winter is due to the difficulties in achieving nitrification in the cold season.

The Danish climate can be characterized as a temperate coastal climate with an average yearly temperature of 8°C. During the winter, the temperature is normally around 0°C, but varies a lot with occasionally very low temperatures below -10°C during high-pressure periods with easterly wind.

The winter temperature is an important design criterion for Danish wastewater treatment plants. In order to achieve nitrification, plants are normally designed according to the graph in Fig. 1.

It can be seen from Fig. 1 that a relatively small increase in temperature (below 10°C) results in a large decrease of the aerobic sludge age necessary. Thus an increase in temperature from 6° to 8°C will result in a 25 % reduction of the aerobic sludge age.

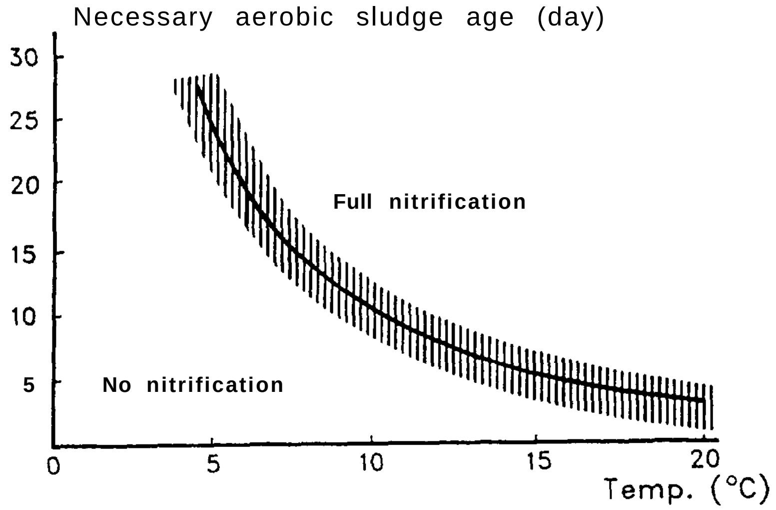

Fig. 1: Typical design curve for nitrification in activated sludge (Jansen et al., 1988)

Consequently, there is a great potential for decrease of volume if the critical design temperature can be increased. A better understanding of the temperature balance of an activated sludge plant and of how to operate wastewater plants in winter may have implications for the operation and design of wastewater treatment plants.

Experience with nitrification at low temperatures

Many Danish wastewater treatment plants have problems with nitrification during the winter.

A survey of 24 wastewater treatment plants on the Danish island of Funen, all designed to achieve nitrification (typical sludge loading of 0.05 kg $BOD_5/(kg\ SS*d)$ (Jansen, 1989a)), showed that the majority of plants were able to achieve an averaged effluent concentration below the requirements, see Fig. 2.

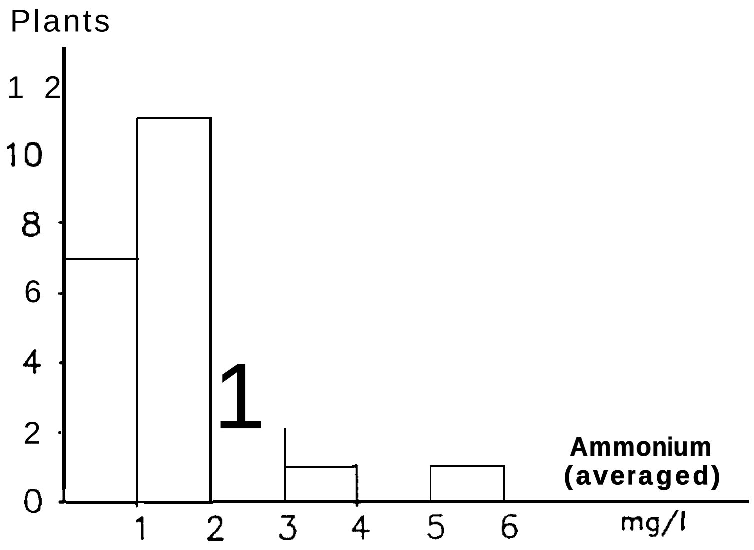

Fig. 2: Distribution of averaged NH,-N effluent concentrations for 24 wastewater treatment plants on Funen

The 24 plants could be divided into 4 groups after the pattern of their ammonia effluent concentration:

1) Plants with a constant low effluent concentration, possibly with a few peaks.

2) Plants with smaller increase during some winters.

3) Plants with higher ammonia effluent concentrations during most winters.

4) Plants with generally high ammonia effluent concentrations all the year round.

It can be seen that many plants have winter problems, but are nevertheless able to achieve an averaged concentration under the requirements. However, it could not be determined on the basis of the data material whether the winter problems are caused by increased loading, lower temperature, toxic substances, bad operating practice, plant design, etc.

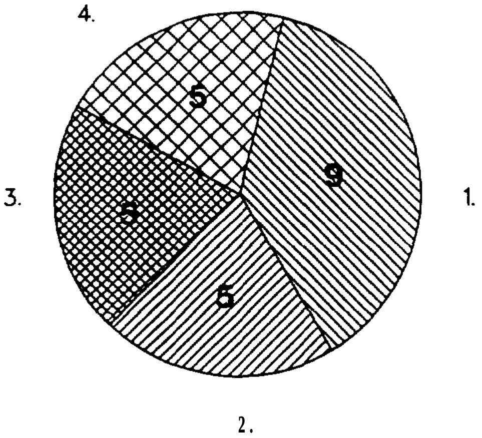

Fig. 3: Distribution of ammonia effluent pattern for 24 wastewater treatment plants on Funen (Jansen et al., 1988)

Fig. 4 shows the variations in temperature and NH,-N concentrations for a plant designed to achieve extended nitrogen removal. It can be seen that the plant failed to nitrify during the winter and spring of 1987, but soon regained its ability when the temperature rose in May. During the autumn, occasional high ammonia concentrations also occurred more frequently. According to the measurements of the county authorities, however, the plant's average NH,-N effluent concentration has been below 2 $gNH_4\text{-}N/m^3$ for a period of several years (Jansen, 1989a).

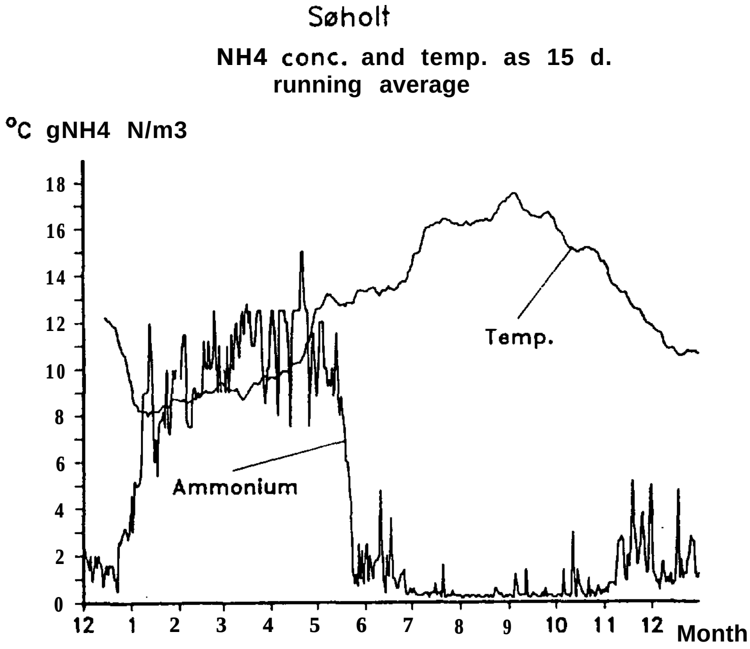

Fig. 4: NH,-N effluent concentration and 15 days' running average temperature for Søholt wastewater treatment plant from 12 th Jan. -1986 to 1st Jan. 1988

Temperature variations

In order to evaluate the influence of temperature on nitrogen removal it is important to know the actual temperature variations and what factors influence the temperature.

Fig. 5 shows the variations in the process temperature at two nitrogen removal plants over period of three years. The two plants are of different designs, so that the surface area/volume ratio is much larger for Søholt than for Frederikssund. It can be seen that the variations in temperature during the years are very similar for the two plants.

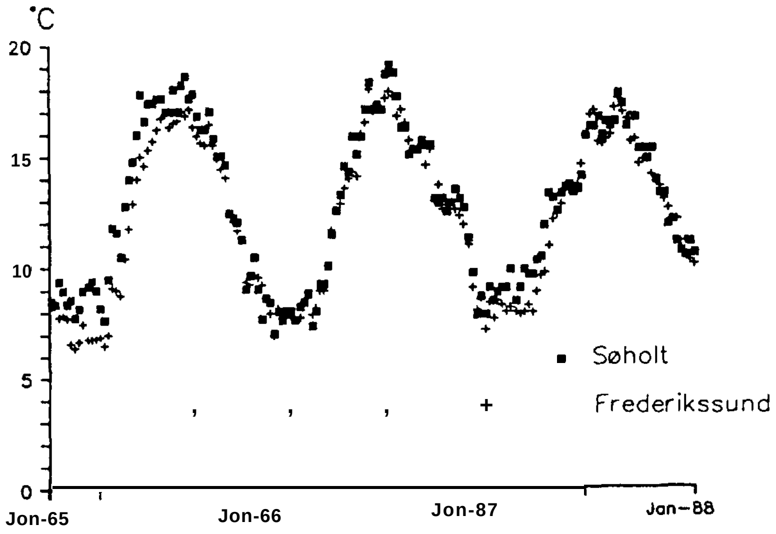

Fig 5: Process temperature variations at Søholt and Frederikssund wastewater treatment plants (Jansen et al., 1988)

From Fig. 6 it can be seen that the water temperature increases when passing the Frederikssund plant in the summer and decreases when passing Søholt during the winter. This means that the design of the plant influences the water temperature, and it is therefore important to establish which design elements are of particular importance.

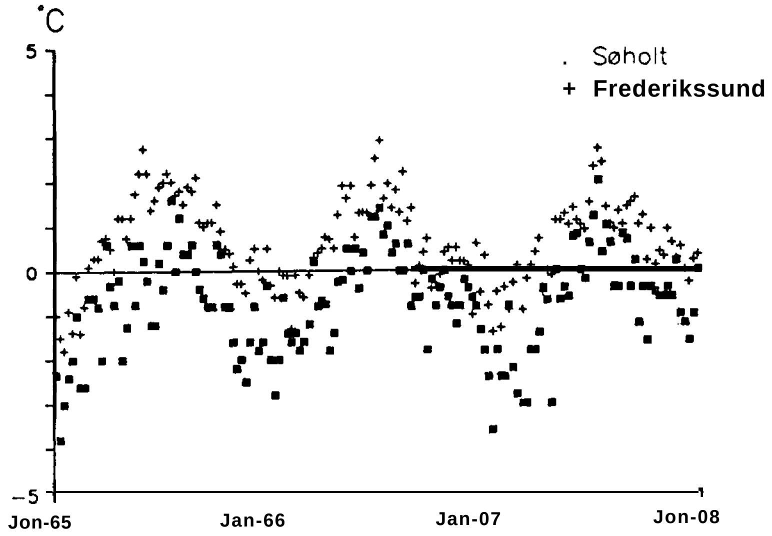

Fig. 6: Change in temperature when passing Søholt and Frederikssund wastewater treatment plants (Jansen et al., 1988)

Temperature model

The energy balance of a wastewater treatment plant is influenced by many factors. The most important ones are shown on Fig. 7.

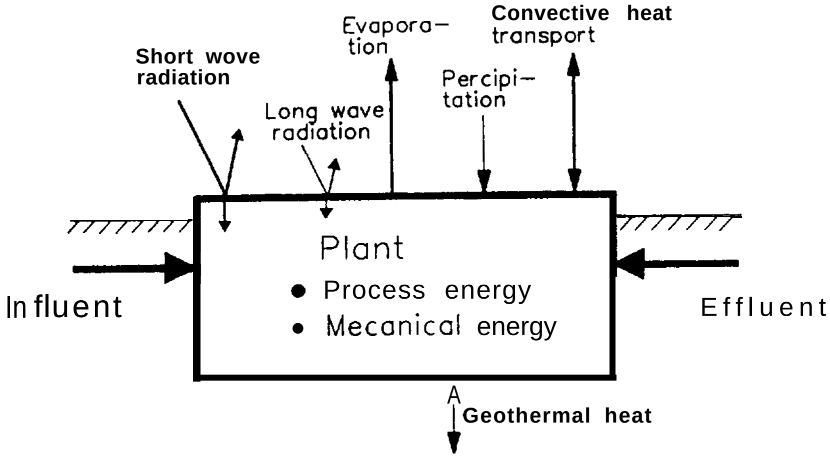

Fig. 7: Factors influencing the temperature in a wastewater treatment plant (Jansen et al., 1988)

These factors are not equally important. It was found that the following were the most important ones:

Influent/effluent
Convective heat transport
Evaporation
Net shortwawe radiation
Energy from the process

The calculation also showed that the influent temperature has a great influence on the process temperature, so that little can be done to change the process temperature during snow melting.

Using the model, a calculation has been made for Søholt wastewater treatment plant, and relevant data concerning the plant and local climate have been collected. The model was then calibrated for the month of January and the constants used to calculate the rest of the year. See Fig. 8.

Fig. 8 shows that the model is able to perform an acceptable simulation of the temperature variance during the year. However, the simulation of certain days was not very good. This was expected since climatic data were obtained from the nearest meteorological station and not from the plant itself. Furthermore, the temperature registrations of the plant were made with an accuracy of only 1°C, so that both the estimates and the temperature registration may be the cause of slight differences.

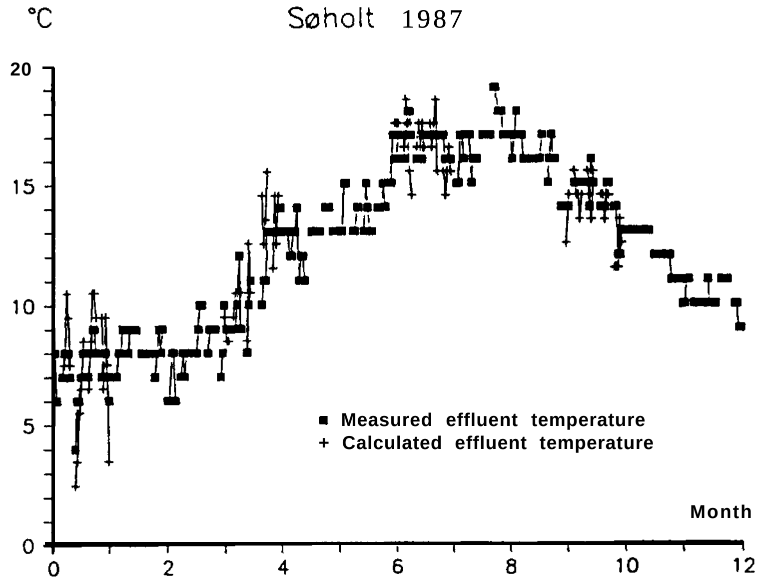

Fig. 8: Calculated and measured effluent temperatures at Søholt wastewater treatment plan (Jansen et al., 1988)

The model was then used to analyse the sensitivity of the model to changes of the parameters in the model. This made it possible to estimate how accurately a parameter has to be determined and also what influence a parameter has on the model and thereby on the temperature of the wastewater treatment plant.

The sensitivity analysis was carried out with data from **Søholt** wastewater treatment plant averaged monthly, thereby simulating the cycle of the seasons.

The sensitivity analysis showed that wind velocity and surface area were important parameters. When designing new plants, it is possible to control these parameters, and wind velocity may be changed in connection with existing plants.

It can be seen from Fig. 9 that a decrease in wind velocity will increase the process temperature. The effect of reducing the velocity will be less significant in summer. It appears that the wind velocity must be predicted fairly accurately in order to get good model predictions. This means that the wind data should be obtained from the plant itself.

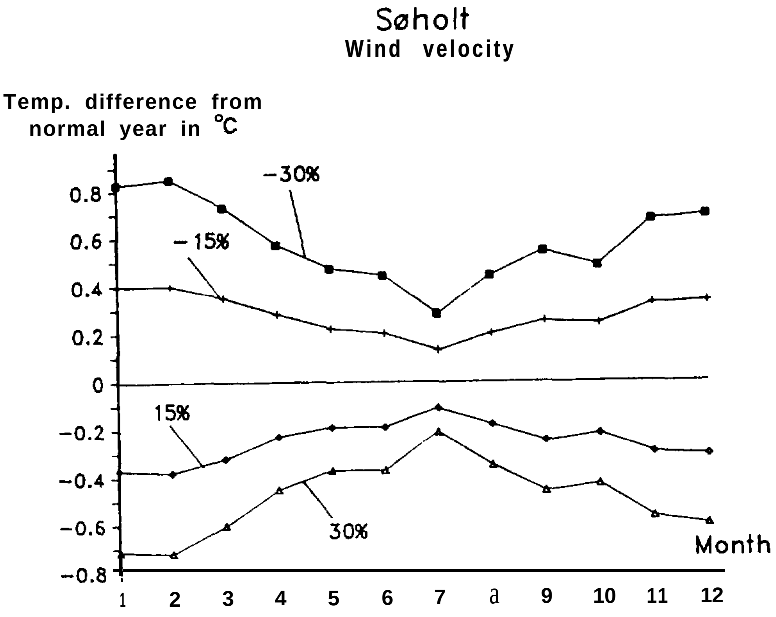

Fig. 9: Sensitivity analysis showing differences in temperature when changing wind velocity parameter

A reduction of the surface area will reduce the energy exchange between the water and the air. Thus the water temperature increases during the winter and decreases during the summer.

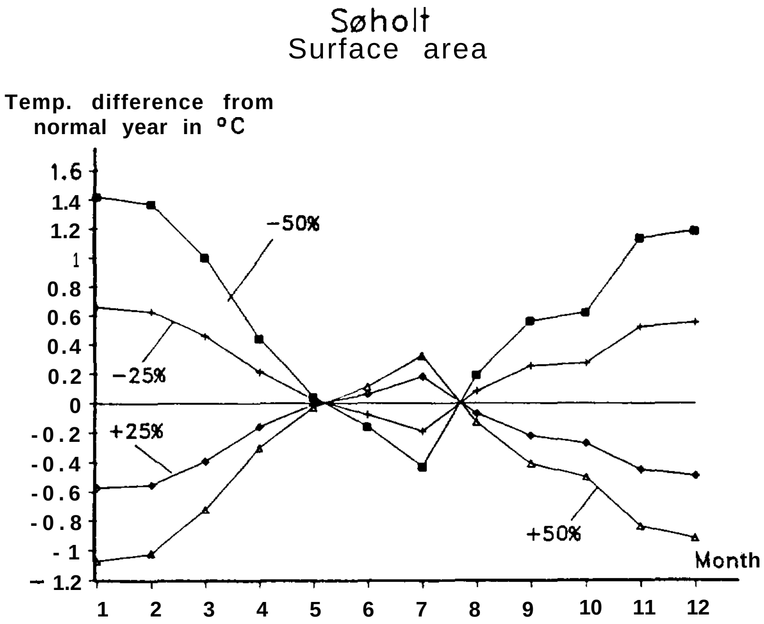

Fig. 10: Sensitivity analysis showing difference in temperature when changing the surface area parameter

The analysis showed that increases in the critical winter temperature can be obtained by altering the design of wastewater treatment plants. For an existing plant, reduction in the wind velocity, for example by covering the reactors or by making a shelter round the plant will improve the process temperature. When designing future wastewater treatment plants, reduction of the surface area-to-volume ratio will establish the potential for a higher critical winter temperature.

Ongoing research program

On a small wastewater treatment plant (Hammersholt) consisting of two oxidation ditches operated in alternate switch mode, extensive temperature registrations have been carried out. The plant has recently been covered with a black tarpaulin, which makes it very interesting with regard to the temperature model investigation. The cover will reduce the wind velocity to zero. The temperature is registered at four points: Influent water, effluent water, air under the tarpaulin, and air in shadow.

The data logging has recently been started and is supposed to continue so that the effect of covering the plant in winter can be established. The weather during the logged period was very warm and sunny, with day temperatures in the high 20s. When studying the data already at hand, see Fig. 11, it is interesting to note the great dynamics of the system. It can already now be concluded that in order to get a true picture of the temperature variation of a plant it is necessary to register the temperature at the same time every day.

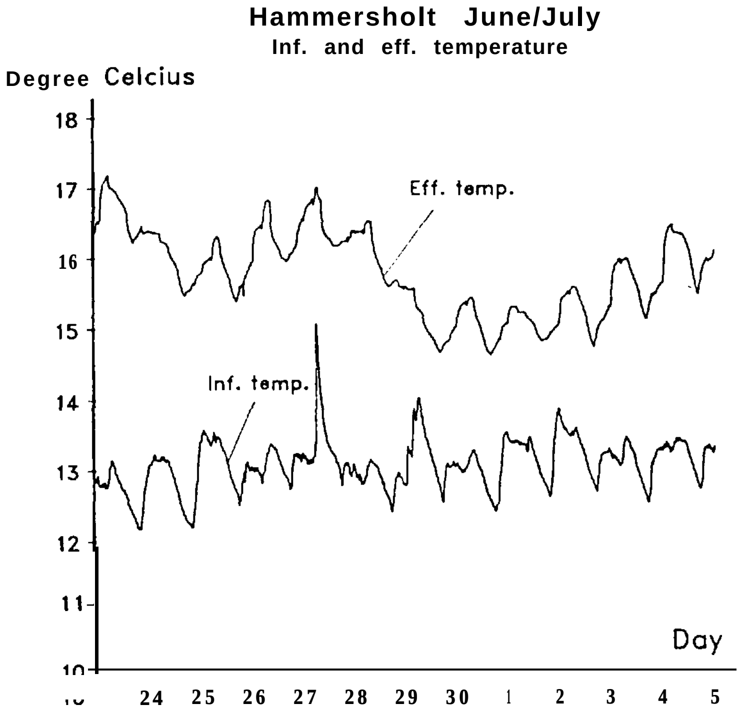

Fig. 11: Influent and effluent temperature at Hammersholt

The peak of the influent on the 27th July was due to rain, but since the day was otherwise sunny, it did not have any significant influence on the effluent temperature. The general temperature decrease from the 28th to the 29th July can be related to changes in the weather, see Fig. 12, where the temperature under the tarpaulin drops. From the 30th July, there is a general tendency towards an increase in the effluent temperature, corresponding to the general increase in the temperature under the tarpaulin. Note also that the influent temperature does not change because of increases in the air temperature. This is due to the underground position of the sewage lines.

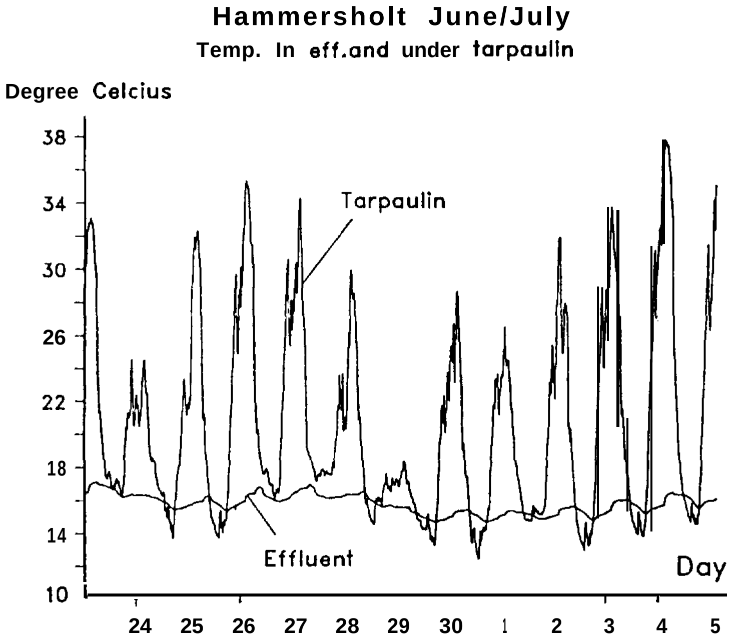

Fig. 12: Effluent and under-the-tarpaulin temperatures at Hammersholt

The program will be continued byt with experimenting with removal of the gover in different weather periods in order to determine its influence. The nitrification rate and nitrification capacity of the plant sludge will be measured in connection with the temperature program.

Conclusion

The investigation of 24 Danish wastewater treatment plants designed for nitrification shows that several have difficulties achieving complete nitrification during the winter.

Analyses of two different plants indicate that temperature changes when passing the plants can be related to the physical design of the plants.

The influent temperature was identified as the most important factor influencing the process temperature, so that low influent temperature in winter and during snow melting will result in low process temperatures. Modelling the temperature balance of a wastewater treatment plant results in identification of wind velocity and surface area as two important parameters in the temperature balance. Reduction of both parameters will reduce the temperature loss at the plant in winter.

Acknowledgements:

The project was financed by the Danish Agency for Environmental Protection, but does not necessarily reflect the Agency's view of the subjects discussed.

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LONG TERM EXPERIENCE WITH NITROGEN REMOVAL

Mr. Erik Bundgaard
Mr. Jan Pedersen
I. Kruger AS

BACKGROUND

Already in the beginning of the 1970s, the first steps were taken to establish plants for nitrogen removal in Denmark. During the following 15-20 years, those plants that were originally dimensioned on the basis of partly empirical dimensioning rules have been further developed. At the same time, a better theoretical basis and understanding of each process step have been achieved through extensive development work performed by I. Krüger AS in cooperation with the Department of Environmental Engineering at the Technical University of Denmark.

Today, more than 30 wastewater treatment plants designed for nitrogen removal are in operation in Denmark, and as a result of the Danish action plan on the aquatic environment a much larger number of plants are either at the planning stage or under construction. The operating experience gained from some of the existing treatment plants is very well-documented, and this is utilized to a high extent for the new plants, both as regards dimensioning and establishment of control systems and operating strategies.

CHOICE OF PROCESS

As previously mentioned, Denmark is today faced by the necessity of extending a very large number of highly different wastewater treatment plants to incorporate nitrogen removal. In this connection, it should be emphasized that there is not one particular treatment process that is the best suited for all conditions.

Most essential to any plant extension is to ensure optimum compliance with the demands required for obtaining satisfactory functioning of the various biological processes. The basis for an extension of a plant will always differ in respect of wastewater composition, plant design etc. The final design of 2 practically similar plants may therefore end up being widely different.

The following presentation will, however, primarily focus on the Danish developed Bio-Denitro process.

THE BIO-DENITRO PROCESS

Development

The Danish environmental legislation has for many years been ahead concerning requirements degradation of nitrogen in wastewater treatment plants. Already in the 1960s, it became normal to require full nitrification in treatment plants having water courses or lakes as recipients. This paved the way for introduction of the oxidation ditch system in Denmark, a system ensuring full nitrification and sludge stabilisation due to a long treatment period - and in some cases also a very high degree of nitrogen removal (60-70 %).

Through systematic investigation and optimization of these plants, the Bio-Denitro process was developed. Fig. 1 shows the first oxidation ditch types and how they can be extended for the Bio-Denitro process which is described in the following. Other types of tanks and aeration equipment may however also be applied in those cases where it will be more economical or practical to do so.

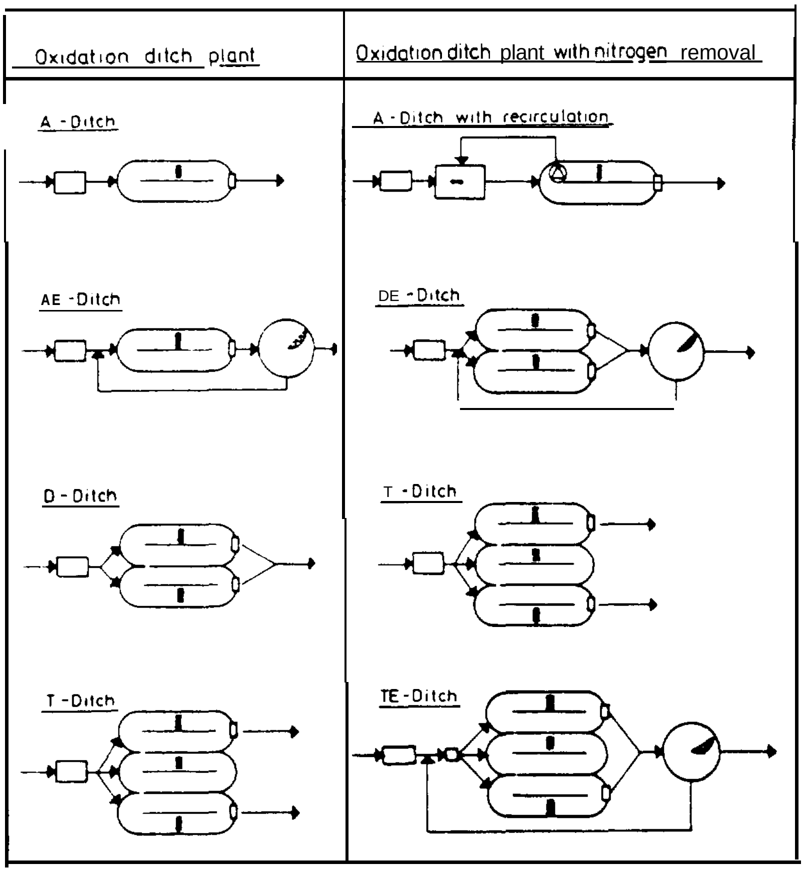

Fig. 1 Extension of Oxidation Ditches to Bio-Denitro Plants with Nitrogen Removal

Plant Design and Operation

For the Bio-Denitro method - the most widely used process for nitrogen removal in Denmark - two tanks are used which are interconnected by means of a pipe or through a hole in a common wall. The tanks can be operated with denitrification under agitation and intake of wastewater or with nitrification including aeration. The wastewater is distributed between the two tanks via a mechanical inlet distributor and the effluent is discharged in turns via mechanical outlet weirs installed in both tanks. The direction of flow through the plant from inlet to final clarifier can thus be controlled by adjustment of the inlet distributor and the outlet weirs. In this way, a simple design is obtained in combination with a flexible control of the plant.

The operating mode consists of 4 phases with a total duration of 3-6 hours, during which both the direction of flow through the plant and the process conditions in the tanks are controlled automatically to obtain the correct process conditions. Fig. 2 shows a flow and phase diagram for a Bio-Denitro plant.

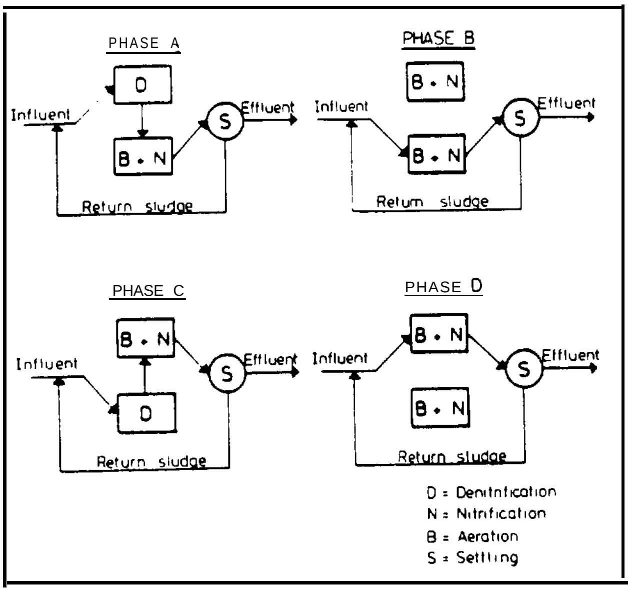

Fig. 2 Flow and Phase Diagram for a Bio-Denitro Plant

In phase A, wastewater is introduced into tank 1 where mixing takes place under anoxic conditions. This causes a denitrification of the nitrate nitrogen formed and accumulated in the previous phases. At the same time, activated sludge flows from tank 1 to tank 2 concurrently with the inflow of raw wastewater and return sludge. Tank 2 is operated with aeration, i.e. under aerobic conditions, this resulting in nitrification and removal of any organic matter remaining from the denitrification. During phase A, the nitrate concentration is reduced in tank i and increased in tank 2. The duration of phase A corresponds to the period of time required for removing the nitrate in tank 1. Due to the flow of wastewater into tank 1, the ammonia concentration rises in this tank.

Phase B is a short intermediate phase with aeration in both tanks during which the wastewater is only led through tank 2. The duration of phase B corresponds to the period of time required for obtaining aerobic conditions and partial nitrification in tank 2.

Phase C is the second main phase. The flow is now directed from tank 2 to tank 1 and the function of the two tanks is interchanged. Phase D is the second intermediate phase which corresponds to phase B.

Monitoring and Process Control

All functions of the inlet distributor, outlet weirs, aerators and agitators are monitored automatically according to programmes adapted to each plant. When commissioning new plants, random samples are taken on a running basis over a couple of days after which it is possible to establish the optimum operating programme.

Besides the dissolved oxygen set points, the most essential parameter that can be changed is the duration of the denitrification phases (A and C) in relation to the nitrification phases (B and D). A typical programme operates with aerobic conditions approx. 66 % of the time and anoxic conditions approx. 34 % of the time, this applying to both tanks. The use of several different programmes in the control system has turned out to be advantageous, facilitating the changing of this parameter either towards a larger nitrification capacity or a larger denitrification capacity. This will be elaborated in the following section.

OPERATING EXPERIENCE FROM TREATMENT OF MUNICIPAL WASTEWATER

Normally, Bio-Denitro plants can be dimensioned on the basis of information on the wastewater amount and its composition. In those cases where the nitrogen removal is to be combined with pretreatment processes, biological phosphorus removal, or where several process designs are feasible, pilot studies are often performed in order to evaluate the relevant processes.

Experience from Pilot Studies

Through pilot studies it is possible to simulate the full-scale situation so well that a basis for determination of design parameters, such as degradation rates, sludge production, sludge properties etc., can be established. The duration of the pilot studies is normally 6-18 months so that seasonal variations can also be investigated.

Table 1 shows the operating results obtained from pilot studies in one Bio-Denitro plant and two Bio-Denipho plants, the latter being a Bio-Denitro system extended to include biological phosphorus removal. The Kolding plant (Bio-Denipho) treats pre-settled wastewater, primarily from households, whereas the loading of the plants in Avedøre (Bio-Denitro) and Fredericia (2-stage Bio-Denipho plant) consists of a considerable volume of industrial wastewater besides normal domestic sewage.

Table 1 Operating Results Obtained from Pilot Plants with Bio-Denitro and Bio-Denipho

PLANT	AVEDØRE		KOLDING		FREDERICIA	
Capacity, full scale	360.000 PE		125.000 PE		180.000 PE	
Parameter(mg/l)	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.
Total COD	270	60	260	35	495	99
Dissolved COD	208	-	130	-	334	-
Total BOD	100	9	125	9.4	305	9.8
Dissolved BOD	73	-	73	-	220	-
Total N	31	5	29	7	28	3.5
Ammonia-N	20	2	1	5	≤1	1.2 1.4
Nitrate-N	90	< 5	100	6	138	12
BOD/N	3.2		4.3		11.1	

It appears from the table that optimization of the operation has been possible for all three plants, thus obtaining a very satisfactory effluent quality even though the wastewater composition and operating conditions have been different.

Significant Factors

The results obtained from the existing full-scale plants have shown that many different factors are decisive for the degree of stability of nitrogen removal. The parameters of great importance to the plant function are:

- Load
- Wastewater composition
- Temperature
- Variation of these parameters

Furthermore, the function of the treatment plants is highly dependent on the plant operator's knowledge and commitment.

Another important prerequisite for optimizing the operation of a plant is performance of the necessary measurements and analyses.

As an example of the above problems, reference can be made to a small plant in Jutland which was converted to incorporate nitrogen removal and the suddenly had problems meeting the effluent demands. Around 1st April 1988, the analysis sheet revealed that something was wrong. The experience documentation available was, however, far too limited to be able to intervene immediately in the correct way. Only 3 data sets were available, as shown in Table 2.

Table 2 Results of Analyses Covering a S-Month Period for a Wastewater Treatment Plant with Nitrogen Removal

		Flow	BOD (mod.)	SS	NO_3-N	NH_3-N	Kj-N	Tot-N	Org-N	C:N
Date		m^3/d	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	calcul.
28/1	Infl.	1503	40	77	1.4		9.1	10.5		4.4
	effl.		2	5	2.5	0.7	2.0	4.5	1.3	
10.2	infl.	1962	80	120	0.9		15	16		5.3
	effl.		4	6	3.6	0.3	2.0	5.6	1.7	
14.3	infl.	-	230	220	1.1		35	36		6.5
	effl.		7	11	13.0	0.2	3.9	16	3.7	

If, as so far, the plant should only have removed BOD, ammonia and suspended matter, this would have been sufficient and satisfactory. However, when it comes to nitrogen removal, the situation is considerably more difficult.

It appears from the table that the concentrations and amounts of matter introduced varied by a factor 5, but that certain data are missing (flow). The carbon-nitrogen ratio (C:N) seems to be satisfactory in this case, but it has not been possible to observe the effluent demand of 8 mg/l N under all conditions without intervening in the process control.

Another important variable is the content of organic non-degradable nitrogen. The table shows that this figure varies considerably (1.3-3.7 mg/l), but there are normally no direct interventions that can be performed on the plant to improve this. In this case, an investigation of any industrial discharges should perhaps be carried out.

The only way of obtaining a satisfactory nitrogen removal in a plant with the above load conditions is by watching the operation carefully and making (daily) measurements of ammonia and nitrate in the effluent, and subsequent operations adjustments. Such measurements are easily performed on random samples or 24-hour samples by means of a simple test kit. Furthermore, it is a condition that the plant operator understands the functioning of the biological processes and is able to adjust the operation accordingly.

Operating Results

Table 3 shows a survey of the operating results obtained from 17 Danish plants with nitrogen removal. As it appears from the table, there is a wide spread of the analysis results, but with reference to the above example it is not possible to make any generalization. The only common feature is that the most stable effluent quality is achieved in the well-tended plants.

In the following is given a comment on the results obtained from 6 of the plants in order to illustrate the complexity of operating analyses. For the 3 plants with effluent values exceeding 10 mg/l total nitrogen as mean value, the following 3 quite different explanations of the high effluent values can be given.

The plant in Skals has been used for experiments and has been extended with an anaerobic pretreatment tank, among other things. Figure 3 shows a plot of the results for the plant obtained over the last 3 1/2 years. In this period, 3 different operating conditions have contributed to the high mean value for total nitrogen. The figure is divided into 3 periods with their respective operating conditions. In the first period, which was bad, the influent contained approx. 55 mg BOD_5/l on the average, and it has not been possible to maintain anoxic conditions in the denitrification phases. In the second period, with better nitrogen removal, the anaerobic pre-tank has been put into operation and the agitation in the tanks improved. In the third period, the content of organic nitrogen has increased to 4.7 mg/l on the average, resulting in a considerable increase of total nitrogen.

The plant in Fåborg is not operated according to the normal Bio-Denitro principles and there are no demands for nitrogen removal. Consequently, no operations adjustments have been performed despite load variations.

The plant in Odense N.Ø is a two-stage plant loaded only 1/3 of the dimensioning basis. Consequently, the influent to the second stage contains practically no organic matter, but has a C:N ratio of less than 2.

Table 3 Mean values of analyses performed on Danish plants with nitrogen removal

		Dimensioning basis	Influent		Effluent				
Name of Plant	Type	1000 PE	BOD5 mg/l	Total N mg/l	BOD5 non-mod/mod.	Total N mg/l	NO_3-N mg/l	NH_3-N mg/l	Number of Data infl./effluent
Bording	DE/BD	6	138	31	-/5		8.6	0.6	8/3
Engesvang	DE/BD	5	152	33	-/6		6.3	0.4	5/3
Fiskbæk	DE/BD	4,4	280	37	9/4	8.2	4.6	1.0	23/25
Hørning	one-tank	18	-		-/6	5.5		1.3	-/30
Jerslev	recirc.	3	53	17	-/7	6.3	4.4	1.0	6/6
Karup	DE/BD	9,6	154	23	5/-	7.6	6.5	0.4	3/3
Løvel	recirc.	0.8	210	44	10/4	8.3	5.0	1.3	18/27
Skals	DE/MP	3.5	116	25	13/5	11.8	8.4	0.9	24/-
Odense NØ	2-st. BDP	30	140/39*	29/22*	a/-	11.6	7.3	2.8	40/45
Odense NV	2-st. BD	85	238/ *	40/ *	8/-	7.6	4.1	1.4	43/39
Nr. My	DE/BDP	12,5	206	25	7/-	4.0	2.7	1.0	31/31
Trankær	recirc.	10	330(COD)	37	-/2	5.6		0.3	11/11
Vammen	recirc.	0.8	216	38	8/3	9.6	6.0	1.2	17/24
Vejby	DE/BD	2.2	103	16	4/-	7.5	6.1	0.9	5/9
Søholt	T/BD	105	197	30	-/6	8.3	4.2	2.1	121/119
Fåborg	T	105	346	62	8/-	11		2.0	44/41
Frederikssund	DEAD	33	300	36	-/9	3.5	1.5	0.5	120/118

Explanation of signs and abbreviations: BD = Bio-Denitro, BLIP = Bio-Denipho, 2-st. = 2-stage plants,
* 1st stage/2nd stage

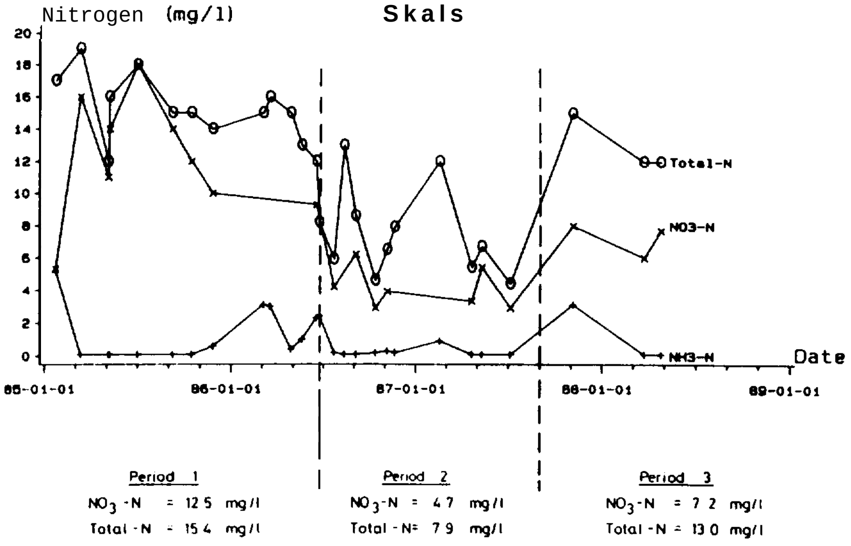

Fig. 3 Skals Wastewater Treatment Plant - Operating Results Obtainded during 3 Different Periods

Figure 4 shows the results obtained from 2 plants, Hørning and Ldvel, of which it appears that the reduced effluent quality may either be attributable to an increased ammonia content (Hørning) or an increased nitrate content (Løvel). In both cases a more detailed operations analysis will be required to establish the cause.

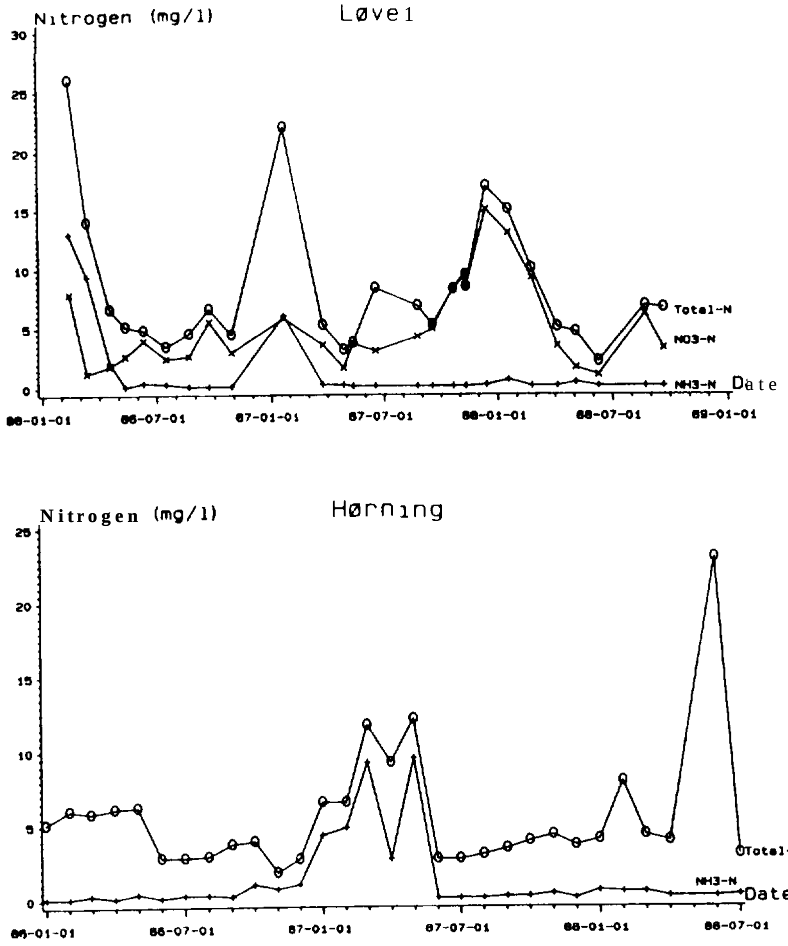

Fig. 4 Effluent Result from Løvel and Hdrning Wastewater Treatment Plants

Figure 5 shows the analysis results obtained from the Søholt wastewater treatment plant in the period 1984-1988 (120 data sets), presenting curves for ammonia and ammonia + nitrate against total nitrogen. It appears from the figure that there is some variation in the content of organic nitrogen (2-4 mg/l). Furthermore, it is seen that full nitrification is necessary to maintain a content of organic nitrogen of less than approx. 8 mg/l, i.e. NH,-N < 1.5 mg/l. When the ammonia content starts increasing, the effluent values will inevitably exceed the permitted limit value of 8 mg/l N as the nitrate content is rarely below 3-4 mg/l. For this reason, nitrification is always given considerably higher priority than denitrification in connection with optimizations of operation.

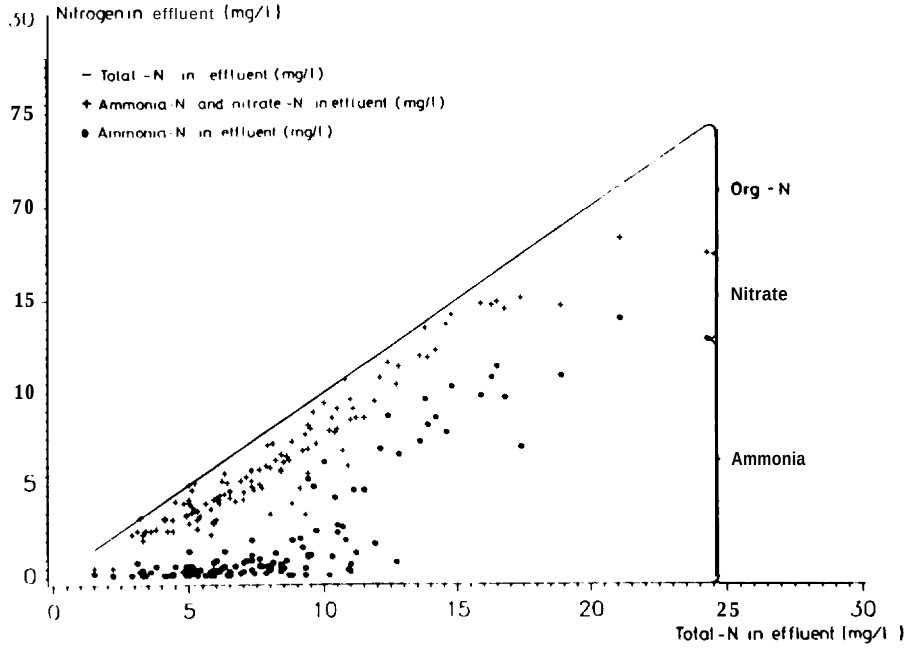

Fig. 5 Analysis Results Obtained from Søholt Wastewater Treatment Plant 1984-l 988

Figure 6 shows a quantile diagram of the analysis values for all 17 plants stated in Table 3. It appears from the figure that the mean value (60 % quantile) for the plants tested is NH,-N = 1.2 mg/l, NO,-N = 6.0 mg/l, inorganic N = 7.2 mg/l and total N = 8.2 mg/l. Considering the explanations given for the plants with the poorest results, there is - on the basis of the experience gained so far- every reason to expect that Danish wastewater treatment plants will be able to meet the demands of the action plan.

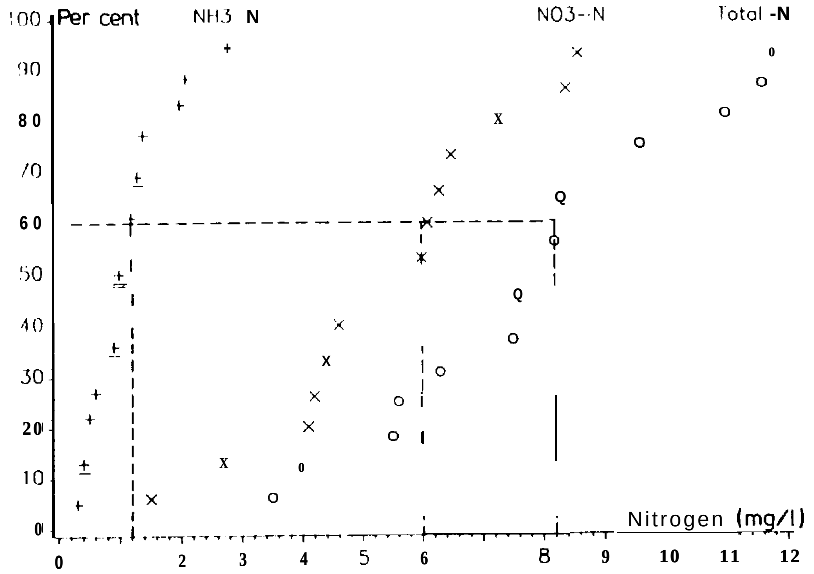

Fig. 6 Quantile Diagram for 17 Danish Wastewater Treatment Plants with Nitrogen Removal

Operating Experience from Treatment of Industrial Wastewater

Industries with separate discharge of wastewater must also remove nitrogen. Many years' experience has already been gained from treatment of wastewater from rendering plants. Under controlled operating conditions and with sufficient amounts of organic matter in the wastewater, the content of total nitrogen can be reduced from more than 400 mg/l N to less than 10 mg/l.

This type of wastewater is relatively uncomplicated to treat as long as a pH-adjustment is ensured to compensate for the acidification resulting from the nitrification.

The Bio-Denitro method can also be used for more complex types of wastewater from the chemical industry. For a couple of years, pilot studies have been carried out on wastewater from the company Grindsted Products A7S which produces additives for the food and drug industries. Several of the substances contained in the wastewater have a certain toxic effect on micro-organisms and are quite heavily degradable. The studies have shown that the degradation rates for nitrogen in the plant are reduced by approx. 40 % compared with normal domestic sewage, but that complete removal of the degradable nitrogen in the untreated wastewater is possible. The nitrogen removal thus corresponds to approx. 300 mg/l N with NH,-N and NO,-N of 10 mg/l and 2 mg/l, respectively, in the effluent, at a load of 0.1 kg COD/kg SS x d at approx. 20°C. It should be noted that the salt content in the wastewater is approx. 3-4000 mg/l.

DEVELOPMENT TRENDS

Besides removal of nitrogen, demands in respect of phosphorus removal have been made for all Danish wastewater treatment plants over 5000 PE. Good experience has been gained from phosphorus removal with simultaneous precipitation and biological phosphorus removal at the same time as the plant is operated with nitrogen removal.

The latest trend of developments is towards optimizing the pretreatment processes, such as settling, biosorption and presettling, concurrently with hydrolysis of the settled sludge. The liquid from the hydrolysis is then used as carbon source in the subsequent nitrogen removing process stage which will thus be considerably smaller in volume than in the case of a onestage plant. The joint Nordic EUREKA project HYPRO, among others, deals with this trend.

In connection with the development of design and optimization tools for plants for biological removal of nutrient salts, dynamic mathemathical models of the type developed within IAWPRC - by Mr. Mogens Henze, among others, ass. professor at the Dept. of Environmental Engineering, the Technical University of Denmark - have been introduced. These models can calculate the degradation rates of organic matter and nitrogen in activated sludge plants. A comparison of calculated values with experimental data has shown that the models can be calibrated to pre-calculate operating results in connection with plant extensions, operating changes etc.

As an example of this, Fig. 7 shows a comparison of experimental data from the Aveddre pilot plant (Table 1) with modelcalculated results before and after calibration of the model.

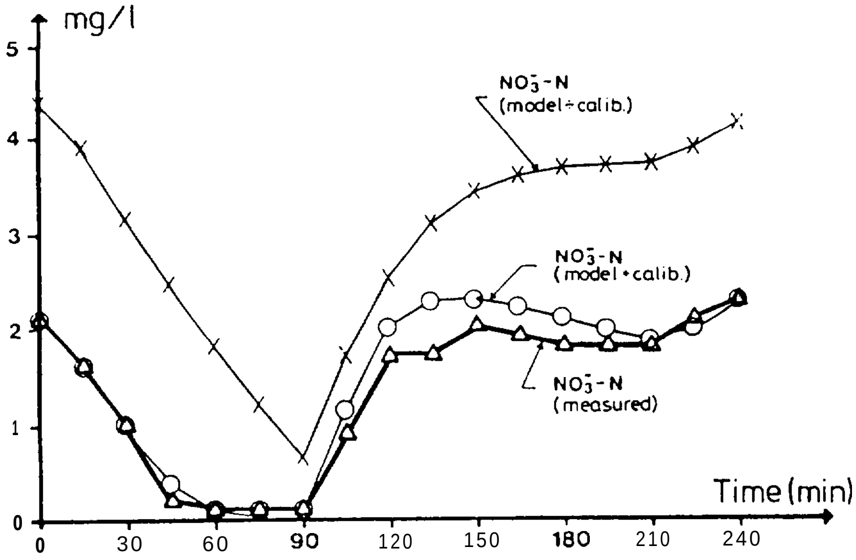

Fig. 7 Results Obtained from **Avedøre** Bio-Denitro Pilot Plant, Compared with Model Data (Uncalibrated and Calibrated)

CONCLUSION

Good experience has been gained from 15 years' operation of a large number of plants with nitrogen removal, primarily by the use of the Bio-Denitro process.

Analysis results of 17 plants have shown that the average values (60 % quantile) of the mean values from these plants are approx. 1 mg/l NH,-N, approx. 6 mg/l NO,-N and approx. 8 mg/l total nitrogen. The highest mean values have been obtained in plants with quite special operating conditions and problems. A general effluent demand of 8 mg/l total nitrogen will therefore normally be observable.

Results obtained from treatment of industrial wastewater from the food and chemical industries in full-scale and pilot-scale plants have shown that also for this type of wastewater satisfactory nitrogen removal can be achieved.

The prerequisites for obtaining good operating results are careful operations monitoring and flexibility of the plants in respect of design and control to such an extent that the denitrification and nitrification capacity can easily be changed in relation to the load variations.

In the years to come, the focus will be on compact processes comprising pretreatment and sludge hydrolysis for production of carbon. At the same time, mathematical models will be developed which can be used for dimensioning, operations optimization, control and monitoring of the plants.

However, the plant operators will always be important persons the training and skills of which will be decisive for proper functioning of the plants.

EXPERIENCES IN THE SWEDISH NITROGEN PROJECT

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Mr. Bengt Göran Hellström
Himmerfjarden Treatment Plant

Introduction

The extent of object research conducted in the field of water supply and sewerage at universities and institutes of higher education in Sweden has been extremely limited in recent years. The money has instead been invested in other fields. We therefore largely lack the advance knowledge that is needed now that nitrogen reduction is to be introduced over a short period of time at a large number of treatment plants in Sweden. The demand for trained staff within the process sector has already increased as a result of the fact that more complicated processes and combinations of processes are to be introduced. However, the training offered at universities and institutes of higher education is lagging a long way behind, and most of the training that is required has to be provided at the treatment plants. So too must a large proportion of the research and development work that now has to be conducted with a minimum of delay as a consequence of the nitrogen reduction requirements that have been imposed by the Government.

One of the objectives of the Nitrogen Project, which is described in another Swedish paper, is to collect, process and to spread information from the research and development on nitrogen removal that are conducted at different treatment plants. The idea behind this is to maximize the efforts that are being made on each treatment plant.

The following is a short review of nitrogen projects currently in progress in Sweden.

Ongoing development work

There has been a significant increase in the interest shown in introducing nitrogen reduction at Swedish treatment plants during recent years. The timetable adopted by the authorities for introduction of nitrogen reduction at plants in particularly sensitive coastal areas has, however restricted the opportunities for examining a number of alternatives to nitrogen reduction. The emphasis in the research and development work has been placed on biological nitrogen reduction and in particular on pre- and post-denitrification. Today development work in pilot plant and full scale are in progress at approximately 30-35 different treatment plants. Quite a few results have come from both pilot and full-scale plants. The interest in research into alternative methods has also increased, and Table 1 provides a summary of ongoing activities in Sweden.

Table 1 Nitrogen reduction projects in Sweden

Process systems	
Activated sludge processes	
- Pre-denitrification, one-sludge system	approx. 20 treatment plants, see SNV Report 3527 (1) Nitrogen reduction at municipal treatment plants
- Post-denitrification, one and two-sludge systems	Norrkoping, Malmö Himmerfjbrden, Halmstad, Helsingborg, Eskilstuna, Goteborg, Laholm
- Intermittent denitrification, SBR	Lund, Gällivare
- Alternating denitrification, Biodenitro	Laholm
- Fixed-bed processes	Malmd, Helsingborg, Örebro
- Proportion of anoxic/oxic zones	The Royal Institute of Technology, Stockholm (KTH), most plants under predenitrification
- Effect of pre-precipitation	Helsingborg, Halmstad
Trickling filters	
- Pre-denitrification, one and two-sludge systems	Lund, Karlskrona

- Post-denitrification, one and two-sludge systems	Malmo, Karlskrona, Lund, Varberg
- Increase of bed height	Malmo
- Effect of pre-precipitation	Karlskrona
Treatment of sidestreams	
- Nitrification/denitrification	Bromma, Värmdö, Eslöv, Norrköping
<u>Carbon sources</u>	
Wastewater (characterization)	The Hypro Project
Internal carbon sources (primary sludge, hydrolysed sludge)	Lund Institute of Technology (LTH), Chalmers University of Technology (CTH) Falkenberg, Halmstad, Laholm, Västerås, Klippan, Malmö, Oskarshamn the Hypro Project
External carbon sources (methanol, starch, industrial wastewater etc)	Värmdö, Norrkoping, Malmo, Himmerfjarden, Västerås, Eskilstuna, Göteborg, Halmstad, Helsingborg, Stockholm, Laholm, Varberg.
<u>Special studies</u>	
Testing of aeration systems	Malmo, Henriksdal, Kappala, Himmerfjarden, Bromma
On-line instrumentation	LTH, VAV (TR43)
Automatic control, modelling, knowledge-based systems	LTH, KTH
Sedimentation, sludge properties	CTH, KTH, the Rya plant, Bromma, Kappala, Himmer-. fjarden, Malmo.

Pre-denitrification

Many Swedish treatment plants have relatively long detention times in the aeration tanks and low sludge loads, which is shown in an investigation conducted by the National Environment Protection Board, SNV (2). This frequently leads to spontaneous nitrification at many plants, at least during the summer months. It has therefore been natural at these plants to in the first instance use pre-denitrification, since this also results in a reduced operating cost owing to lower oxygen consumption.

The goal has been to achieve 50 % nitrogen reduction with this method of operation, which is realistic. However, it requires complete nitrification and a recirculation level of at least 100 %. Accounts of the operating results have been given both in a number of internal presentations from several plants and in published material from Falkenberg (3), Halmstad (4), Himmerfjarden Treatment Plant (5, 6, 7) and Malmö (8, 21).

Falkenberg is the only treatment plant in Sweden with a requirement for nitrogen reduction, at least 60 % counted as mean annual value and at least 70 % as the mean value for the period July 1 up to and including November 30. The plant is equipped with both trickling filters and activated sludge facilities. The incoming water consists to a fairly large extent of industrial wastewater and therefore contains higher concentrations of organic matter than is normally the case at Swedish plants. This means that a typical reduction in nitrogen via the plant due to assimilation may be in excess of 30 %. Despite this, here too a carbon source must be added during the night-time and week-ends in order to optimize the denitrification process. Primary sludge is used for this purpose in combination with manual connection and disconnection of one or two trickling filters. This serves to stabilize operation of the nitrogen reduction plant. In this way it has been possible to meet the imposed requirements.

At Busörs treatment plant in Halmstad one third of the volume of the aeration basin have been arranged into an anoxic zone. Since the spring of 1988 the annual mean value for the nitrogen reduction, has been approximately 50 %. As in Falkenberg, the incoming water consists to a large extent of industrial wastewater wich leads to a high C/N-ratio.

At Västra Stranden treatment plant in Halmstad, the possibilities for nitrogen reduction were investigated during 1986. A summary of the results of trial operation at a temperature of 16°C shows:

- It was possible to achieve 50 % nitrogen reduction, corresponding to at most some 4 mg/l of total nitrogen as a mean value in the water leaving the present treatment plant by raising the sludge content in the aeration tanks and arranging an anoxic zone in the first part of each aeration tank. The sludge concentration could be raised to a high level (3 500 - 4 000 mg/l) without impaired sedimentation.

- In order to increase nitrogen reduction to at least 70 % the volume of the aeration tanks must be doubled. The total nitrogen content in the outgoing water will then be at most approximately 8 mg/l of total nitrogen.

Himmerfjarden Treatment Plant has a low proportion of industrial wastewater and thus fairly low concentrations of organic matter in the incoming water. Denitrification is restricted during a large part of the time by the supply of organic carbon. Figure 1 shows how the carbon/nitrogen ratio and denitrification vary during the day and week. During the course of measurement, on-line instruments have been used for COD and total nitrogen. The assimilative nitrogen removal is normally 10 - 12 % of the incoming nitrogen. In order to achieve 50 % reduction, it is necessary to add a carbon source during periods of low load. Pilot trials were therefore carried out during the summer and autumn of 1988 with a number of carbon sources: primary sludge, water from primary sludge thickeners, acetic acid and glycol. An interim report on the results shows that the rate of denitrification was increased by between 50 and 88 % when acetic acid and glycol were used. During a two months period using glycol, the mean value of nitrogen reduction was 72 %.

At Klagshamn Treatment Plant in Malmö, the situation is very similar to that at the Himmerfjarden plant, a carbon shortage restricts the denitrification which stops at a level of about 30 %. In this case, starch has been used as an additional carbon source.

These experiments are reviewed under the chapter headed “Carbon sources”.

Studies at Sjölunda treatment plant in Malmö (21) on pre-denitrification in combination with a fixed-bed material in the aeration tank, have resulted in a nitrogen reduction of 70 % (mean valve).

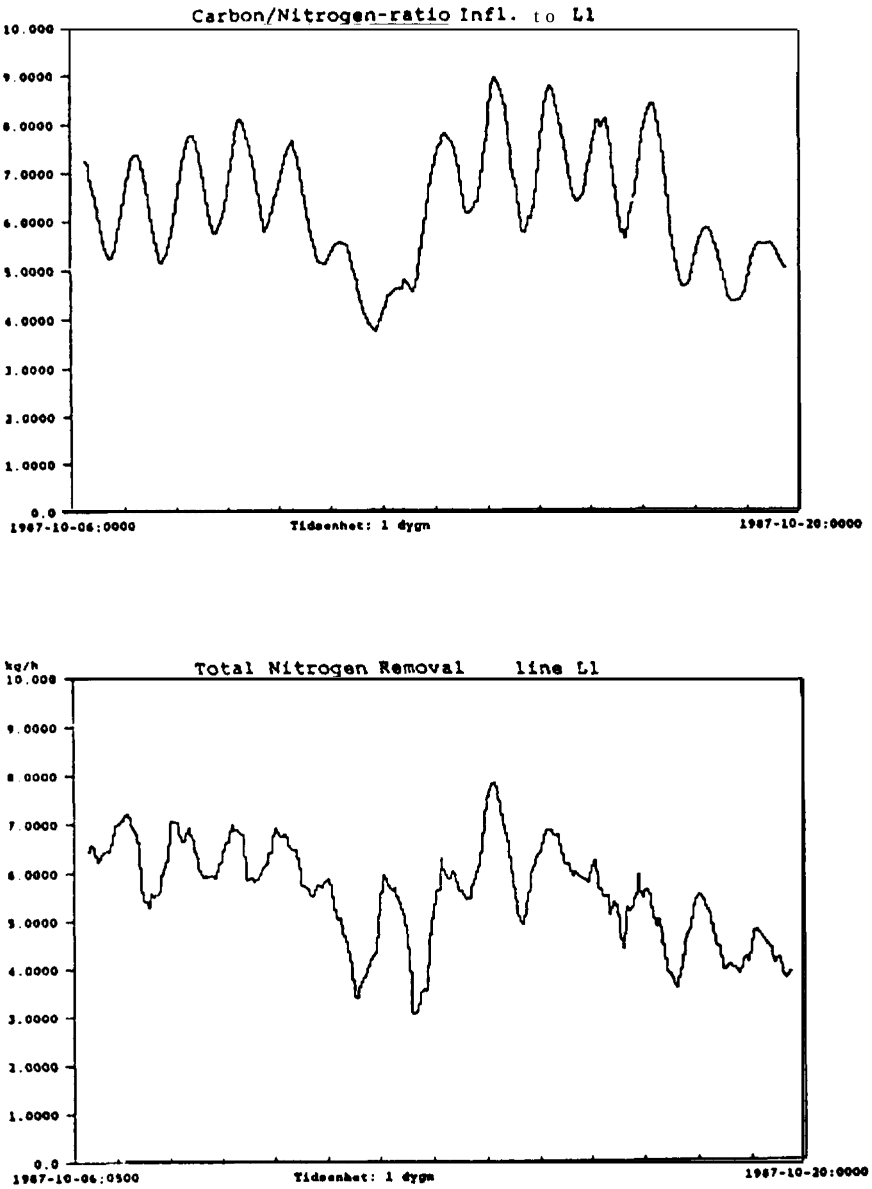


Fig. 1 Variations in nitrogen reduction at Himmerfjarden Treatment Plant

Post-denitrification

Many Swedish wastewater treatment plants are designed for post-precipitation. Since the introduction of pre-precipitation and its optimization, a number of post-precipitation plants have been closed down or not used optimally. It is possible to use these volumes for post-denitrification in the way outlined in Figure 2.

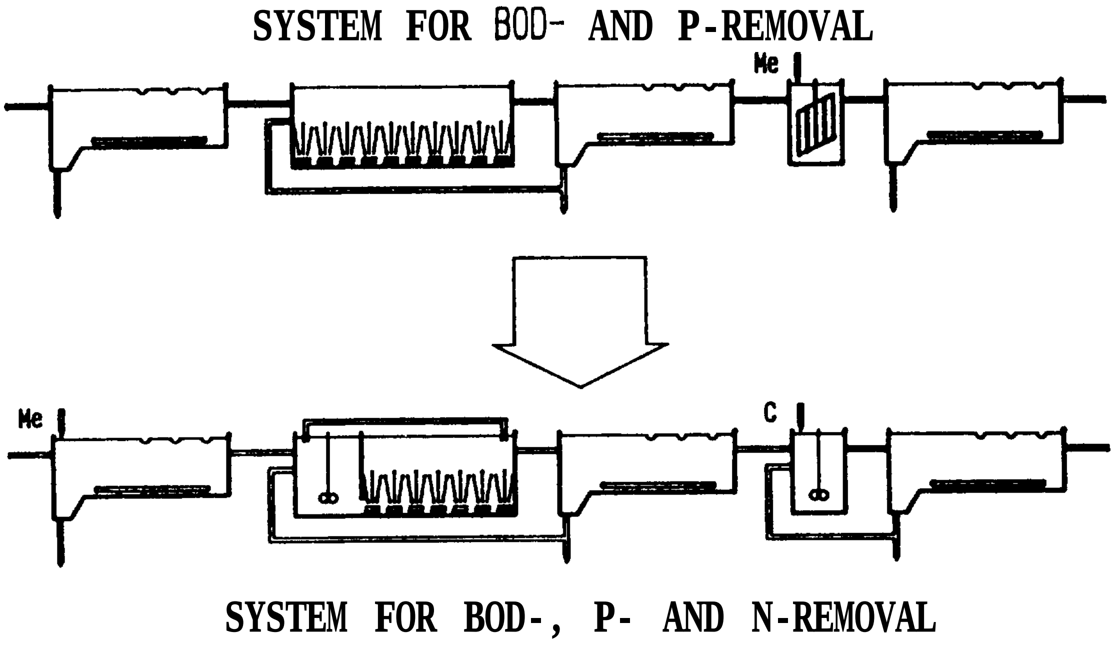
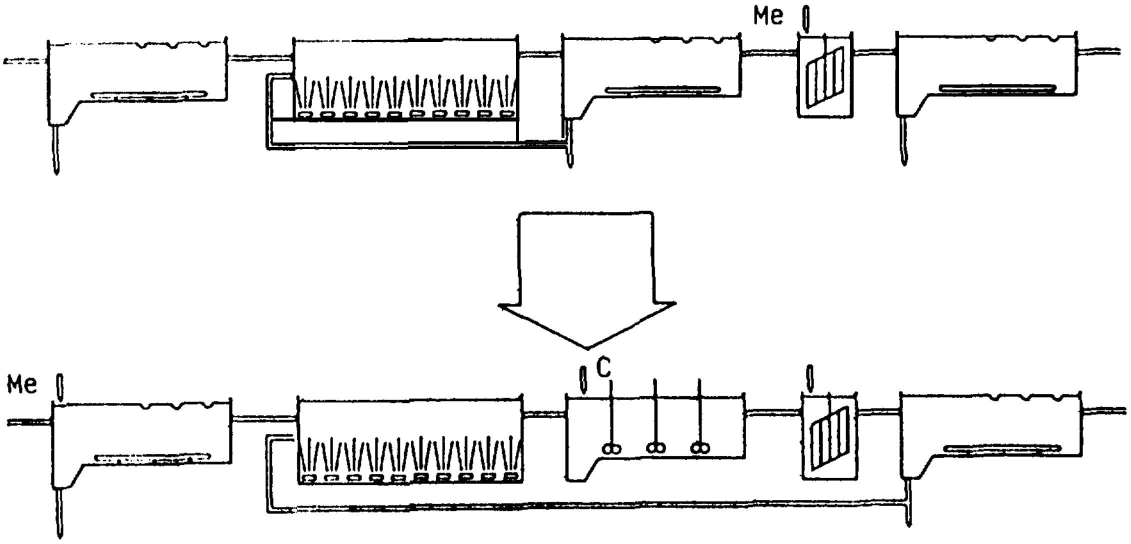


Fig. 2 Alternative methods of operating a post-precipitation plant

This concept has been successfully tested in Norrköping (9). Experiments with a system of sludge recirculation have been in progress since 1987. The changeover to pre-precipitation with ferrous chloride made the section for chemical treatment redundant. This section has subsequently been used for post-denitrification. Hydrolysed starch has been used as an external carbon source. The results show that the ingoing nitrate nitrogen concentration to the post denitrification plant was approximately 12 mg/l and in the outgoing water some 4 mg/l. The consumption of starch corresponds to approximately 1.6 g of carbon per gram of nitrogen removed.

The concept is also being tested in Malmö at the Sjölunda plant. The water from a pre-denitrification plant is led to two flow lines in the post-precipitation plant, where the flocculation tanks have been converted to permit experiments with post-denitrification. Fixed-bed material with a density of 200 m^2/m^3 has been applied in the flocculation tanks, and the system is operated as a non-recirculated system. Studies are made in connection with the addition of different carbon sources.


SYSTEM FOR BOO- ANO P-REMOVAL

SYSTEM FOR **BOD-, P- ANO N-REMOVAL**

Figure 3. Alternative methods of operating a post-precipitation plant

Post-denitrification experiments have also been carried out at Himmerfjarden Treatment Plant with the aid of subsidies from the National Environmental Protection Board, see Figure 3. These subsidies are referred to as New Technology Grants (5). The results showed that the volumes for post-denitrification, in this case the converted secondary precipitation tanks, were not sufficiently large for the endogenous respiration to provide an adequate addition of available organic carbon. In order to achieve a sufficiently high level of nitrification, methanol has to be added as a carbon source, which was shown in full-scale trials.

Carbon sources

During the biological denitrification, the ratio between organic carbon and nitrogen in the wastewater is of considerable importance. As demonstrated by the experiments reviewed above, shortage of carbon has tended to restrict the denitrification at a number of plants. There is therefore considerable interest in studying various external carbon sources, and a number of experiments have been carried out on a laboratory and pilot scale, as well as several in full scale. In the full-scale trials, primary sludge has been used as a carbon source at Falkenberg (3) and Halmstad (4), as well as in treatment of sidestreams at Bromma (10) and Värmdö (11).

Raw wastewaters from food-processing industries are to be tested as carbon sources in Laholm and Varberg.

Hydrolysed starch has been used at the Klagshamn plant and the Sjölunda plant in Malmö (8, 21) and Norrkoping (9), and methanol at the Himmerfjarden plant (5). Acetic acid, acetate, formate, saccharose and glycol have also been studied in experiments on a laboratory and pilot scale. In connection with the laboratory tests, a simplified method of measuring the denitrification rate has been worked out by Anox Ab in Lund, and used in the tests of carbon sources that have been made in Malmö and Norrkoping.

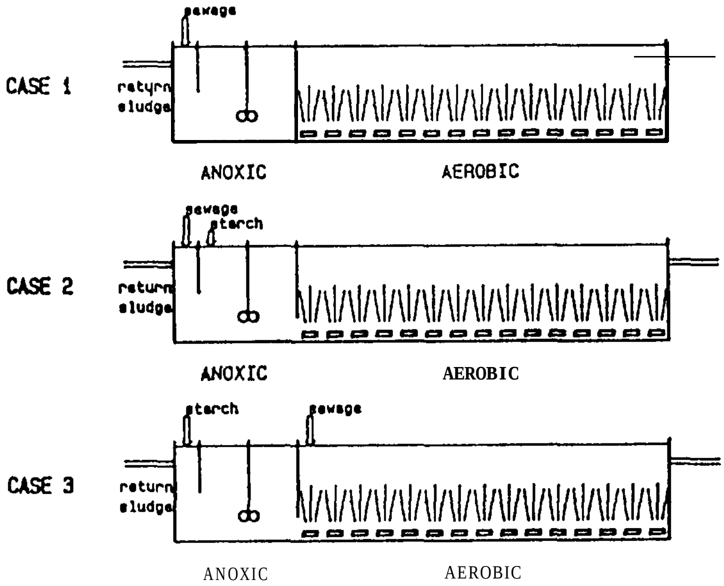


Figure 4. Alternative dosing points for external carbon source

Alternative dosing points for the external carbon source have been investigated at the Klagshamn plant (see Figure 4). If only return sludge and external carbon are added to the anoxic zone, the concentrations of both nitrate and organic carbon will be higher. This in turn gives higher denitrification rates and double the detention time in the anoxic zone. The preconditions for a high level of denitrification increase. The wastewater is then added after the anoxic zone. There are many indications to suggest that improved sludge sedimentation capacity is obtained if there are high contents of easily-degradable organic material when the sludge flocks are formed. In these experiments, it appeared that the starch was not degradable to a sufficiently rapid extent in order to permit evaluation of the method of operation. Carbon sources of the methanol or acetic acid type are needed for this purpose. However, this process alternative is interesting and will continue to be studied.

The result from the Kalgshamn plant in Malmö, where a hydrolysed starch was used as the external carbon source in a pre-denitrification stage, differ significantly from those presented from Norrkoping. Despite a dosage of starch, the denitrification in the anoxic zone failed to increase, and nitrate was found to remain in the water leaving the zone. However, the nitrogen separation increased throughout the entire plant by approximately 15 %, although this can be attributed to increased assimilative reduction which manifested itself in a substantial increase in sludge production. Laboratory tests has confirmed that starch in this pre-denitrification plant is not degradable to a sufficiently easy extent. In Norrkoping, starch is used in a post-denitrification stage with extremely successful results.

The possibilities of producing easily-degradable carbon through the hydrolysis of sludge have attracted a lot of interest. Experiments were carried out during 1988 at a pilot plant in Halmstad. The results show that fats are not broken down under the prevailing anaerobic conditions. Experiments have therefore been carried out with a complementary alkaline hydrolysis. The experiments have been conducted both without heating and at 33 °C, in which context a study was made of the temperature effects. Since the experiments gave the anticipated results, a full-scale trial started during the winter of 1988 in a thickener. Also the questions of separation are being studied. The results have not yet been published.

Similar full-scale experiments are also planned in Västerås. There, however, it is also possible to study the separation between sludge and water phases in a separate thickener.

Experiments on biological and chemical hydrolysis of pre-precipitated sludge at a pilot-plant in Helsingborg, has indicated that a convertion of approximately 20 % of the sludge content of COD to easily-degradable carbon is possible.

In conjunction with experiments concerning biological phosphorus reduction in a pilot facility at Sjölunda Treatment Plant in Malmö, the hydrolysis of sludge has been used for the production of easily-degradable carbon. The experiments have been carried out at room temperature in a 1.5 m^3 tank and various detention times have been studied. A report on the experiments is currently being drafted.

Sludge hydrolysis is included as part of a Nordic research project called HYPRO, the Hydrolysis PRoject. Representatives for Sweden (KEMIRA), Denmark (Kruger, DTH, VKI) and Norway (NTH, Ferriklor) are involved in the project, which has Eureka status. It is to be carried out in two years and have a budget of SEK 18 million. The two other main parts of the project are chemical precipitation and biological nitrogen reduction. The project aims at developing a process for advanced wastewater treatment including extensive treatment of organic matter as well as nitrogen and phosphorus. The concept is shown in Figure 5.

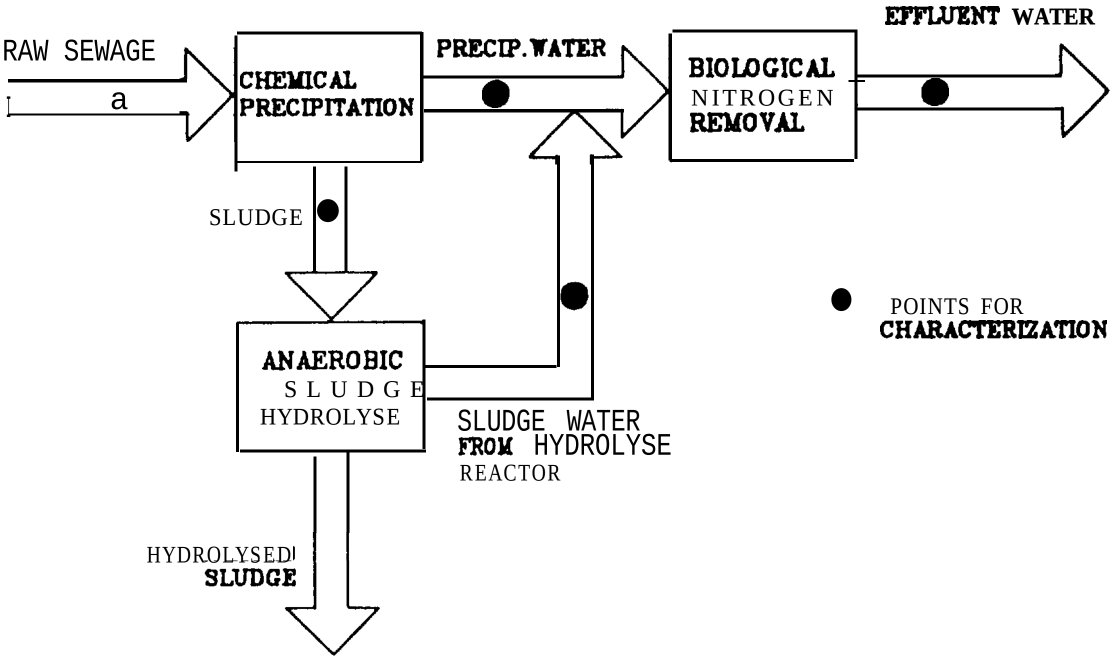


Figure 5. The HYPRO Project

The bological nitrogen reduction is accelerated through the addition of easily-degradable, organic carbon produced through biological or chemical hydrolysis of chemically-precipitated sludge. One important goal of the project is to investigate and characterize the wastewater in the various process stages. New specific characterization methods shall be developed for this purpose.

Treatment of supernatant from sludge dewatering

As a complement to pre-denitrification, it may be of interest to specifically treat more concentrated internal flows. Biological treatment of supernatant from sludge dewatering has been investigated at Bromma Treatment Plant, Stockholm, Eslöv, Norrköping and Värmdö.

The work at the Bromma plant was carried out as a licentiate task at the Royal Institute of Technology, Stockholm (10). During the experiments, a reduction of about 60 % was achieved in the ammonium content, primarily due to an oxidation of ammonium to nitrite. Continued oxidation of nitrite to nitrate was probably inhibited by the low pH value (approx. 5.6 - 6) and the high content of nitrous acid. During the experiments, the alkalinity of the water dropped from 3 500 - 4 800 mg/l HCO, to 50 - 100 mg/l HCO,.

This shows that the alkalinity may be an important factor which prevents extensive oxidation of ammonium. A moderate denitrification (approx. 10 - 20 %) took place in the denitrification zone. The access to organic carbon was the governing factor in this context. An addition of external carbon was made in the form of primary sludge. The denitrification thereby increased by (16 - 28 %) as a consequence of the addition of primary sludge.

Another study of biological nitrogen reduction in the reject water has been carried out at Tjustvik Treatment Plant in Värmdö (11). The plant has a special treatment line for supernatant from sludgewatering. The idea was that nitrification of the supernatant would be obtained at the same time as nitrification bacteria from this plant was used as graft material, and thereby simplified nitrification throughout the entire plant.

In the supernatant line, an anoxic zone was created in the aeration tank. During experiments, it was shown that the alkalinity was usually sufficient for a 50 % denitrification. During denitrification, the alkalinity increases proportionally to the degree of denitrification. In order to permit complete nitrification, hydroxide was added. The organic matter in the supernatant was only sufficient for 10-20 % denitrification. The nitrification level was increased to max 70 % by the addition of well sludge. The primary sludge was also tested on a full-scale basis. In addition, methanol, acetic acid and hydrolysed starch were tested on a laboratory scale. Methanol proved to give the highest denitrification rate of the three.
The study in Varmdo will continue on larger scale during 1989. Hydrolysis of sludge,the ratio between aerobic and anoxic zones, and fixed-bed materials will also be investigated.

In Norrköping a full-scale trial of biological nitrification in supernatant from sludge dewatering and return sludge started in december 1988. The purpose is, as in Varmdo, to produce nitrification bacteria, wich are seeded into the water treatment plant during cold seasons. In order to prevent low pH value in the nitrification process lime is added. The result has been promising. The nitrification in the water treatment plant started for exampel 30-40 days earlier 1989, compared to 1988.

Intermittent methods

The intermittent method that has attracted most interest in Sweden is Sequencing Batch Reactors (SBR).

It has been investigated on municipal water in Lund, where a pilot plant with two reactors was used. The results have been encouraging, with full nitrification and a high mean level of denitrification. The average nitrogen reduction during the test period has been 73 % (22). There are now hopes of even better results with an optimization of the sequence periods.

The technique has also been used for the treatment of leachate in a 500 litre reactor in Varberg, and was shown to work even with waters as thick as this. The ingoing nitrogen content was 400-450 mg/l and the outgoing content normally 50-60 mg/l. During certain periods the reduction was over 90 %.

Interest is being shown at several municipal plants in testing the technique on a full-scale basis. Several experiments will probably be started during spring 1989. In addition, there is a National Board for Technical Development (STU) project being conducted at the University of Luleå (13) in which biological phosphorus reduction by the SBR technique in cold climates will be investigated.

Increase in sludge content

One of the most important factors that affects nitrification is the sludge age. At a temperature of 20°C, a sludge age of 5 days is sufficient, whereas it hast to be increased to about 20 days when the temperature drops to 6 or 7°C. The sludge age is influenced by the sludge production and quantity of sludge in the system.

It is possible to increase the sludge concentration in the system to a critical level. Studies of the sludge properties in connection with nitrogen reduction have been made at Käppala Treatment Plant (15, 16) and a major study has been initiated at Bromma Treatment Plant during 1988. Both tasks are being conducted in cooperation with the Royal Institute of Technology, Stockholm (KTH). KTH is also running an STU project entitled "Improvements in sludge properties in order to permit biological nitrogen reduction at existing wastewater treatment plants in Sweden". A status report is available on this study (16).

The function of the sedimentation tanks at the Rya plant in Gothenburg has been studied in detail at CTH by Lumley (17).

One way of increasing the sludge concentration in the aeration tanks is to use a fixed-bed process. An increase of 1.5 in the sludge concentration to 9 kg/m^3 has been reported in the literature. This corresponds to an increase in the sludge concentration of between 50 and 300 % in a conventional activated sludge facility. Apart from an increase in sludge concentration, benefits such as a more stable process and reduced sensitivity to lower temperatures have been repoded.

Experiments have been carried out on a full scale in Örebro and Malmö, and on a pilot scale in Helsingborg.

At Sjölunda Treatment Plant in Malmö, two parallel lines have been converted for experimental use (8, 21). These lines each treat 10 % of the total flow. Both the lines have anoxic zones in their inlet sections (see Figure 6). The zones are separated by wooden walls and the anoxic zones are fitted with agitators. In one of the lines, fixed-bed material trate with a density of 150 m^2/m^3 has been installed. This takes up approximately 25 % of the total tank volume. Beneath the fixed-bed, a fine-bubble aeration system covers the entire floor in order to furnish the oxygen supply and combat blockage and choking of the fixed-bed. The experiment was initiated during the summer 1988.

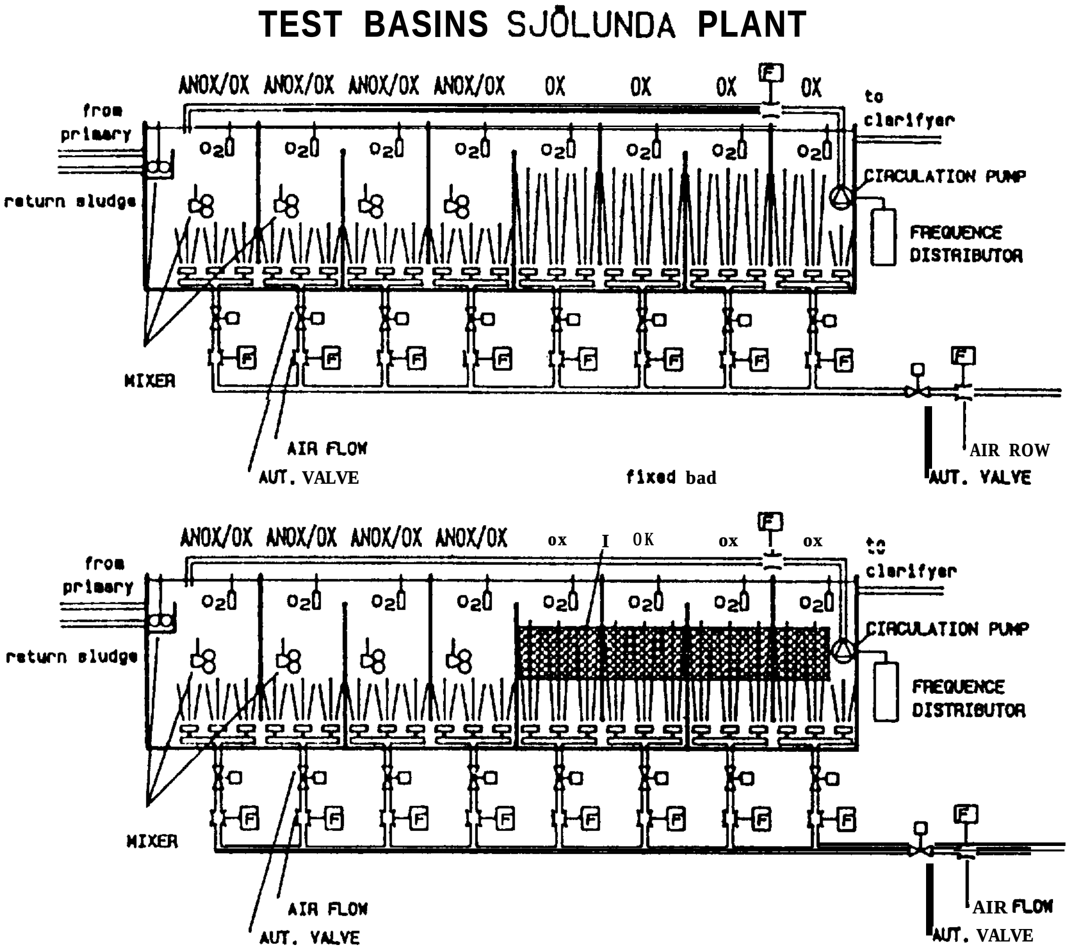


Figure 6. Experimental plant at Sjölunda Treatment Plant, Malmö

The results of the study shows that:

- The sludge concentration in the line fitted with fixed-bed material could be increased to 6 000 mg/l, compared to 3 000 mg/l in the line without fixed-bed material. The sludge properties of the sludge from the line with fixed-bed material also where better.

- Sludge production was 50 % lower in the fixed-bed line.

- Nitrification and denitrification rates were 50 % higher in the fixed-bed line. Total nitrogen reduction was approximaterly 70 %.

At Sjölunda fixed-bed materials also have been tested in anoxic volumes for post-denitrification. The denitrification rate was increased dramatically when starch was added, but the fixed-bed material got clogged after two weeks due to intensive bacterial growth, and the experiment was stopped. Inspite of this the experiment was judged as promising and will be continued with other kinds of carbon sources.

In Helsingborg experiments have been carried out at a pilot plant with fixed-bed material (23). This has made it possible to study a number of different process variations in parallel, including nitrification, pre-nitrification, post-nitrification, the addition of a carbon source, precipitation and simultaneous precipitation.

Aeration system

Owing to variations in temperature and load, it may be extremely advantageous to be able to vary the size of the anoxic and aerobic sections. This has been made possible at several treatment plants by subdividing the aeration tanks into several sections separated by walls. In each section there is an aeration system covering the floor of the tank with a separate air supply. The diffusers are of the finebubble type with a flexible rubber membrane. It is possible to use this type of diffusers intermittently. In this way, when necessary, one zone can be aerated, and on another occasion it can be closed on and become anoxic without the aerators clogging up. The efficiency of this type of diffusers has so far proved to be good. However, one question that still remains is the life-span of the rubber membrane.

Tests incorporating IFU and Nopol diffusers are being carried out at Sjölunda, Henriksdal and Himmerfjardplants. In order to evaluate their efficiency, a test method referred to as the “off-gas” method is being used. The gas that leaves the aeration tanks is collected by means of a floating hood. This is referred to as “off-gas” and its oxygen content is compared with the oxygen concentration in the air to the aeration system. The method, which is described in several articles, has proved to be fast and comparatively simple, at the same time as the analysis results are reliable. The test results are currently being compiled in a joint report from the plants mentioned above. All the systems were installed during the spring and summer of 1988 and thus still have comparatively short operational histories.

Modelling, simulation and control of treatment plants

A simple design model for one-sludge plants for biological nitrogen reduction has been developed by Hultman with the help of data from the literature available on the subject (20). The model is based on variables that are normally measured at treatment plants. This shall make it possible to verify the model with the experimental findings that are now being obtained at pilot and full-scale plants. The model provides the answer to total detention times in the biological plant and in the anoxic and aerobic parts.

Research concerning the control of treatment plants has been carried out at the Institution for Automatic Control at the Institute of Technology, Lund. The interest shown by purchasers in dynamics and automatic control has increased during recent years. Now that nitrogen reduction has also become of interest, there will be a significant increase in the need to understand and improve operation.

A project referred to as “Modular model systems for the simulation and control of treatment plants” has been started during the autumn of 1988 at LTH (20). The project incorporates two sub-areas, one of which comprises the development of a dynamic simulator for treatment plants and the other knowledge-based systems for the diagnosis of operational status and operator management in treatment plants.

The object of the first sub-project is to make use of knowledge on and developed software for dynamic models for activated sludge plants in order to construct a process simulator. This shall be utilized in prototypes directly in treatment plants as an advisor instrument for technicians and process engineers. One way of using simulations is to test measures in advance, especially manual actions, the result of which can be shown in an extremely slow time scale. In addition, the simulator may become valuable training instrument for technicians and process engineers in order to gain a clearer idea of different sub-processes.

The second sub-project aims at systematizing a set of rules for diagnosing different operating conditions in the activated sludge process. This set of rules shall utilize both on-line information as well as laboratory samples and other observations. This means that the rules must vary depending on the degree of plant instrumentation. With an expert system or a knowledge-based system, a technical aid is created which provides a “partner” for the technician or process engineer in working out the reason for a certain operating condition. When counter-measures are to be tested the simulator outlined above will be a natural aid.

The demand for continuous measurement sensors will naturally be greater when the dynamic sequence is to be decided. A working group within VAV, TR 43, is engaged in reviewing sensors available on the market that may be of interest in experiments with nitrogen reduction. A list of the instruments that are available is currently being compiled. Consequently, an attempt will be made at evaluating the function, reliability and maintenance requirements based on instruments in operation at the treatment plants.

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CRITICAL FACTORS FOR NITROGEN REMOVAL - REPORT ON SIX YEARS FULL SCALE OPERATION IN FALKENBERG

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Anox Ab

INTRODUCTION

Falkenberg is a town on the Swedish west coast with some 40 000 inhabitants. The waste water treatment plant is also receiving waste water from different industries like brewery, dairy, slaughter house, distilling plant, metal recovery plant. To be able to treat this mixed waste water the treatment plant was originally designed for 160 000 population equivalents.

Full scale tests with biological nitrogen reduction took place at Falkenberg waste water treatment plant from July 1, 1983 to June 30, 1984. After this date the treatment plant has been operating with nitrogen reduction. The permit for the effluent standard was revised by the Swedish authorities during 1985 and it was required that the treatment plant should be reconstructed before January 1, 1987 to permanently achieve not less than 60 % total nitrogen reduction as a yearly average and not less than 70 % during the period from July 1 to November 30. The BOD and phosphate limits were decided to be 25 mg/l and 0.5 mg/l respectively.

The treatment plant was build in 1976 and the process at Falkenberg comprises mechanical treatment followed by two trickling filters in parallel after which follows an activated sludge process and finally chemical treatment.

Table 1. Design data for Falkenberg Treatment Plant

The process comprises:

Mechanical treatment	
screens and grit removal	
3 primary clarifiers, total	630 m2
	1.320 m3
Biological treatment	
trickling filters	
2 units in parallel	
plastic media	2 * 2.600 m3
Activated sludge	
4 aeration tanks, total	3.970 m3
5 secondary clarifiers	5 * 280 m2
total	4.510 m3
Chemical treatment	
4 two-stage flocculators	
4 flotation units	4 * 120 m2
	3.5 m/h
Sludge treatment	
primary sludge gravity thickening	
secondary sludge flotation thickening	
chemical sludge direct to flotation	
lime dosing on mixed sludge	
filterpress	

During 1985 and 1986, after extensive trials, parts of the treatment plant was changed in order to permanently incorporated nitrogen reduction. The most important changes were the introduction of anoxic zones for predenitrification and a possibility to by pass the tricklingfilters.

The original design was to treat 13 ton BOD/d of which 9 ton was from industrial origin. The modification caused by introducing nitrogen reduction has reduced the capacity to 10 t BOD/d.

The following data is a summary of average daily loads and reductions during the last five years of operation:

Table 2. Results from Falkenberg treatment plant, yearly average

Year	1984	1985	1986	1987	1988
Flow					
m3/d	16720	18548	17495	17624	18716
% of design	55	62	58	59	62
BOD load					
% of design	30	41	38	50	47
BOD, effluent					
mg/l	13	12	7.2	3.4	3
totP, effluent					
mg/l	1,8	0.75	0,69	0,43	0,35
SS, effluent					
mg/l	23	22	20	6,9	7,8
N load					
kg/d	565	693	717	680	600
N reduction					
%	64	52	55	69	65

The reconstruction work 1985 and 1986 in the treatment plant caused lower reduction of nitrogen. During 1984 and three months in 1985 chemical precipitation of phosphor was not done.

INDUSTRIAL EFFLUENTS

The strong influence of industrial waste waters on the load to the treatment plant is illustrated in table 3.

Table 3. Waste water composition in Falkenberg

		1987		1988	
		industry	sewage	industry	sewage
Flow	m3/d	2380	15244	2499	16217
	%	13	a7	13	a7
BOD	kg/d	4085	907	3476	1246
	%	82	18	74	26
Total P	kg/d	44	108	39	95
	%	29	71	29	71
Total N	kg/d			292	306
	%			49	51

Different industries contribute varying amounts of different pollutants to the waste water. The major industrial sources for BOD, and phosphorus are brewery, diary and distilling plant. The single largest industrial source of nitrogen is an industry which recovers silver from photographic film. Out of the average daily load of 292 kg N/d of industrial origin during 1988, 188 kg/d came from this industry alone with a flow of only 8 m^3/d.

The are also large variations in industrial waste water composition between different periods. To some extent on a yearly basis, but more so between different days of the week, with low amounts during the weekends.

CARBON SOURCE

In order to reduce nitrate to nitrogen an energy source is necessary. The theoretical amount of BOD needed for this reduction can be estimated to be 2,86 gram BOD per gram nitrate-nitrogen reduced.

In most cases, the waste water coming to a treatment plant contains sufficient BOD, but after pretreatment the BOD often turns out to be limiting, partly because a portion is not accessible in the time available for predenitrification, but will be oxidized in the aerobic zone of the process.

The nitrogen reduction varies over the year and the ratio BOD/N do not give a good correlation with nitrogen reduction, Table 4. In August there is a high temperature in the aeration tank, the BOD/N ratio is the lowest in the whole year but the denitrification is at a peak.

Table 4. Monthly average values for the activated sludge plant in Falkenberg

Month	DNG %	BOD/N	Temp. C	Sludge age Aerated d	Sludge age Anoxic
Jan	24.5	5,8	9,4	4.5	0.8
Feb	9.7	5,3	8,3	3.5	0.6
Mar	21,4	5,7	8,9	6.9	1.2
Apr	24,1	5,7	11.0	9.2	1,6
May	42,7	4.6	15,0	7.9	1.3
Jun	45,4	3.2	17,7	7,3	1.2
Jul	57,7	4,2	18,8	8,0	1,4
Aug	61.6	2,3	17,6	9,2	1,6
Sep	52,7	3.6	17,6	6,6	1,1
Oct	46,6	4,8	14,6	6,3	1,1
Nov	46,9	4,9	12,7	6.7	1,1
Dec	49,9	4.5	11.1	7.0	1,2

% DNG = % of total nitrogen to activated sludge which is calculated to be reduced to nitrogen gas

BOD/N = in the waste water to the activated sludge process

The waste water that comes to the treatment plant during the weekends do not contain as much BOD as during the rest of the week, and the nitrogen reduction is also much lower during the weekends, as low as 30 %.

Table 5. Variations between days of the week

Day	% Nred	BOD/N	BOD kg/d	Total N kg/d
Sunday	41	2,7	1528	458
Monday	46	4,9	3102	588
Tuesday	52	4,3	2667	565
Wednesday	54	3,6	2069	544

% Nred = % of total nitrogen to the activated sludge removed by denitrification and excess sludge

Of % Nred approximately 15 % can be attributed to removal with the sludge, Figure 1.

OPERATION PROCEDURES IN RESPONSE TO VARYING RATIO BOD/N

The load on the treatment plant varies both on a yearly, weekly and daily basis. To be able to handle these variations and maintaining a good nitrogen reduction the trickling filters are operated intermittent. When the load is high they, one or both, are taken into operation in order to maintain a BOD load on the activated sludge low enough to allow nitrification but the load must be high enough to achieve anaerobic conditions in the anoxic zones to allow denitrification. The water leaving the trickling filter is almost saturated with oxygen.

To improve the nitrogen reduction and to make the best use possible of the available BOD during periods of limiting amount of easily degradable organic material, two measures has been taken.

First, the high concentrated waste water from the metal recovery industry, which contained approximately 200 kg N/d, is transported by truck to the treatment plant and dosed when the operator decide.

Secondly, extra carbon is added during the weekends. Several external carbon sources has been evaluated, acetate, formiate and locally available high concentrated waste waters. By adding methanol the nitrogen reduction during Saturday and Sunday could be increased from 30 % to 70 %. The same effect was also obtained by using primary sludge.

The sludge in one of the primary clarifiers is allowed to stay longer in the clarifier and is pumped out of the clarifier but returned not far from the outlet from the clarifier. In this way the sludge undergoes a fermentation and is “washed” before added to the anoxic zone and the heavy particles is not added to the biological treatment. This way of producing an easily dagradable carbon source is now permanently installed, Figure 2.

In practical terms BOD and BOD/N can not be used as an operational parameter. Control must be based on something that response reliably and quickly to any change in load. In Falkenberg it has been found, by experience, that flow, and to measure if oxygen is present in the anoxic zone, is useful as operational parameters.

OXYGEN CONTROL

By taking the trickling filters in or out of operation, and by the addition of primary sludge to the anoxic zones during weekends, the presence of oxygen in the anoxic zone is controlled.

It is also important that the oxygen concentration is controlled in the nitrification zones to give optimum conditions for ammonium oxidation, but not to put more oxygen into the waste water than necessary, to avoid oxygen in the recirculation stream going to the anoxic zone. It proved impossible to meet these requirements and at the same time have an economical aeration system, without an automatic control. Variable speed compressors were therefore installed during 1988.

VOLUME OF ANOXIC ZONE

During the trial in 1983 and 1984 the volume of the anoxic zones were approximately 1/3 of the aerated volume. When the process were introduced permanently the anoxic volume was reduced to half that size and is today approximately 500 m^3, the aerated volume is approximately 3500 m^3.

Table 6. Flow and detention time

Flow 1988	m3/d	Hours in: aerated zone	anoxic zone
Maximum	39070	2,1	0,3
Average	18716	4,5	0,6
Minimum	10590	7,9	1,1

The recirculation of nitrified water and return sludge is almost constant at 4 200 m^3/h of which 1 200 m^3/h is return sludge. This recircle ratio allows for 85 % nitrogen reduction by denitrification at average flow and up to 65 % at maximal flow. At average flow the detention time for each passage through the anoxic zone is only 6 minutes.

In theory, any oxygen present in the incoming waste water and recirculation water shall first be depleted and thereafter will nitrate be reduced. That nitrate is only reduced in the anoxic zone has not been shown and denitrification is expected to take place also in the aerated zone, especially immediately after the anoxic zone, and in the clarifier. To establish anoxic conditions in the anoxic zone has never the less been shown to be a critical factor for successfull nitrogen reduction.

CALCULATING NITRIFICATION

Figure 3 shows the nitrification rate during the week calculated in two different ways. The curve with ope symbols is calculated by using the total soluble nitrogen in the effluent and curve with the filled symbols by using total nitrogen. The latter means that suspended solids in the effluent will influence the calculation and reduce the calulated rate. This is the recommended way to calculate nitrification in Sweden but is to our opinion not the best way. (Suspended solids influence the calculation since nitrogen not nitrified in the effluent is taken as the difference between total nitrogen and nitrate).

SLUDGE ACTIVITY

In table 7, 8 and 9 are data for some key parameters presented. The general trends in these monthly average values coincide with the general view of biological nitrogen reduction.

Microbial activity is, among many factors, dependent upon temperature. In the data below there is a trend of higher activity at higher temperature, Figure 4. On a shorter term than monthly average, the activity varies very much but the temperature is changing only slowly. Therefore, temperature, and the other parameters listed below, are of limited value as operational parameters for the daily control of the treatment plant.

Table 7. **Nitrification** data

Month	Temp C	ss g/m3	NIT kg/d	N-ox g/kg h	NG %
Jan	9,4	3834	160	0.50	45
Feb	8,3	3440	104	0.37	34
Mars	8,9	4399	173	0,47	47
April	11.0	5807	161	0,33	40
May	15.0	6157	307	0,59	65
June	17,7	6484	403	0,74	81
July	18,8	5150	465	1,09	90
Aug	18,8	5509	470	0,93	91
Sep	17.6	5327	354	0,80	al
Oct	14,6	4040	301	0,89	75
Nov	12,7	4035	277	0,82	70
Dec	11,1	4938	325	0,79	71

SS = Suspended substance in activated sludge process
NIT = amount of nitrogen nitrified
N-ox = specific **nitrification** rate
NG = nitrogen nitrified in % of nitrogen possible to nitrify
Aerated volume 3.470 m^3.

Table 8. Sludge data

Month	Temp. C	Sludge age Aerated d	 Anoxic d	NG %	sludge load g BOD/g SS d
Jan	9,4	4,5	0.8	45	0,19
Feb	8.3	3,5	0,6	34	0,17
Mar	8,9	6,9	1.2	47	0,15
Apr	11.0	9,2	1,6	40	0,09
May	15.0	7,9	1,3	65	0.11
Jun	17.7	7.3	1,2	81	0,08
Jul	18,8	8,0	1.4	90	0,13
Aug	17,6	9,2	1,6	91	0,06
Sep	17,6	6.6	1,1	al	0,10
Oct	14,6	6,3	1.1	75	0.15
Nov	12,7	6.7	1,1	70	0,16
Dec	11.1	7,0	1,2	71	0,14

NG = nitrogen nitrified in % of nitrogen possible to nitrify

Table 9. Denitrification data

Month	Temp C	ss g/m3	DEN kg/d	N-red g/kg h	DNG %
Jan	9,4	3834	123	2,7	60
Feb	8,3	3440	42	1,0	30
Mars	8,9	4399	99	1,9	48
April	ll,o	5807	123	1,8	67
May	15,0	6157	241	3,3	76
June	17,7	6484	277	3,6	66
July	18,8	5150	355	5,7	72
Aug	18,8	5509	373	5.6	75
Sep	17,6	5327	295	4,6	77
Oct	14.6	4040	229	4,7	71
Nov	12,7	4035	244	5,0	78
Dec	11,1	4938	298	5,0	82

DEN = amount of nitrogen denitrified
DNG = nitrogen denitrified in relation to how much nitrogen there was available to denitrifie
N-red = specific denitrification rate anoxic volume in calculation; 500 m^3

TEMPERATURE, NUTRIENT AND FLOW INFLUENCE ON NITRIFICATION

The response of the treatment process depends on many variables and the personnel at Falkenberg treatment plant has found that a combination of flow and concentration of nutrients in the waste water is a useful basis for predictions of nitrogen reduction. Flow, and nutrient concentration shows a correlation with nitrification. At high flows the concentrations are lowered and nitrification drops. Periods of high flow often coincide with low temperature.

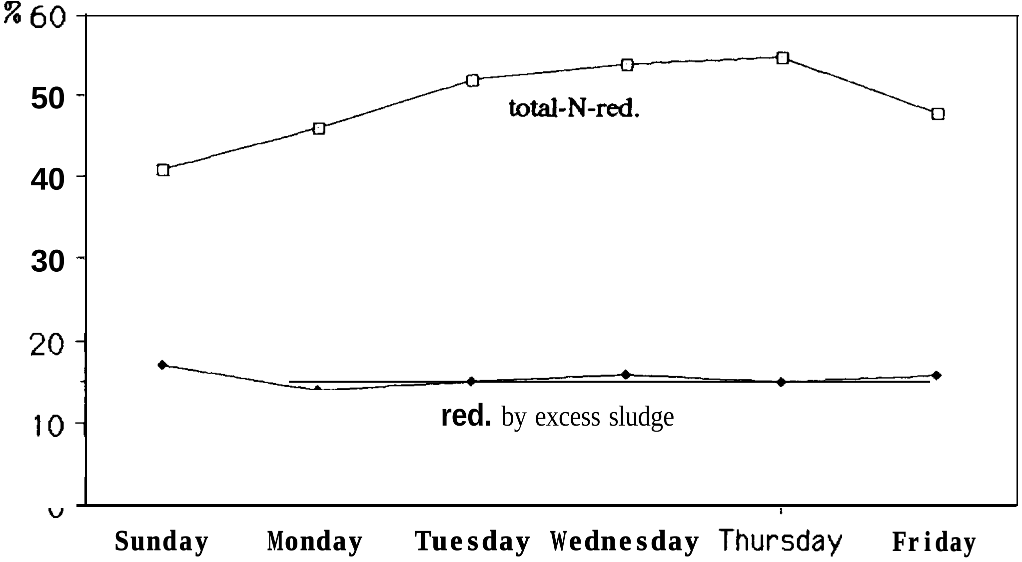
In Figures 5, 6, 7 and 8 data found at different nitrification percent has been put together in such a way that data for flow, temperature, phosphor and nitrogen concentration corresponding to values of % nitrification between 0 to 10 %, 10 to 20 %, etc. up to 90 to 100 % has been collected in ten groups and an average value for each 10 % segment of nitrification were calculated. There are clear correlation between nitrification, temperature, flow and nutrient concentrations.

Figure 9 and 10 shows the type of daily variation that can be observed for nitrification, flow and nutrient concentration. An experienced operator can make use of these variations to predict changes in the treatment result from day to day.

PERSONNEL AND LABORATORY RESOURCES

Perhaps the most important factor for a successful implementation of biological nutrient removal is to have trained and skillful people operating the treatment plants. The importance of this can hardly be overestimated. It is also important for most plants to have the ability to analyze nitrogen compounds regularly and to have both the knowledge and resources to not only supervise but also investigate and control the treatment plant. This will then result in better treatment performance and that the personnel can produce the material needed to make decision about how to run the process and to calculate massbalances of the process. Figure 11.

Figure 1
% nitrogen reduction in the activated sludge process



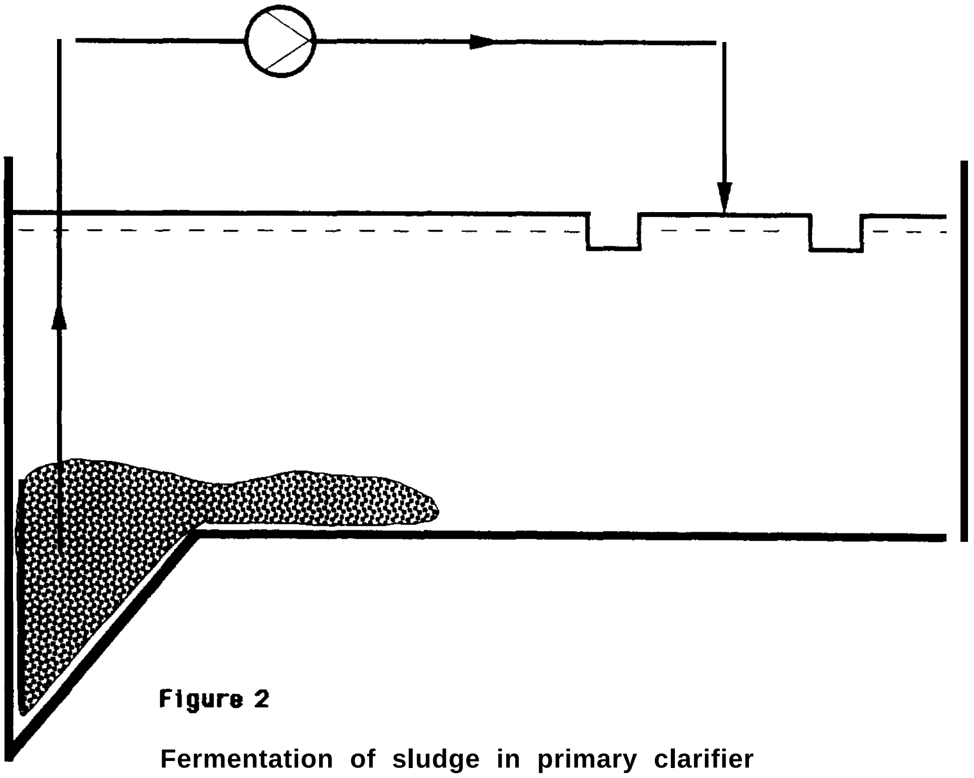


Figure 2

Fermentation of sludge in primary clarifier

Figure 3
Different ways of calculating % nitrification

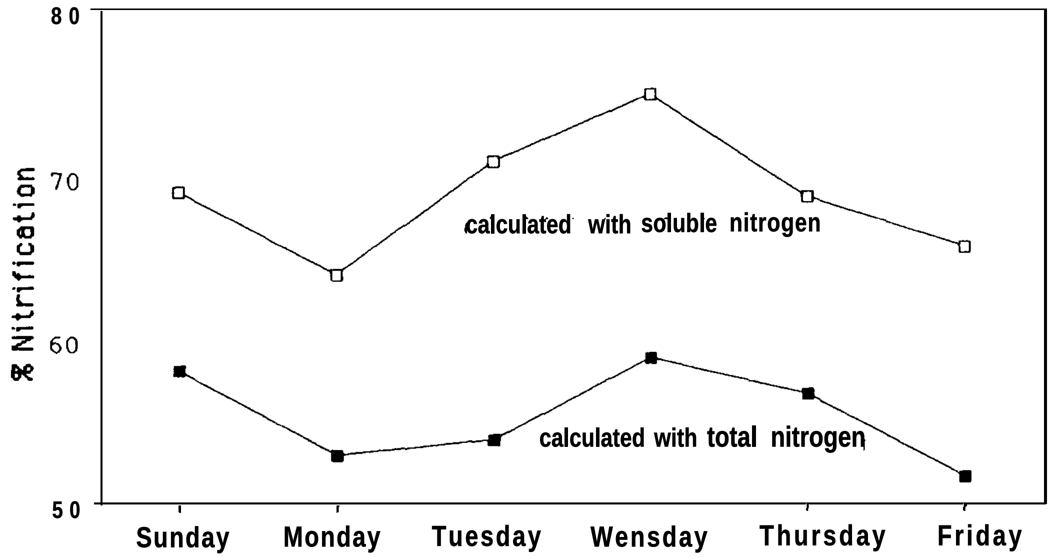
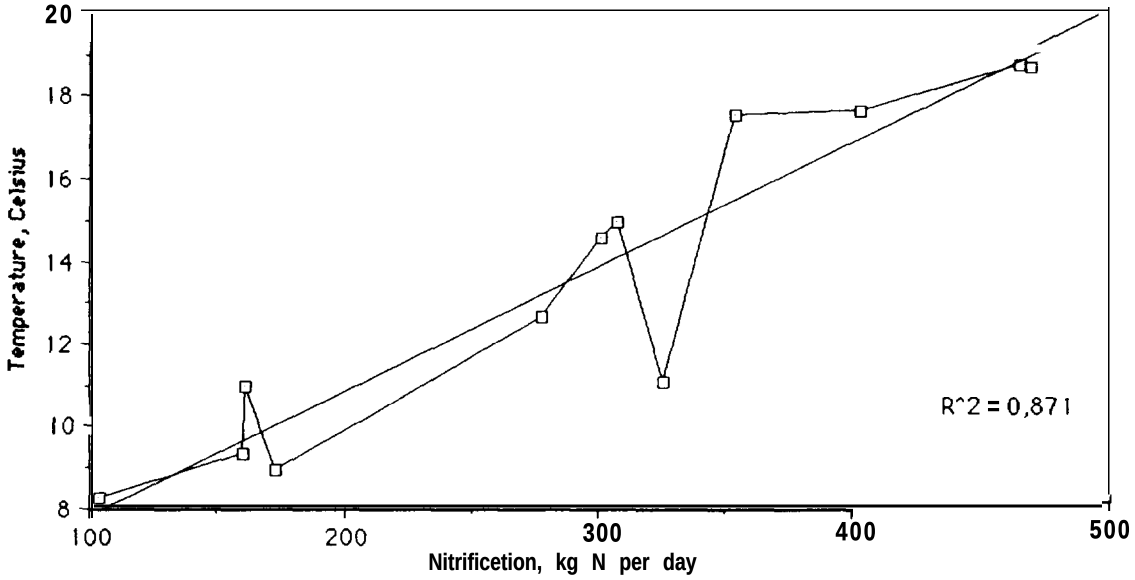


Figure 4.
Nitrification versus temperature, monthly average



Figur 5
% of nitrogen avaible for nitrification
that has been nitrified versus temperature

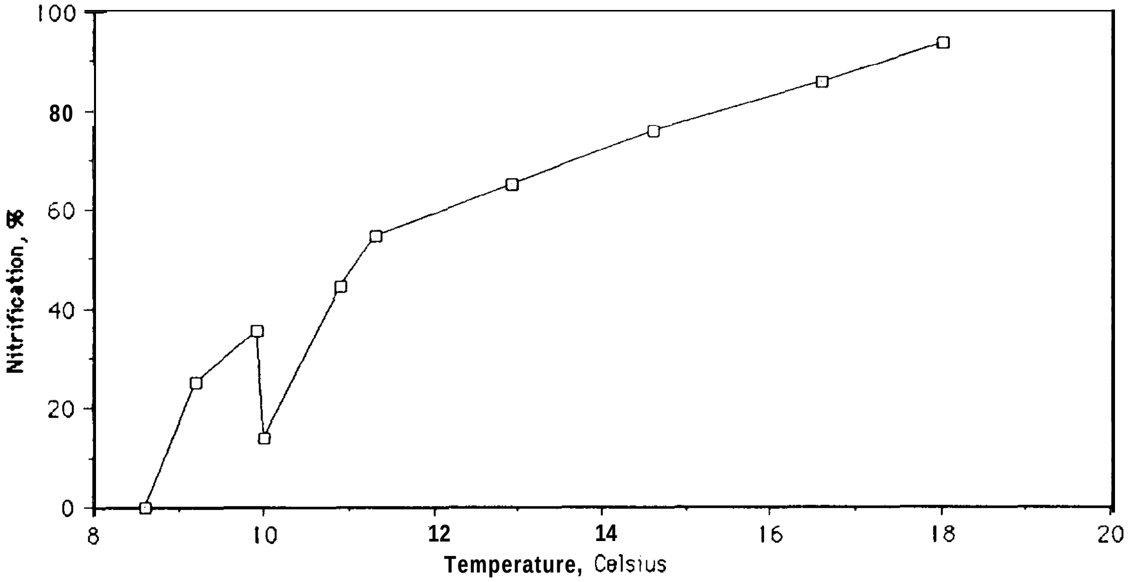


Figure 6
% nitrogen avaible that has been
ni trified versus flow

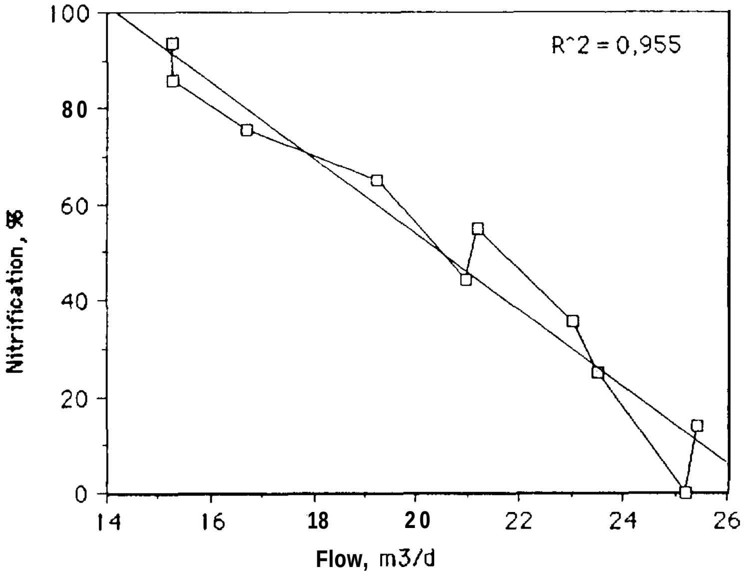


Figure 7
% avaible nitrogen that has been nitrified versus total soluble phosphor

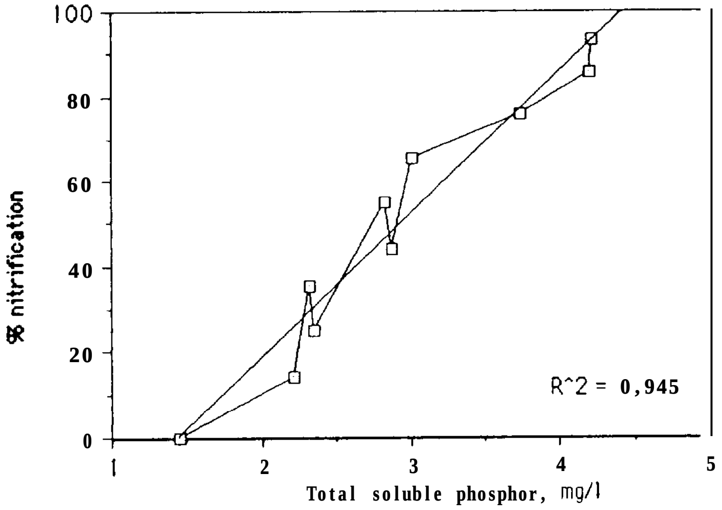


Figure 8
% nitrogen avaible that has been nitrified versus total soluble nitrogen

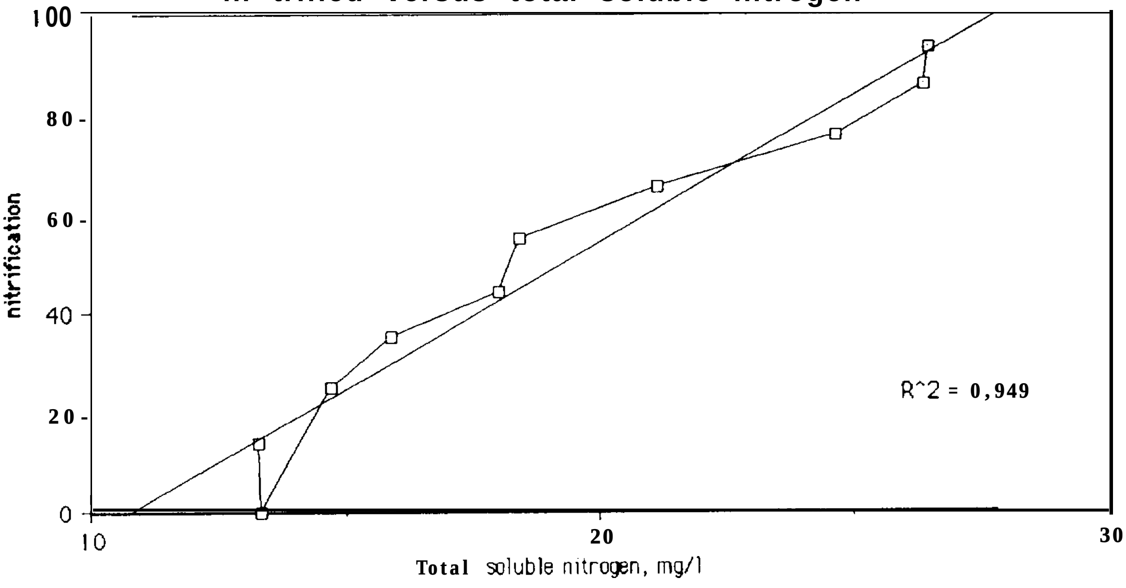


Figure 9
% nitrification and total soluble phosphor to aeration, Mars, 1988.

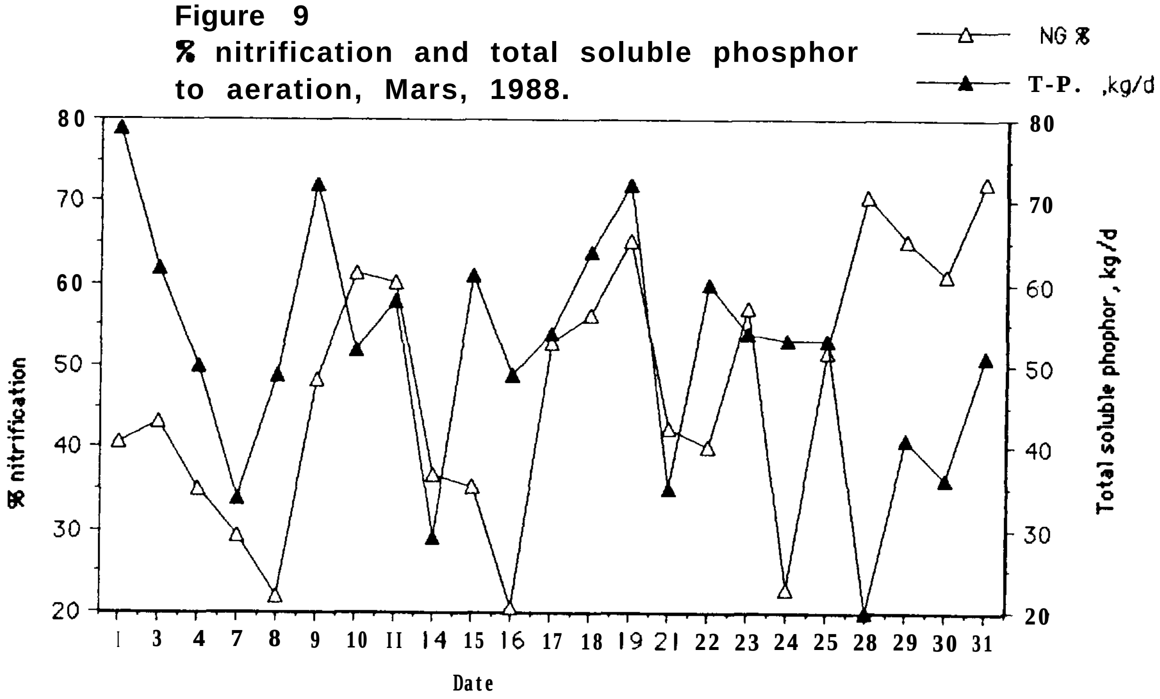


Figure 10
% nitrification and flow i August, 1988.

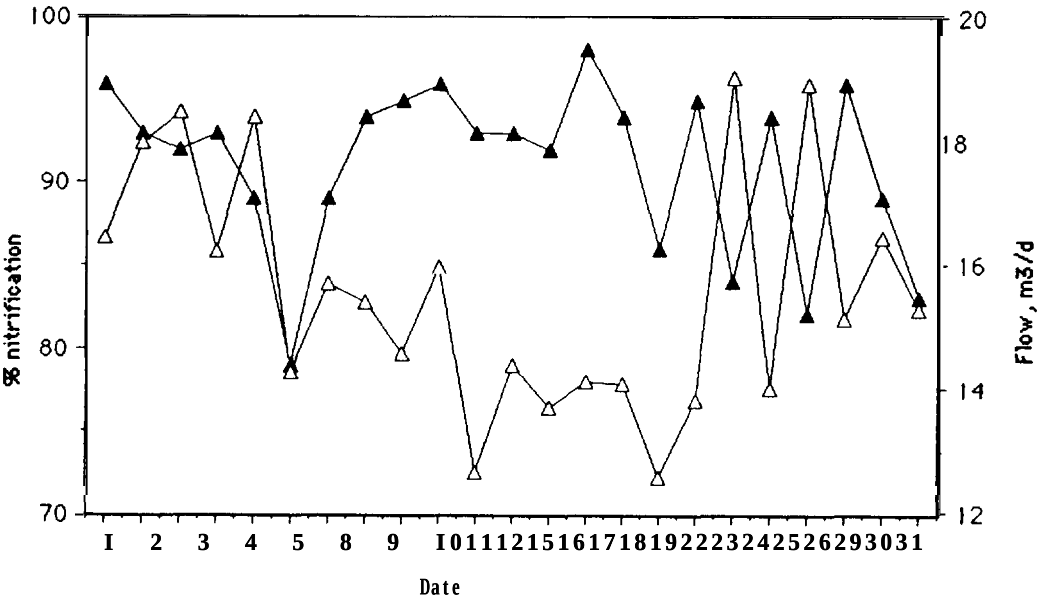
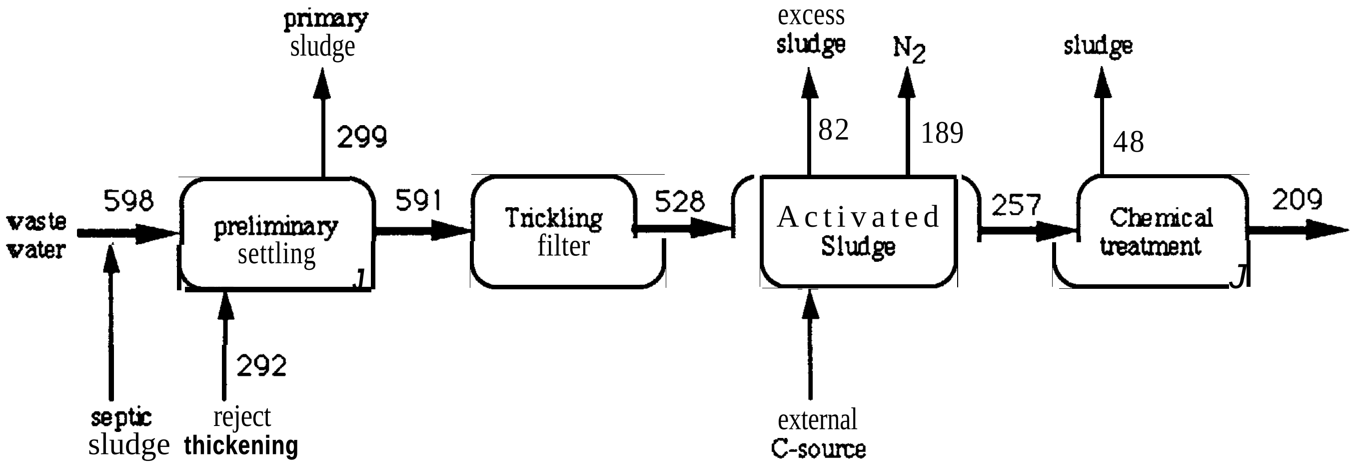


Figure 1 1

FALKENBERG 1988

Balance of Nitrogen; kg N/d



%-reduction : 1.2 10.5 45.3 8.0

CARBON SOURCES FOR DENITRIFICATION OF WASTEWATER

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1 INTRODUCTION

Biological denitrification is based on bacterial respiration with nitrate. A carbon source is needed in all cases, and in most cases organic carbon is needed as an energy source for the bacteria. The exceptions are bacteria that can use hydrogen and sulphur as energy source. These types of bacteria are not of general interest to wastewater treatment, but are of more interest for drinking water treatment and processes in groundwater.

Biological denitrification of wastewater has been used in practise for 20 years. The first generation of plants was based on use of external carbon sources (primarily methanol1 while the second generation of processes has been using internal carbon sources (primarily organic matter in raw wastewater).

Recently, the interest in carbon sources has developed towards the utilization of carbon sources produced at the treatment plant, either by-products from other processes (supernatant from digesters and dewatering equipment) or main products produced from wastewater or sludge (e.g. by hydrolysis).

2 COD TO NITROGEN RATIO

The organic matter (COD) present in a denitrification process will in practise be used for 3 purposes:

I. Conversion of nitrate to nitrogen gas
I I. Production of sludge
III. Respiration with oxygen.

If the magnitude of all 3 processes are known, then the COD/N-ratio can be calculated for a given process.

If COD is used for characterization of the organic matter then an exact calculation of the COD/N-ratio can be made. The use of BOD, TOC etc. will make the calculations less general and more uncertain.

In Table 2.1 the calculations of COD/N-ratios for the 3 uses of organic matter are shown. When based on COD, these are exact stoichiometric calculations, which are true for all wastewater treatment plants.
From table 2.1 the total COD consumption is calculated to
Total COD = $2.86 \cdot \triangle NO_3 + F_{SP} + F_{02}$ (1).
The problem in practise is that $\triangle NO_3$, F_{SP} and F_{02} are not known, or only known roughly.

Table 2.1 COD uses in denitrification tanks in wastewater treatment.

I. Nitrate to nitrogen gas.

NO, + 1.25 “COD” $\rightarrow \frac{1}{2}N_2$ + CO,

Based on weight this gives a ratio

COD/N = 1.25 mole COD·(32 g O_2/mole COD)/(1 mole NO_3N) (14 g NO,-N/mole NO_3-N) = 2.86 g COD/g NO,-N

Total COD used = $2.86 \cdot \Delta NO_3$
(ΔNO_3 = mass of nitrate-nitrogen converted to nitrogen gas in the plant)

---

11. Production of sludge in denitrification.
Total sludge production = F_{SP}
If the sludge production is expressed as kg COD/d then this directly gives the amount of COD used for this.
The sludge production can be estimated from $F_{SP} = Y \cdot Q \cdot \Delta C$
where Y= yield kg COD (sludge)/kg COD (organic matter)
Q = flow m^3/d
AC = organic matter removal, kg COD/m^3.

III. Respiration with oxygen.
If the oxygen used is F_{02} kg/d, then the COD used is F_{02} also.

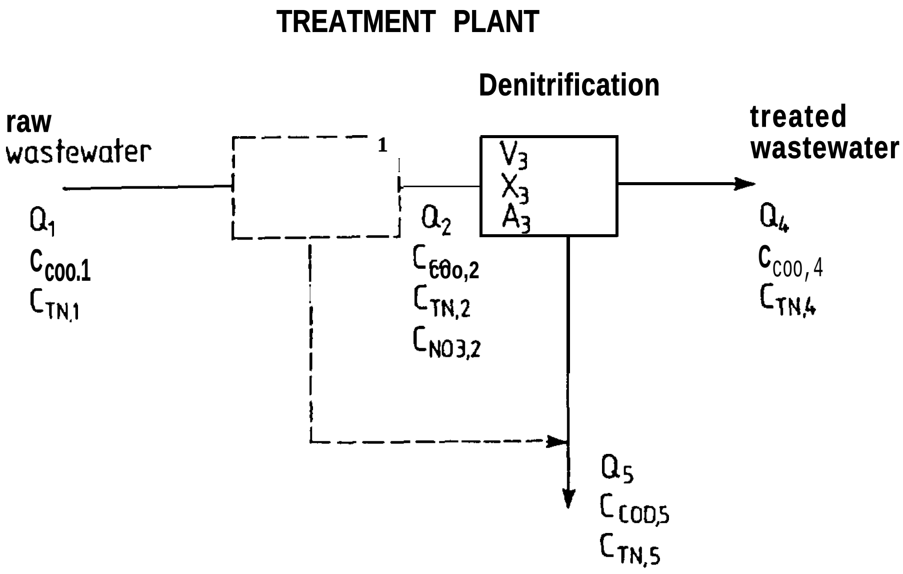


Figure 2.1 Denitrifying treatment plant, symbol definitions.

The total amount of nitrate converted is ΔNO_3 and the total amount of nitrogen converted is

$$\text{Total nitrogen} = \Delta NO_3 + N \text{ in sludge}$$
$$= \Delta NO_3 + F_{SP} \cdot f_N \qquad (2)$$

where f_N is nitrogen fraction in sludge, kg N/kg COD

2.1 C/N-ratio theoretically

The theoretical C/N-ratio can be found from equation(1) and (2):

$$(C/N)\text{theory} = 2.86 \cdot \Delta NO_3 + F_{SP} + F_{02}/(\Delta NO_3 + F_{SP} \cdot f_N) \qquad (3)$$

Equation (3) expresses the amount of COD used per amount of nitrogen removed from the wastewater, in the actual treatment process.

2.2 C/N-ratio in practise

Of the total COD consumption in equation (1), the part oxidized by oxygen, F_{02}, is the only one influenced by the design and operation of the treatment plant. The two other factors are determined almost solely by the effluent criteria.

The COD wasted through oxidation by oxygen varies considerably from plant to plant. Thus an effectiveness factor for COD utilization, $f_{C/N}$, can be defined as

$$f_{C/N} = (2.86 \cdot \Delta NO_3 + F_{SP})/2.86 . \Delta NO_3 + F_{SP} + F_{o2}) \qquad (4)$$

In table 2.2 the optimum C/N-ratios are listed for various carbon sources, for an effectiveness factor, $f_{C/N} = 1$. Note that the optimum C/N -ratio is the smallest obtainable. For all practical purposes the C/N-ratio needs to be higher than the optimum value,

because $f_{C/N} < 1$. In table 2.3 the effectiveness factor for various denitrification processes is shown, and some of the plant/-process types are shown in figure 2.2.

The C/N-ratio in practise can be calculated from equation (5).

$$(C/N)\ practise = (C/N)optimum/f_{C/N} \qquad (5)$$

As an example the (C/N) practise for a recirculation process using wastewater organic matter as carbon source and having an effectiveness factor, $f_{C/N} = 0.4$ is

(C/N)practise = 3.2/0.4 = 8 kg COD/kg N
(C/N)optimum = 3.2 kg COD/kg N is taken from table 2.2.

If the above mentioned example has a 80 percent nitrogen removal, the needed C/N-ratio based on influent values is $0.8 \cdot 8 = 6.4$ kg COD/kg N.

If The C/N-ratio in a given wastewater is low and internal carbon sources are intended to be used for denitrification, then a process with a high effectiveness factor should be selected. Good process control can increase the effectiveness factor for a given process.

Table 2.2 C/N-ratio for denitrification, without carbon source oxidation by oxygen. (Yield constant 0.4 kg COD/kg COD).

Carbon source	$(C/N)_{optimum}$, kq COD/kg N	for $f_{C/N}$ = 1.0 kg compound/ kg N
Wastewater organic matter	4.8	
Methanol	3.8	2.5
Acetic acid	3.4	3.2
Hydrolysed starch	3.4	3.2

2.3 Oxygen and C/N ratio

The oxygen influence, on the C/N-ratio, F_{02} in equation (3), derives from 3 sources:

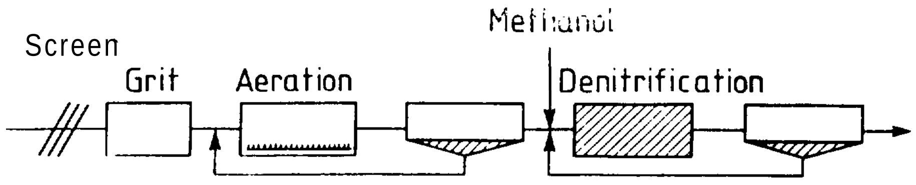
a. Oxygen input caused by mixing in the denitrification tank.
b. Oxygen input with wastewater.
c. Oxidation of organic matter in non-denitrifying tanks.

In order to save carbon source, the oxygen influence should be kept as low as possible.

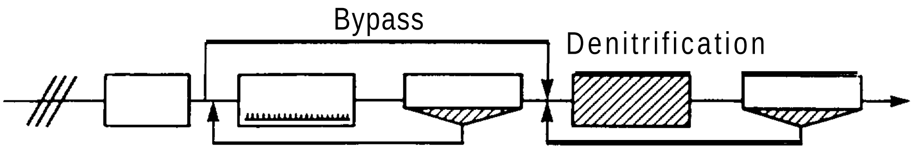
Item a. cannot be avoided, but can be reduced by proper design of the mixing. Item b. can be reduced by proper design and operation. Item 3. is inherent in the overall process design, and operation can increase the effectiveness factor, and thus decrease the overall consumption of organic matter, the C/N-ratio.

Table 2.3 Effectiveness factor, $f_{C/N}$, for various denitrification plant types.

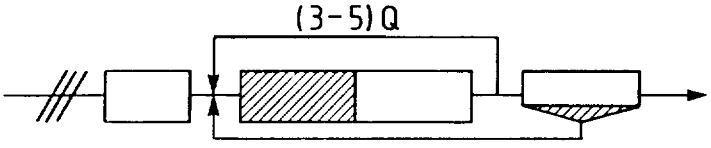
Plant/process type	Effectiveness factor $f_{C/N}$
Activated sludge	
Separate	0.9-1.0
Post denitrification	0.2-0.5
Post denitrification with external C-source	0.8-0.9
Alternating	0.4-0.6
Recirculation	0.4-0.6
Alternating, one-tank	0.3-0.6
Simultaneous	0.3-0.5
Filters	
Rotating disks	0.4-0.7
Packed stationary	0.4-0.7
Backwash type	0.5-0.8
Fluidized	0.4-0.7



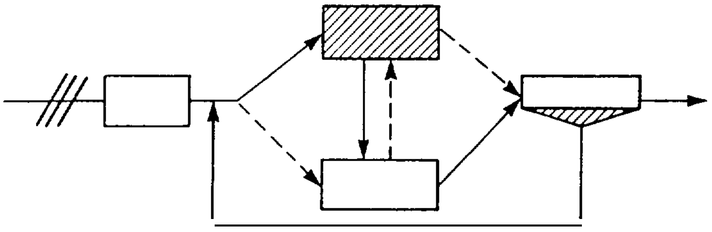
TWO- SLUDGE SYSTEM WITH METHANOL



TWO- SLUDGE SYSTEM WITH BYPASS



SINGLE- SLUDGE SYSTEM WITH RECYCLE



SINGLE- SLUDGE SYSTEM WITH ALTERNATION

Figure 2.2 Various plant/process types for denitrification. /Harremoes et al. 1985/

3 DENITRIFICATION RATES

The volumetric denitrification rates, g NO_3-N/(m^3·h), that can be obtained depends upon many factors:

- concentration of sludge (biomass)
- denitrifying capacity of sludge
- carbon source available
- environmental factors (pH, temperature, oxygen etc.)

3.1 Concentration of biomass

For a given carbon source and for given environmental conditions, the only way to increase the volumetric denitrification rate is to increase the sludge concentration. In many cases this is a more theoretical than practical possibility.

Often, process lay-out puts restrictions on biomass concentrations (e.g. settler design). Another problem can be mass transfer limitations which means that a doubling of the biomass does not lead to a doubling of the volumetric denitrification rate. In figure 3.1 two examples on this is given. The figure shows that for activated sludge an biomass increase of 10 times does not increase denitrification rate with a factor 10 but with a factor 2.5. A similar tendency holds for biofilms.

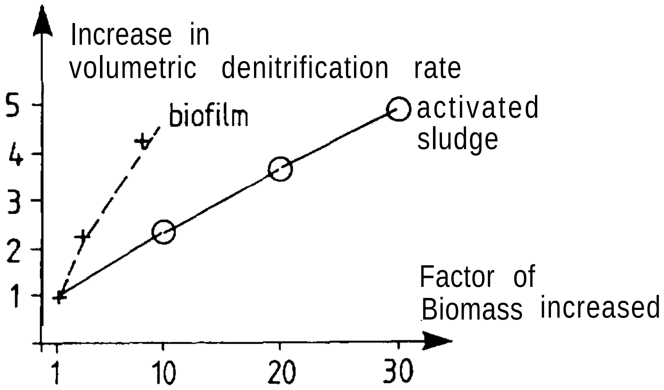


Figure 3.1 Increase in volumetric denitrification rate with increase in biofilm thickness (data from Harremoes et al, 1981) and activated sludge concentration (data from Jørgensen, 1988).

3.2 Quality of biomass

The biomass present in a given denitrification tank might be more or less suited for denitrification.

The sludge in a biological treatment process has its origin from two sources

a. Inocculation with biomass in influent
b. In-situ production in the tank.

Both sources play an important role for the final composition of the biomass.

Figure 3.2 shows that the denitrification rate obtained with in-situ produced biomass (centrifuged wastewater) is smaller than the one obtained when the biomass is dominated by that present in the influent (raw and raw + extra ss). In this case the biomass present in the raw wastewater gives a high denitrification rate. This might not be a general situation, but it illustrates a factor that can play an important role for a denitrification process.

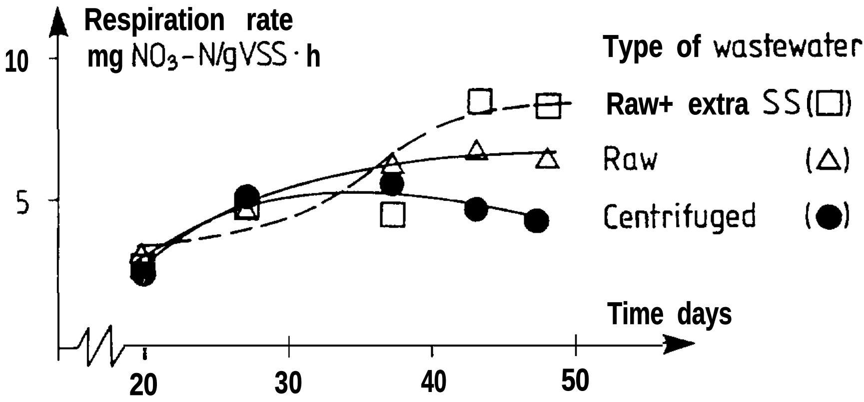


Figure 3.2 Denitrification rated and type of wastewater. /Henze, 1988/

3.3 Carbon Sources

Biological denitrification is widespread among bacteria in nature. This means that numerous carbon sources can be used in the process. Table 3.1 lists carbon sources used for denitrification of wastewater. There are many more possibilities than those listed in table 3.1.

The important factors with respect to selection of carbonsource are

- denitrification rate obtained
- cost
- sludge production
- handling (dosage, control, storage)
- excess carbon source removal.

The cost is highly variable and will not be dealt with here. The other items will be discussed below.

Table 3.1 Carbon sources for denitrification - a selection.

internal	raw wastewater
	sludge (endogenous)
	digester supernatant
	dewatering supernatant
	sludge concentration overflow
	methane
internal (produced)	hydrolyzed sludge
	hydrolyzed sludge supernatant
	scredded sludge
	hydrolyzed wastewater
external	methanol
	ethanol
	acetic acid
	hydrolyzed starch
	molasses
	whey
	brewery wastewater
	pulp from food industry

3.4 Denitrification rates

Denitrification is a respiration process performed by facultative bacteria. The respiration rate with nitrate, r_{NO3}, and the respiration rate with oxygen, r_{02} are related by equation (5)

$$r_{NO3} = \eta_g \cdot r_{O2} \tag{5}$$

(both rates expressed as electron-equivalents per time unit). The value of $_g$ is typically 0.6-0.8 /Henze et al, 1987/. Converted to mass units of oxygen and nitrate the equation is changed to

$$r_{NO3} = 0.35 \cdot \eta_g \cdot r_{O2} \tag{6}$$

where r_{NO3} is nitrate respiration rate, $gNO_3\text{-}N/(g\ VSS \cdot h)$
r_{O2} is oxygen respiration rate, $g\ O_2/(g\ VSS \cdot h)$
η_g denitrifying fraction of oxygen respiration sludge

Oxygen respiration rates in activated sludge (without nitrification) varies from 4-60 g $O_2/(kg\ VSS \cdot h)$ at 20°C. Conversion to nitrate by equation (6) gives 1.4-21 g NO_3-N/(kg VSS•h). Taking the η_g factor into account gives 1-15 g NO_3-N/(kg VSS•h).

The highest respiration rates are obtained with the most easily degradable carbon sources. This means that it is difficult to get higher denitrification rates than those quoted above. Thus there is no need to look for new external carbon sources, hoping that they will give higher rates. The only advantage of "new" external carbon sources can be the cost, handling, control etc.

Table 3.2 groups the various carbon sources, according to the denitrification rates that can be obtained in practise, and figure 3.3 shows the effect of temperature on the rates for denitrification with methanol, raw wastewater carbon and endogenous carbon sources.

The denitrification rate obtained with wastewater carbon sources depends heavily on the detailed composition of the wastewater in question. If the easily degradable fraction is high, the overall rate will be high. The composition of the wastewater depends not only on what is entering the sewer system, but also on what happens in the sewer system. Aerated sewers (gravity flow) will reduce the amount of easily degradable material, while anaerobic (septic) sewers will increase the amount of easily degradable organics due to acidification/hydrolysis. This phenomena is actively utilized in hydrolysis processes at the treatment plant, see section 4.

Table 3.2 Carbon sources and maximum denitrification rates in full scale plants

Carbon source	Denitrification rates obtainable, 20°C. g NO_3-N/(kg VSS·h)
Methanol	7-20
Acetic acid	
Hydrolyzed sludge	
Brewery wastewater	
Digester supernatant	
Hydrolyzed starch	
Easily degradable part of raw wastewater	
Ethanol	1-5
Whey	
Raw wastewater	
Molasses	
Endogenous	0.2-0.5
Methane	

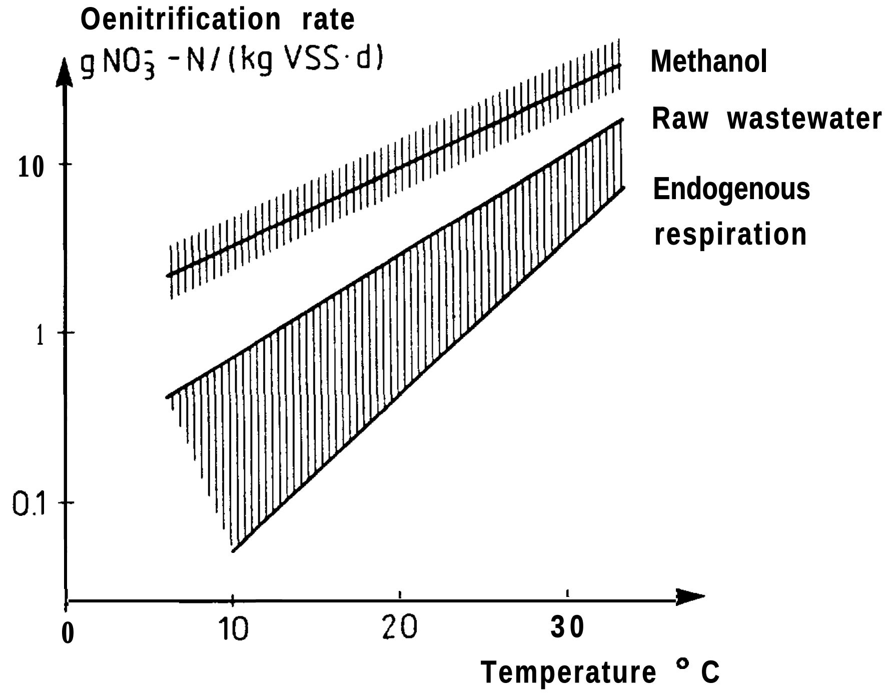


Figure 3.3 Temperature effect of denitrification rates based on /CHRISTENSEN and HARREMOES, 1978/

3.5 Simultaneous denitrification

Denitrification can occur, also when oxygen is present in a tank. This means that in every nitrification tank some denitrification will occur simultaneously. The magnitude of this can vary, but oxygen concentration influences the denitrification rate considerably. Figure 3.4 illustrates the basic phenomena.

The denitrification rates will be small compared to the rates obtained in "real" denitrification tanks, but on a total basis the simultaneous denitrification can add significantly (10-20 percent) to the overall nitrogen removal. Figure 3.5 illustrates the effect of oxygen on simultaneous denitrification rates.

Denitrification will also occur in one tank nitrification-denitrification processes - see figure 3.6. In such processes oxygen concentration will be low either due to anoxic zones in the tank (spatial variation) or due to an on-off operation of the oxygen supply (temporal variation).

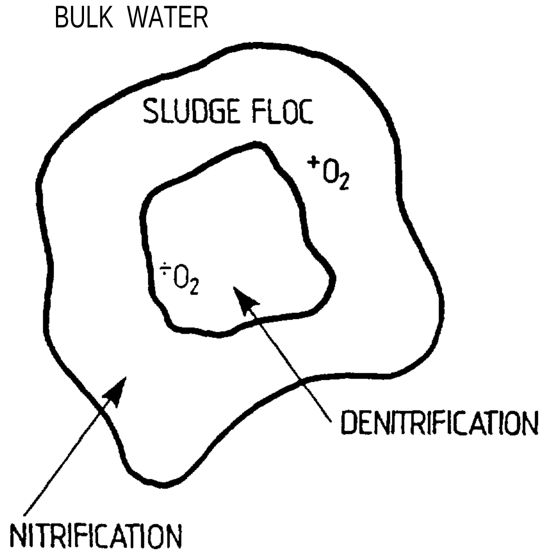


Figure 3.4 Simultaneous nitrification-denitrification in an activated sludge floc. A similar phenomena will happen in biological filters.

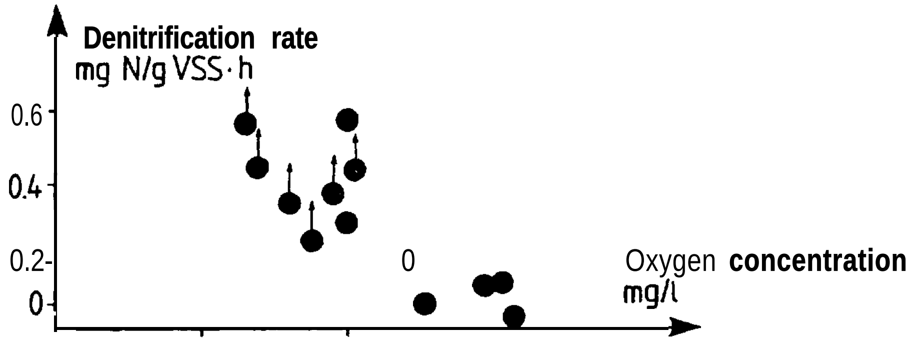


Figure 3.5 Simultaneous denitrification /KRISTENSEN and JANSEN, 1986/.

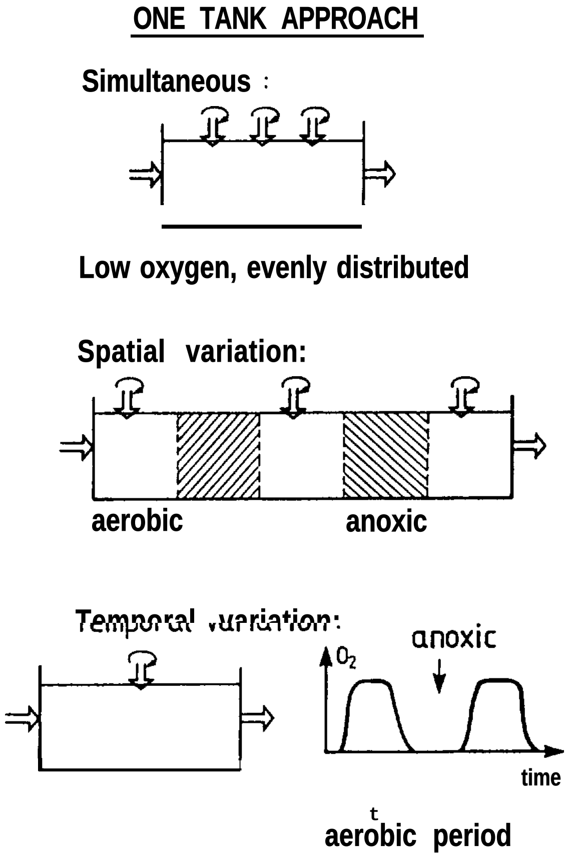


Figure 3.6 One tank nitrification-denitrification processes.

4 PRODUCTION OF CARBON SOURCES FOR DENITRIFICATION AT THE TREATMENT PLANT

Various methods for production of easily degradable carbon at the treatment plant are heavily investigated all over the world.

Most processes are based on hydrolysis, either in a separate tank, as shown on figure 4.1 or in the primary settler.

There are various methods of hydrolysis

- Biological
- Chemical (acid or alkaline)
- Enzymatical
- Heat/pressure

Some of the methods can be coupled in order to obtain a higher yield.

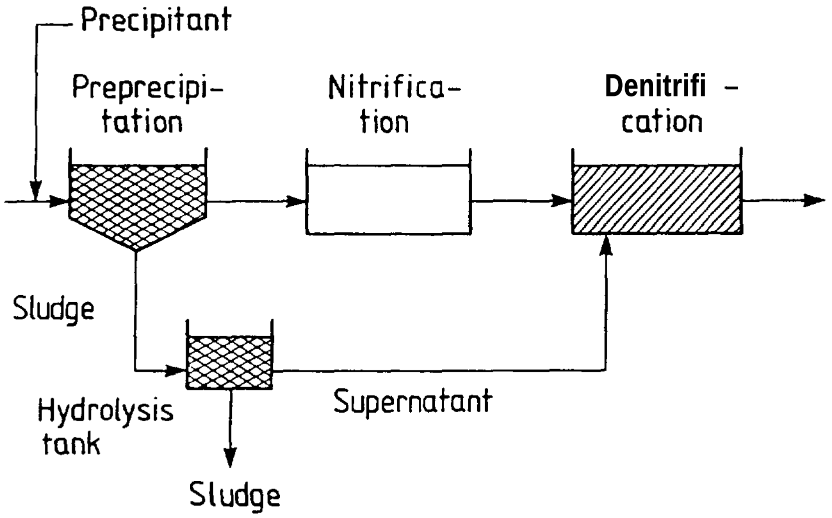


Figure 4.1 Hydrolysis of sludge in a separate tank.

A Scandinavian Eureka project named HYPRO, studies the various aspects of hydrolysis in wastewater treatment. The aim of the project is to improve and study

- the characterization of wastewater
- preprecipitation with the dual option of removing phosphorus and producing a sludge well suited for a hydrolysis process
- knowledge of the hydrolysis processes and the effect of hydrolysis products on biological denitrification.

The Scandinavian partners in the HYPRO project are:

- Technical University of Norway, Trondheim
- Kemira Water Treatment, Sweden
- Water Quality Institute, Denmark
- I. Kruger, Denmark
- Technical University of Denmark, Copenhagen.

The project has been running since 1988 and will be finished in 1990.

For sludge hydrolysis, the fraction of the organic matter that can be hydrolysed is 5-30 percent, depending upon the method and the sludge.

The soluble product of the hydrolysis process is what can be characterized as easily degradable material. This means that the denitrification rates that can be obtained are high, and comparable to those obtained by the use of methanol or acetic acid, cfr. table 3.2. The biological hydrolysis process produces primarily low molecular fatty acids (acetic acid and propionic acid) which the chemical hydrolysis process does not produce.

Of the various chemical fractions in the sludge, the fat/grease/oil fraction seems to be rather unaffected by all hydrolysis process. The proteins are solubilized by heat/pressure and by chemical hydrolysis, while the biological hydrolysis seems to act more on the carbonhydrates and partially on the proteins.

The composition of the soluble phase after hydrolysis has considerable interest in the process design for denitrifying treatment plants. The soluble phase might add some ammonia to the treatment plant for nitrification-denitrification, but the hydrolysis process will under most circumstances increase the ratio between easily degradable carbon and the nitrogen that has to be denitrified. This is shown in figure 4.2.

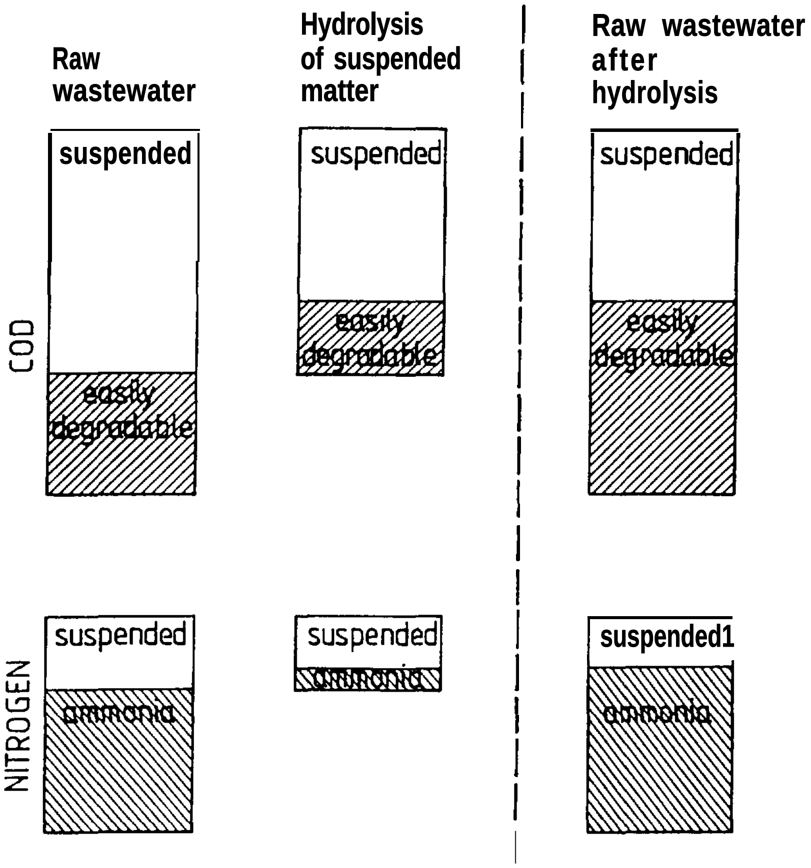


Figure 4.2 Changes in easily degradable carbon (COD) and ammonia by hydrolysis of the suspended fraction of raw wastewater.

5 ADDITION OF CARBON SOURCES TO DENITRIFICATION

When wastewater carbon sources are used for denitrification, control of the dosage is difficult. This is because the carbon source and the nitrogen to be denitrified are present in the same water volume. Minor diurnal variations in the C/N-ratio will occur in domestic and municipal wastewater. This might be exploited through holding tanks, but this has never been tried out in practise and will be very complicated.

The addition of internally produced and external carbon sources can be controlled more easily. Table 5.1 lists various parameters that could be used to control the addition of these types of carbon sources.

The choice between the various control parameters depends upon the actual type of process. For a two-sludge process - see figure 2.2, the nitrate concentration in the influent can be used, while for one-sludge process the total nitrogen or ammonia concentration in the influent can be used, but not the nitrate concentration.

The development of reliable sensors for wastewater treatment plants in these years is believed to improve the process control possibilities in the future.

Table 5.1 Potential parameters to control the addition of internally produced and external carbon sources:

- Nitrate in effluent
- Total nitrogen (or ammonia) in influent
- Nitrate influent
- Specific nitrate respiration rate
- Enzyme activity
- COD in influent
- Time (diurnal variation in dosage)

5.1 Supportive addition of carbon sources

The denitrification processes that use wastewater carbon sources might need extra carbon source support occasionally. This could be due to strong diurnal variations in influent nitrogen, low temperatures, problems which low suspended solids concentration or difficulties to lie up to effluent nitrogen criteria.

Under such circumstances external or internally produced carbon sources can be added. The main problem in this connection is the adaption of the sludge to the new carbon source. If the new carbon source is added frequently, f.ex. each day during some peak hours, then no adaption problems will be observed. If the addition takes place infrequently, f.ex. each winter, or every second month, then an adaption period might be needed. This phenomenon is most pronounced when methanol is added. As methanol is not normally present in the process, then the adaption period might be a week or more /Bentsen and Vendrup 1988/. Thus, methanol cannot be used for immediate action. For acetic acid or acetic acid containing carbon sources (from hydrolysis, digester supernatant etc.) the picture varies more. Some raw wastewaters contain significant amounts of acetic acid and denitrification processes with such types of wastewater will react rather quick to external addition of acetic acid.

6 SLUDGE PRODUCTION AND CARBON SOURCES

The carbon source used for denitrification will effect the overall sludge production in the wastewater treatment plant.

The use of raw wastewater carbon sources will be neutral for a denitrification process as compared to a nitrification process. The use of internally produced carbon sources might reduce the sludge production with up to 10 percent, while the addition of external carbon sources might increase the sludge production with 20-30 percent. Thus the use of external carbon sources might affect the overall process economy significantly. It must be studied whether the smaller tank volumes needed for denitrification will be more than counterbalanced by the cost of the external carbon source and the increased cost of sludge treatment.

7 REMOVAL OF EXCESS CARBON SOURCE

The carbon source added to the denitrification might not be oxidized fully during denitrification in all cases. This extra carbon will add to the overall effluent concentration of organic matter (BOD, COD, TOC). A proper process control can reduce this problem, but in some cases it is still needed to remove excess carbon source.

In activated sludge systems this polishing can be done by a short aeration of the mixed liquid after the denitrification and before the sedimentation tank. This will also reduce problems with denitrification in the final settler (such problems are most effectively reduced by an effective denitrification process that only leaves minor amounts of nitrate in the liquid in the effluent).

For biofilter systems (and for activated sludge systems as well) an aerated polishing filter can be used, for example in combination with a final removal of suspended solids.

8 ALKALINITY AND CARBON SOURCE

For most carbon sources the alkalinity is increased approx. 0.9-1.0 eqv./mole nitrate-nitrogen denitrified. For the acetic acid containing carbon sources the alkalinity increase is 0.7-0.8 eqv./mole nitrate-nitrogen. From this must be extracted the negative alkalinity (acidity) in the external carbon source. For pure acetic acid this corresponds to approx. 0.4-0.5 eqv./mole nitrate-nitrogen. The overall increase in alkalinity is thus 0.3-0.4 eqv./mole nitrate-nitrogen denitrified in this case. For wastewater with low alkalinity, this could create a problem because nitrification removes alkalinity. It could thus be necessary to add lime to the nitrification-denitrification process in order to keep the pH in the wastewater at a reasonable high level.

9 CONCLUSIONS

The carbon to nitrogen ratio for denitrification of wastewater is influenced by the carbon source and especially by the denitrification process type.

Several carbon sources can be used for denitrification. The production of easily degradable source (primarily acetic acid) at the treatment plants is under strong development in these years.

The use of external carbon sources will increase the overall sludge production in the treatment plant.

The denitrification rates that can be obtained varies with varying carbon source and thus play a role for the overall process economy (together with the cost of the carbon source, the overall sludge production, the alkalinity production and the handling of the carbon source).

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MATHEMATICAL MODELLING OF NITROGEN AND PHOSPHORUS REMOVAL.

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ABSTRACT

The purpose of this paper is to describe the development of a mathematical model for activated sludge including biological phosphate removal from the mixed liquid. The paper includes a presentation of this model and the work done to test this against measured data.

The model presented, is developed, as an extension to the model developed by the IAWPPRC group for modelling (M. Henze et al, 1987). This model is tested against measured data from Frederiksund wastewater treatment plant to see if it was possible for the model to simulate biological phosphate removal. Generally the model reflects the measured date very well, even so there still are discrepancies.

Two possibilities are located, which could make a reasonable explanation on these discrepancies. At first the problems are coused by inflexibility in the constants, because that some kinetic constants, in the present model, are reused intensively in different processes. Another possible explanation of the problems with fitting the observed data for nitrate and orthophosphate with the modelled could be the fact that the model is so complex that the data collected are not sufficiently detailed or representative to be used for a fitting procedure.

INTRODUCTION

In the past years there is offered a great deal of effort in both modelling aspects of waste water and in the research of the biological phosphorus removal processes connected to activated sludge treatment plants.

Because of this and because of the increasing interest in Denmark for construction of waste water treatment plants which includes biological phosphorus removal, it is obvius to try to develop a mathematical model which can be used to simulate activeted sludge with biological phosphorus removal.

The mathematical model presented in this paper is based on the concept of the IAWPRC group for modelling of the activated sludge process. (M. Henze et al., 1987). This model is then extended to include processes for biological phosphorus removal.

BIOCHEMICAL MODEL

The bacteria found in wastewater treatment plants able to remove phosphate are characterized by the ability to accumulate substrate and store it as PHB (Poly -Hydroxy Butyrate) (Pogieter, 1983.) or PI-IV (Poly -Hydroxy Valerate) (Comeau et al., 1987.) under anaerobic conditions, in contrary to other groups of bacteria. The energy for this uptake is gained from the degradation of polyphosphate stored in the bacteria. The degraded polyphosphate is released to the bulkphase as orthophosphate. The storage of the phosphate in the bacteria as polyphosphate occur under aerobic conditions, where the energy to this is gained from normal metabolism of external substrate.

The main group of bacteria able to accumulate phosphorus are presumably Acinetobacter sp. (Buchan,1983), but also other bacteria sp. are found to play a role in the biological phosphorus removal process (Brodish and Joyner, 1983). So in the rest of this document, the phosphate accumulating bacteria are for short called Poly- P bacteria.

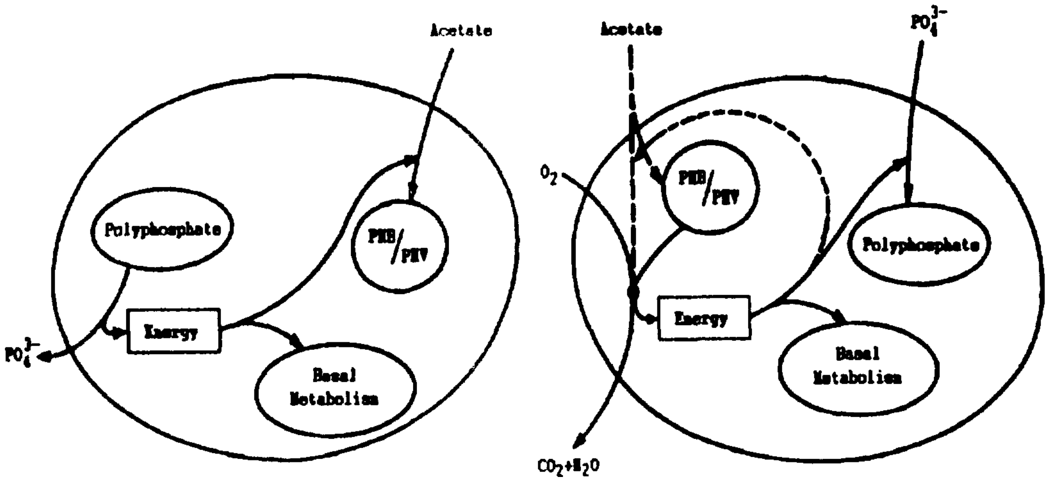


Figure 1 Pathways for phosphorus and substrate exchange under respectivly anaerobic and aerobic conditions.

It is seen from the pervious that an essential prerequisite for the biological phosphorus removal process is the alternating anaerobic/-aerobic conditions. In fig 1 is shown the process paths under respectively anaerobic and aerobic conditions for the biomass.

The biochemical model which makes the basis for the development of the mathematical model, and which is described in the following, is not an attempt to describe all details in the processes involved with biological phosphorus removal. For example it does not take into account that the uptake and release of phosphate and substrate actually is regulated by the internal ATP/ADP and NADH/NAD ratios. It only reflects the effects of this, on the growth rates for the bacteria and on the bulk concentrations' components included in the model. As a consequence of this, the biochemical model is rather an empirical model than an exact model. The biochemical model description is mainly extracted from the work of Wentzel. (Wentzel, 1988).

Anaerobic conditions:

If there is substrate available in the bulk phase and the Poly-P bacteria contains stored polyphosphate, then release of phosphate to the bulk phase, as a result of energy production from degradation of the polyphosphate will occur. The energy produced, are used by the Poly-P bacteria to accumulate substrate into a store of PHB/PHV.

If there is no substrate in the bulk phase then there will be some release of phosphate to the bulk phase, as a result of basic metabolism and eventually decay of the bacteria.

If there is neither stored polyphosphate nor substrate available or if there is substrate available but no stored polyphosphate, then no processes regarding excess polyphosphate uptake will occur, and the Poly-P bacteria behave like other heterotrophic bacteria.

Aerobic conditions:

In case there is an internal PHB/PHV pool but no easily degradable substrate in the bulk phase then the Poly-P bacteria will use the stored PHB/PHV for basal metabolism, growth and excess phosphate uptake. This will normally be the situation in wastewater treatment plants. If there is external substrate available then the Poly-P bacteria will not use the stored PHB/PHV, but instead primarily use the external substrate. Under these conditions one would observe a simultaneous build up of both a PHB/PHV and a polyphosphate storage.

If there are neither substrate nor internal PHB/PHV then the Poly-P bacteria would release phosphate to gain energy for basic metabolism.

Anoxic conditions:

What happens in this zone is still a bit unclear, but it is believed that both phosphate release can occur, as in the anaerobic zone, and phosphate uptake as in the aerobic zones. It is believed that a part of the Poly-P bacteria can make denitrification. The Poly-P bacteria which are not able to denitrify will act as under anaerobic conditions, and therefore, release phosphate, and take up external substrate if this is available in the bulk phase. The bacteria able to reduce nitrate would act as under aerobic conditions though the process would be slower, because of the lower energy yield from nitrate reduction. If the bulk phase is going to be nitrate depleted then all bacteria will act as under anaerobic conditions. This description shows that in some cases one would observe an overall phosphate uptake in the anoxic zones, and in some cases one would observe an overall phosphate release in this zone. This depends on the nitrate concentration, the substrate concentration and the fraction of Poly-P bacteria which are able to reduce nitrate.

MATHEMATICAL MODEL

By studying the biochemical model described in the previous passage, we have identified the components and processes that we found should be included in the mathematical model for a phosphorus removal system. This model is shown in its totality on figure 2.

The model is an extended version of the model proposed by the IAWPRC task group for modelling of activated sludge. (M.Henze et al. 1987), and as a consequence it follows the notation used by this task group.

The model concept consists of a matrix in which the selected model components are listed as symbols in the upper top row, and described by a short description in the bottom row. The processes considered are listed in the right column of the matrix as kinetic experiments with a short description listed in the leftmost column. These components and processes are then linked together by the central part of the matrix, which contains the stoichiometric constants in the processes. The total reaction rate for a component is found by taking the stoichiometric constants in the column under the component and multiply this with the kinetic expressions on the right of the stoichiometric constants and sum up these products. To this one should add the transport terms to get the mass balance equation for the component in the reactors.

Component i →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Process rates (ρ)
Process j ↓	X_{BH}	X_{BP}	X_E	X_{BA}	X_S	X_{SP}	X_I	X_{ND}	X_{PD}	X_{PP}	S_{SS}	S_{SR}	S_{NH}	S_{ND}	S_{NO}	S_{PP}	S_{PO}	S_{PD}	S_{ALK}	S_O	S_I	$M\ L^{-3}\ T^{-1}$
1 Aerobic growth of heterotrophic bacteria.	1											$-\frac{1}{Y_H}$	$-i_{nb}$				$-i_{pb}$		$\frac{-i_{nb}}{14}$	$-\frac{1-Y_H}{Y_H}$		$\mu_H \frac{S_{SR}}{K_{SH}+S_{SR}} \frac{S_O}{K_{OH}+S_O} \frac{S_{NH}}{K_{NH}+S_{NH}} X_{BH}$
2 Anoxic growth of heterotrophic bacteria.	1											$-\frac{1}{Y_H}$	$-i_{nb}$		$\frac{-1+Y_H}{2.86Y_H}$		$-i_{pb}$		$\frac{1-Y_H}{14\cdot 2.86Y_H}-\frac{i_{nb}}{14}$			$\mu_H \frac{S_{SR}}{K_{SH}+S_{SR}} \frac{K_{OH}}{K_{OH}+S_O} \frac{S_{NO}}{K_{NOH}+S_{NO}} \eta_g X_{BH}$
3 Decay of heterotrophic bacteria.	-1		f_e		$1-f_e$			$i_{nb}-f_e i_{ne}$	$i_{pb}-f_e i_{pe}$													$b_H X_{BH}$
4 Aerobic growth of Poly-p bacteria on normal substrate.		1										$-\frac{1}{Y_P}$	$-i_{nb}$				$-i_{pb}$		$\frac{-i_{nb}}{14}$	$-\frac{1-Y_P}{Y_P}$		$\mu_P \frac{S_{SR}}{K_{SP}+S_{SR}} \frac{S_O}{K_{OP}+S_O} \frac{S_{NH}}{K_{NP}+S_{NH}} X_{BP}$
5 Anoxic growth of Poly-p bacteria on normal substrate.		1										$-\frac{1}{Y_P}$	$-i_{nb}$		$\frac{-1+Y_P}{2.86Y_P}$		$-i_{pb}$		$\frac{1-Y_P}{14\cdot 2.86Y_P}-\frac{i_{nb}}{14}$			$\mu_P \frac{S_{SR}}{K_{SP}+S_{SR}} \frac{K_{OP}}{K_{OP}+S_O} \frac{S_{NO}}{K_{NOP}+S_{NO}} \eta_g X_{BP}$
6 Aerobic growth of Poly-p bacteria on PHB substrate.		1				$-\frac{1}{Y_P}$							$-i_{nb}$				$-i_{pb}$		$\frac{-i_{nb}}{14}$	$-\frac{1-Y_P}{Y_P}$		$\mu_P \frac{X_{SP}/X_{BP}}{K_{SBP}+X_{SP}/X_{BP}} \frac{S_O}{K_{OP}+S_O} \frac{S_{NH}}{K_{NP}+S_{NH}} X_{BP}$
7 Anoxic growth of Poly-p bacteria on PHB substrate.		1				$-\frac{1}{Y_P}$							$-i_{nb}$		$\frac{-1+Y_P}{2.86Y_P}$		$-i_{pb}$		$\frac{1-Y_P}{14\cdot 2.86Y_P}-\frac{i_{nb}}{14}$			$\mu_P \frac{X_{SP}/X_{BP}}{K_{SBP}+X_{SP}/X_{BP}} \frac{K_{OP}}{K_{OP}+S_O} \frac{S_{NO}}{K_{NOP}+S_{NO}} \eta_g X_{BP}$
8 Decay of Poly-p bacteria.		-1	f_e		$1-f_e$			$i_{nb}-f_e i_{ne}$	$i_{pb}-f_e i_{pe}$													$b_P X_{BP}$
9 Aerobic growth of autotrophic bacteria.				1									$-i_{nb}$ $-1/Y_A$		$\frac{1}{Y_A}$		$-i_{pb}$		$\frac{-i_{nb}}{14}+\frac{-1}{7Y_A}$	$-\frac{4.5-Y_A}{Y_A}$		$\mu_A \frac{S_{NH}}{K_{NA}+S_{NH}} \frac{S_O}{K_{OA}+S_O} X_{BA}$
10 Decay of autotrophic bacteria.			f_e	-1	$1-f_e$			$i_{nb}-f_e i_{ne}$	$i_{pb}-f_e i_{pe}$													$b_A X_{BA}$
11 Storage of substrate by Poly-p bacteria at anaerobic conditions.						f_p				-1		$-f_p$					1					$K_{P1} \frac{K_{OP}}{K_{OP}+S_O} \frac{K_{NOP}}{K_{NOP}+S_{NO}} \frac{S_{SR}}{K_{SP}+S_{SR}} \frac{K_{SRP}}{K_{SRP}+X_{SP}/X_{BP}} \frac{X_{PP}/X_{BP}}{K_{PP}+X_{PP}/X_{BP}} X_{BP}$
12 Storage of substrate by Poly-p bact. at aerobic or anoxic conditions.						f_p						$-f_p$										$K_{P2}\ O_2P \frac{S_{SR}}{K_{SP}+S_{SR}} \frac{K_{SRP}}{K_{SRP}+X_{SP}/X_{BP}} X_{BP}$ *)
13 Storage of phosphate by Poly-p bact. at aerobic or anoxic conditions.										1							-1					$K_{P3}\ O_2P \left[\frac{S_{SR}}{K_{SP}+S_{SR}}+\frac{X_{SP}/X_{BP}}{K_{SRP}+X_{SP}/X_{BP}}\eta_p\right] \frac{S_{PO}}{K_{POP}+S_{PO}} \frac{K_{PP}}{K_{PP}+X_{PP}/X_{BP}} X_{BP}$ *)
14 Release of phosphate by decay of Poly-p bacteria.									1	-1												$\frac{X_{PP}}{X_{BP}} b_P X_{BP}$
15 Hydrolysis of particulate substrate.					-1						1											$K_{HX}\left[\frac{X_S/X_{BH}}{K_X+X_S/X_{BH}}(1+O_2H)\ X_{BH}+\frac{X_S/X_{BP}}{K_X+X_S/X_{BP}}(1+O_2P)\ X_{BP}\right]$ *)
16 Hydrolysis of slowly biodegradable soluble substrate.											-1	1										$K_{HS} \frac{S_{SS}}{K_{SS}+S_{SS}} (X_{BH}+X_{BP})$
17 Hydrolysis of organic particulate nitrogen.								-1						1								$\frac{X_{ND}}{X_S} \rho(15)$
18 Ammonification													1	-1					$\frac{1}{14}$			$K_{HND} \frac{S_{ND}}{S_{SS}} \rho(16)$
19 Hydrolysis of organic particulate phosphor.									-1									1				$\frac{X_{PD}}{X_S} \rho(15)$
20 Hydrolysis of organic soluble phosphor.																	1	-1				$K_{HPD} \frac{S_{PD}}{S_{SS}} \rho(16)$
21 Hydrolysis of Poly-phosphate in wastewater.																-1	1					$K_{HP}\ S_{PP}$
	Heterotrofic bacteria.	Poly-p bacteria.	Endogenic Substrate.	Autotrofic bacteria.	Particulate substrate.	PHB stored in Poly-p bacteria.	Particulate inert substrate.	Particulate biodegradable organic nitrogen.	Particulate biodegradable organic phosphate.	Polyphosphate stored in Poly-p bacteria.	Slowly biodegradable organic substrate.	Easy biodegradable organic substrate.	Ammonia.	Soluble biodegradable organic nitrogen.	Nitrate.	Poly phosphate in wastewater.	Orthophosphate.	Soluble biodegradable organic phosphor.	Alkalinity.	Oxygen.	Soluble inert substrate.	

$$*)\ O_2H = \left[\frac{S_O}{K_{OH}+S_O} + \eta_h\left(\frac{K_{OH}}{K_{OH}+S_O}\cdot\frac{S_{NO}}{K_{NOH}+S_{NO}}\right)\right]$$

$$O_2P = \left[\frac{S_O}{K_{OP}+S_O} + \eta_h\left(\frac{K_{OP}}{K_{OP}+S_O}\cdot\frac{S_{NO}}{K_{NOP}+S_{NO}}\right)\right]$$

Rene Dupont (08/88 2E)

Figure 2 Mathematical model

The concept of modelling the biological processes in this model, is based on the death/regeneration concept. This means that by bacterial decay most of the mass in form of COD, nitrogen and phosphate is recycled back into particulate substrate. This is then hydrolysed to soluble substrates, which could then be used by the bacteria for growth. In figure 3 this principle is shown for the polyphosphate bacteria.

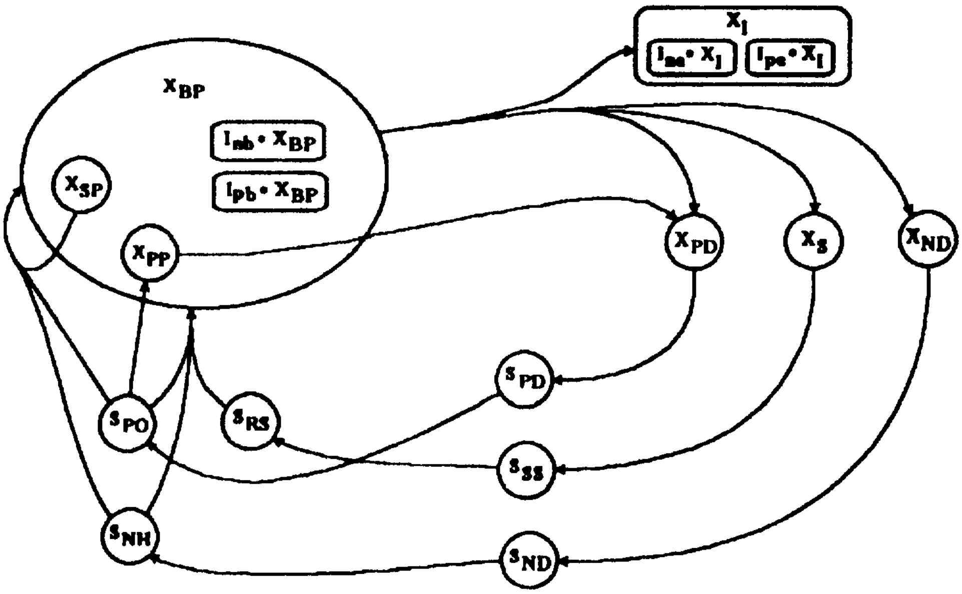


Figure 3 Death / Regeneration princip, shown for Poly-P bacteria. Notation as inmodel, figure 2.

The components and the processes regarding biological phosphorus removal are shortly described in the following, even so that it is not possible to include all details of the model in the description here. Only components and processes that are new or changed compared to the original JAWPRC model (M. Henze et al. 1987.) are included.

New Components

X_{Bp}: Phosphorus accumulating bacteria. (Poly-P bacteria)
These are the bacteria responsible for the accumulation of phosphate from the wastewater. It is assumed that this group of bacteria behaves like other heterotrophic bacteria in all aspects that do not

include phosphorus removal. This is especially of interest in the denitrification processes.

From the biochemical model it is seen that use by the bacteria of the stored PHB/PHV and poly-p are delayed in time and regulated by external conditions, like oxygen and substrate concentrations. Because of this, it was necessary to include two components in the model concerning the internal PHB/PHV and poly-p concentrations in the bacteria, even these two components are very difficult to measure in practice.

X_{SP}: Storage of substrate as PHB/PHV in the phosphorus accumulating bacteria.
X_{PP}: Storage of phosphate as polyphosphate in the bacteria.

The description of the wastewater composition needed to be extended to include the phosphorus components, and because the Poly-P bacteria primarily use the easily biodegradable soluble substrate to build up their PHB/PHV storage, we had to divide the soluble substrate fraction in the original IAWPRC model into two soluble substrate fractions.

S_{PO}: Orthophosphate in the mixed liquid.
X_{PD}: Phosphorus bound to biodegradable particulate substrate.
S_{PD}: Phosphorus bound to biodegradable soluble substrate.
$I_{pb}.X_B$P(Conc. of bacteria: Phosphorus bound in bacteria as normal metabolic uptake.
$I_{pe}.X_1$(Conc. of inert): Phosphorus bound to inert material.

S_{SS}: Slowly biodegradable soluble substrate.
S_{RS}:Readily biodegradable soluble substrate. (Such as acetate)

New Processes

In the following the processes in the model, which directly are included to simulate biological phosphorus removal are shortly described.

In the choice of the constant names for the kinetic constants in the processes, it is tried to reuse the same constants in different processes as much as possible. This gives a model with fewer constants in different processes as mutch as possible. This gives a model with fewer constants to determine. On the other hand it might lead to inflexibility of the model, e.g. it is not possible to fit the constants so that the model reflects the real world properly.

Process 4-7: Growth processes for Poly-P bacteria.

It was necessary to include four growth processes for Poly-P bacteria. Processes 4 and 5 are very similar to the two growth processes for heterotrophic bacteria and consist of Monod terms for substrate, oxygen, and ammonia for the aerobic growth process or nitrate for the anoxic growth rate. The only difference is the name of the kinetic constants. Processes 6 and 7 differ from processes 4 and 5 only by using internal substrate (PHB/PHV) as substrate source.

Process 8: Decay of Poly-P bacteria.

First order process consisting of a rate constant multiplied with the bacteria concentration.

Processes 11, 12 and 13. Uptake and release of phosphate and substrate under different oxygen conditions.

Process 11: Exchange of substrate and phosphorus under anaerobic conditions.

$$K_{P1} \frac{K_{OP}}{K_{OP}+S_O} \frac{K_{NOP}}{K_{NOP}+S_{NO}} \frac{S_{SR}}{K_{SP}+S_{SR}} \frac{K_{SRP}}{K_{SRP}+X_{SP}/X_{BP}} \frac{X_{PP}/X_{BP}}{K_{PP}+X_{PP}/X_{BP}} X_{BP}$$

This process is responsible for simultaneous uptake of substrate and release of phosphorus under anaerobic conditions. The process is as shown composed by a rate constant multiplied with 5 Monod terms and the Poly-P bacteria concentration. The first two Monod terms are swhitch functions for oxygen and nitrate to insure that the process will function under anaerobic conditions only. The third Monod term is the substrate term that ensures that there are enough substrate in the bulk phase available. Otherwise there is nothing to build a PHB/PHV storage of.

The next Monod term is included to regulate the size of the PHB/PHV storage in the bacteria, so it will not increase infinitely. The last Monod term is to insure that there is enough energy in form of poly-p storage to build up the PHB/PHV storage.

Process 12: Uptake of substrate under aerobic or anoxic conditions.

$$K_{P2}\left[\frac{S_O}{K_{OP}+S_O}+\eta_h\frac{K_{OP}}{K_{OP}+S_{OP}}\frac{S_{NO}}{K_{NOP}+S_{NO}}\right]\frac{S_{SR}}{K_{SP}+S_{SR}}\frac{K_{SRP}}{K_{SRP}+X_{SP}/X_{BP}}X_{BP}$$

This process ensures that in case there is enough soluble easily degradable substrate available under aerobic or anoxic conditions, and the bacteria have energy available in form of a poly-p storage, then the bacteria build up a PHB/PHV storage. The process then consists of a rate constant multiplied with a term that ensures that the process only functions under aerobic and anoxic conditions. The fourth Monod term deals with easily biodegradable substrate in the bulk phase. The last Monod term control the size of the internal PHB/PHV storage.

Process 13: Uptake of phosphate under aerobic and anoxic conditions.

$$K_{P3}\left[\frac{S_O}{K_{OP}+S_O}+\eta_h\frac{K_{OP}}{K_{OP}+S_{OP}}\frac{S_{NO}}{K_{NOP}+S_{NO}}\right]\left[\frac{S_{SR}}{K_{SP}+S_{SR}}+\eta_p\frac{X_{SP}/X_{BP}}{K_{SRP}+X_{SP}/X_{BP}}\right]$$
$$\frac{S_{OP}}{K_{POP}+S_{PO}}\frac{K_{PP}}{K_{PP}+X_{PP}/X_{BP}}X_{BP}$$

This process controls the accumulation of phosphate as polyphosphate by the Poly-P bacteria under aerobic conditions. The process is composed by a rate constant multiplied by seven Monod terms and the bacteria concentration. The first three Monod terms are included to ensure that these processes will run only under aerobic and anoxic conditions. The next two Monod terms are included to handle available substrate, either as internal substrate (PHB/PHV) or as external soluble readily biodegradable substrate. The next Monod term slows down the process, if the concentration of phosphate in the bulk phase is low. The last Monod term is included to control the size of the poly-phosphate pool in the bacteria.

Process 14: Release of phosphate from Poly-P bacteria durring decay of the bacteria.

The polyphosphate is released to the bulk phase as orthophosphate. The process is proportional to the decay process with the ratio of polyphosphate concentration over Poly-P bacteria concentration.

Process 19 and 20: Hydrolysis of bacterial phosphate

This takes care of the release of phosphate stored in the bacteria as a result of the normal metabolic process. This phosphate follows the same scheme of death / regeneration as COD and nitrogen. Se figure 3.

CALIBRATION OF THE MODEL

The next step after defining the mathematical model is to calibrate the model. To do this one needs to have good dynamic measurements of the components in the model from wastewater treatment plant. The constants can be calibrated, as a combination of extracting the values, determined from batch experiments and by fitting the model constants to the measured concentrations. In this case we have chosen as a start primarily to fit the constants and pay less attention to constants available from the literature. This is done because it gives the possibility to test whether we altogether can fit the model to give reasonable results compared to the measured values. If not, one needs to review the model and develop new process terms.

The data chosen for calibration is data from Frederiksund wastewater treatment plant. From this treatment plant there is a very comprising set of data, measured over a 24 hour period, by Behrens and Jansen in 1978. (Behrens and Jansen, 1978).

The treatment plant Frederiksund is a well functioning plant of the biodenitro type. It is originally designed only to remove organics and nitrogen, but operational data shows that the plant removes excess phosphate as well. This removal is probably a result of biological phosphorus removal.

The Frederiksund plant consists of gritchamber, 4 reactors of the oxidation ditch type, and one sedimentation tank. (Figure 4).

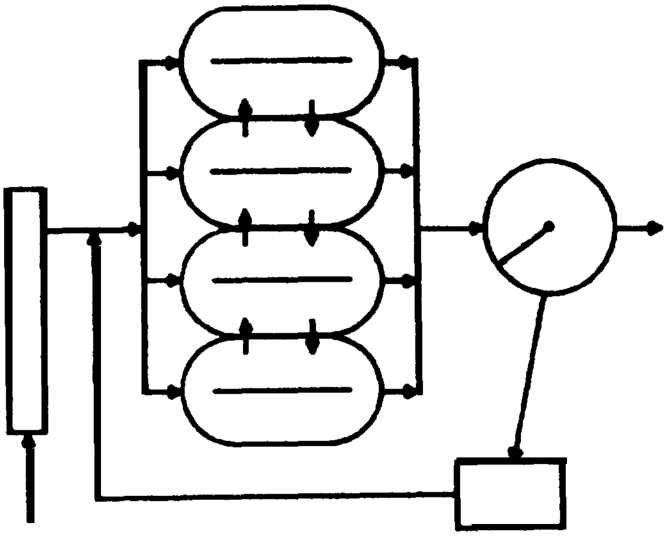


Figure 4 Frederiksund Treatment plant.

The 4 reactors work in two parallel lines, so that the reactors two and two together always work in the same phase. The Frederiksund plant does not have the essential anaerobic reactor needed for biological phosphorus removal. Anyway, it removes phosphate very extensively. The reason for this is probably because the influent water contains a high concentration of easily biodegradable soluble substrate, from a juice factory in the town. This means that there will be enough substrate available, both for the denitrification process and for the biological phosphorus removal process.

In table 1, the configuration and operational parameters are listed.

Table 1 Operational data for frederiksund treatment plant.

Table 1.
Volume : 850 ❑ 3/reactor - 3400 m^3 total.
Mean values for :
Influent flow : 6630 m^3/d.
Recirculation : 4970 m^3/d.
Temperature : 16.3 "C.

Operational **cyclus.**

	Reaktor 1,4	Reaktor 2, 3	Time
Phase 1	**influent** - 02	effluent + 02	1.5 hour.
Phase 2	+ 02	**influent** effluent + 02	0.5 hour.
Phase 3	effluent + 02	**influent** - 02	1.5 hour.
Phase 4	**influent** effluent + 02	+ 02	0.5 hour.

CHARACTERIZATION OF THE WASTEWATER

Characterization of the incoming wastewater is of major importance in connection with modelling. It is by no means possible, with the measuring methods available today, to measure the concentration of all the model components in the model. One must measure what is possible with the methods available, and then make a qualified guess of the concentration of the non measurable components. In table 2 it is listed how we have estimated the concentrations of the non measurable components.

Table 2

Measured data: COD_{total}
BOD_{total}
$BOD_{filtred}$

TABLE 2

Data for BOD converts to COD by division with 0.7 ($\approx BOD_{\infty}$).

$COD_{biodegradable,total} = BOD_{total} / 0.7$
$COD_{biodegradable,soluble} = BOD_{filtred} / 0.7$
$COD_{biodegradable,partikulate} = COD_{biodegradable,total} - COD_{biodegradable,soluble}$
$COD_{inert,total} = COD_{total} - COD_{biodegradable,total}$

The fraction of soluble COD of the total COD are determined by :

$$f(S/T) = \frac{COD_{biodegradable,soluble}}{COD_{bidegradable,total}}$$

$S_I = COD_{inert,soluble} = f(S/T) * COD_{inert,total}$
$X_I = COD_{inert,partikulate} = (1 - f(S/T)) * COD_{inert,total}$

$S_{SS} = S_{SR} = COD_{biodegradable,soluble} / 2$

The following are ● intimated
$X_{BH} = 0.04 \bullet COD_{biodegradable,partikulate}$
$X_{BP} = 0.04 \bullet COD_{biodegradable,partikulate}$
$X_{BA} = 0.02 \bullet COD_{biodegradable,partikulate}$
$X_S = 0.90 \bullet$ a m$_{biodegradable,partikulate}$

The influent concentrations of nitrogen components are calculated by • massbalance far nitrogen.

$Kjeldhal\text{-}N = X_{ND} + S_{NH} + S_{ND} + I_{nb} *(X_{BH}+X_{BP}+X_{BA}) + I_{ne} *(X_I + S_I + X_E)$

Kjeldhal-N, S_{NH}, S_{NO}, I_{nb}, I, are h a values.

Herby are X_{ND} and S_{ND} calculated of :

$X_{ND} = (1-f(S/T)) \bullet (Kjeldahl\text{-}N - S_{NH} - I_{nb} *(X_{BH}+X_{BP}+X_{BA}) - I_{ne} *(X_I + S_I))$

$S_{ND} = f(S/T) \bullet (Kjeldahl\text{-}N - S_{NH} - I_{nb} *(X_{BH}+X_{BP}+X_{BA}) - I_{ne} *(X_I + S_I + X_E))$

On the same way are the concentrations for phosphorus components detremined by help of a massbalance.

$Total\text{-}P = X_{PO} + X_{PP} + S_{PP} + S_{PO} + S_{PD} + I_{pb} *(X_{BH} + X_{BP} + X_{BA}) + I_{pe} *(X_I + S_I + X_E)$

Total-P, S_{PP}, S_{PO}, I_{bp}, I, • r* known values.

$X_{ND} = (1-f(S/T)) \bullet (Total\text{-}P - X_{PP} - S_{PP} - S_{PO} - I_{pb} *(X_{BH} + X_{BP} + X_{BA}) - I_{pe} *(X_I + S_I + X_E))$

$S_{ND} = f(S/T) * (Total\text{-}P - X_{PP} - S_{PP} - S_{PO} - I_{pb} *(X_{BH} + X_{BP} + X_{BA}) - I_{pe} *(X_I + S_I + X_E))$

In figure 5 is shown the diurnal influent variations for COD, ammonia, nitrate and phosphate. It is seen that the COD concentrations as expected is rather high.

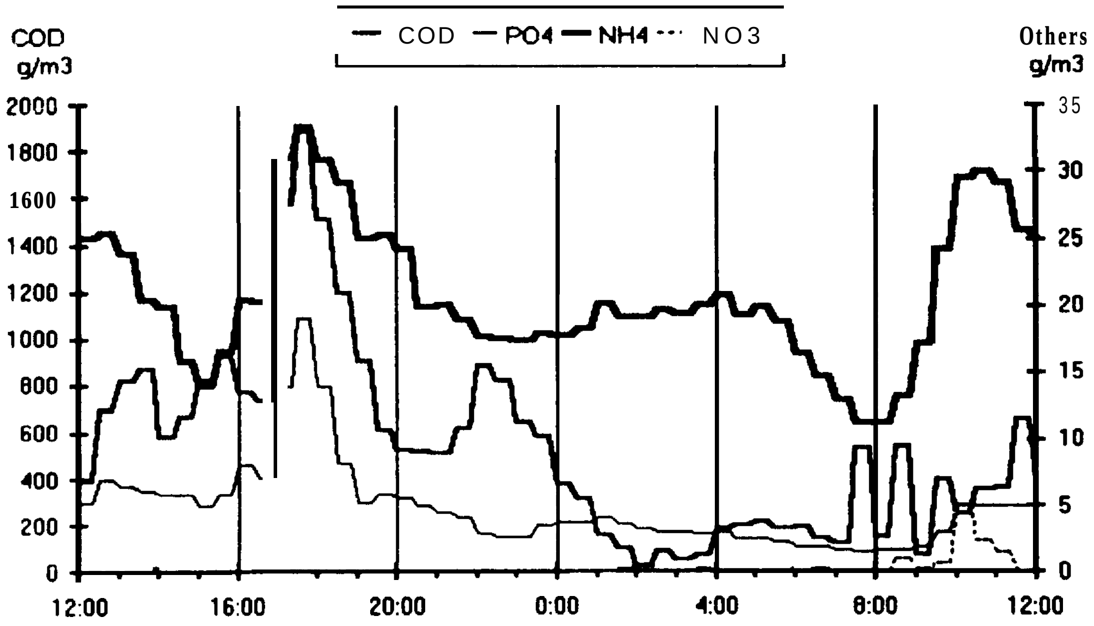
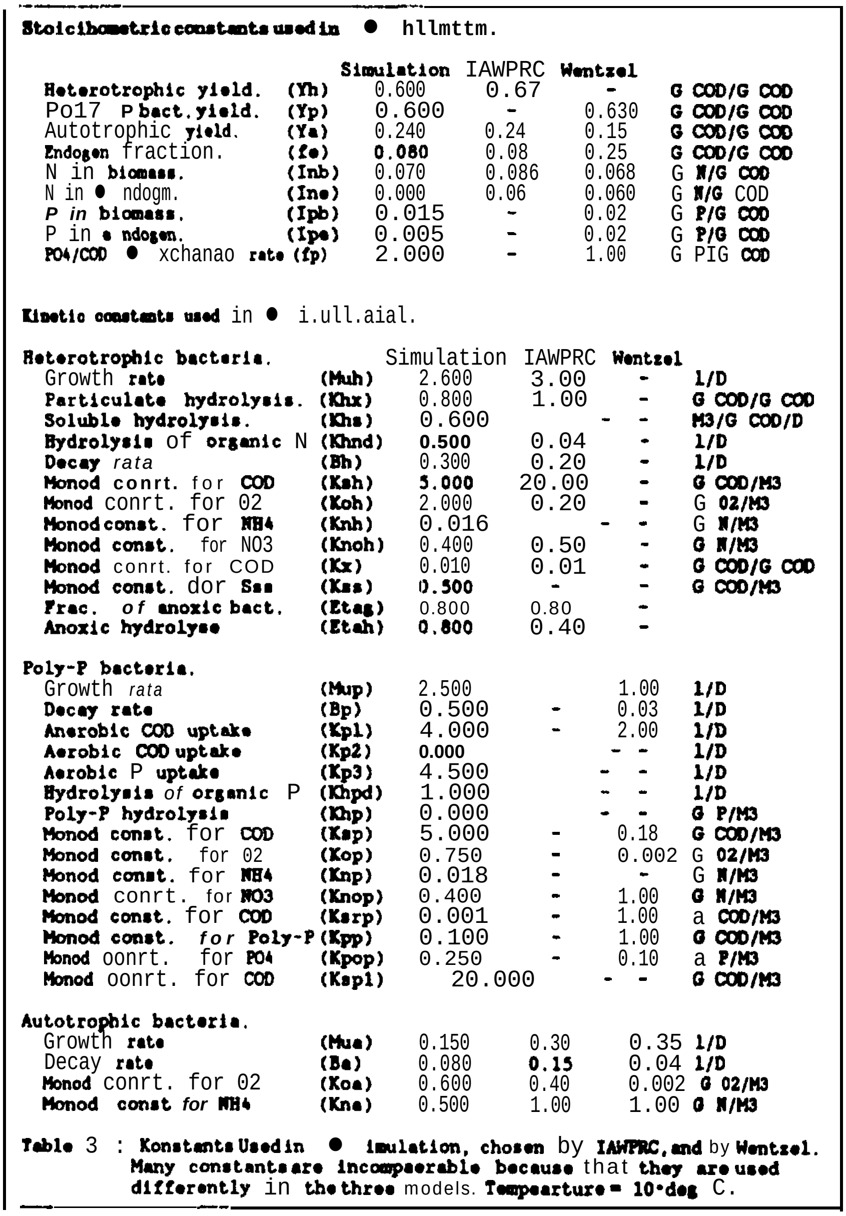


Figure 5 Diurnal influent concentrations at mesureing day.

CONSTANTS UDSED IN THE MODEL

As values for the stoichiometric and kinetic constants used in the model, are generally selected values, which are suggested by the IAWPRC task group for modelling (M Henze et al, 1987) at all places where this was possible. The rest are, as mentioned earlier in the chapter, more or less randomly established. These values are then calibrated by fitting the model in successive runs to the measured values. The values found in this way are listed in table 3 together with the same values found by Wentzel (Wentzel, 1988) and the IAWPRC values.

Table 3 Konstants Used in simulation, chosen by IAWPRC, and by Wentzel. Many constants are incompaearable because that they are used differently in the three models. Temperature = 10·deg C.



Stoicibometric constants used in ● hllmttm.

		Simulation	IAWPRC	**Wentzel**	
Heterotrophic yield.	**(Yh)**	0.600	0.67	-	**G COD/G COD**
Po17 P **bact. yield.**	**(Yp)**	0.600	-	0.630	**G COD/G COD**
Autotrophic **yield.**	**(Ya)**	0.240	0.24	0.15	**G COD/G COD**
Endogen fraction.	**(fe)**	**0.080**	0.08	0.25	**G COD/G COD**
N in **biomass.**	**(Inb)**	0.070	0.086	0.068	G **N/G COD**
N in ● ndogm.	**(Ine)**	0.000	0.06	0.060	G **N/G** COD
P in **biomass.**	**(Ipb)**	0.015	-	0.02	G **P/G COD**
P in • **ndogen.**	**(Ipe)**	0.005	-	0.02	G **P/G COD**
PO4/COD ● xchanao **rate**	**(fp)**	2.000	-	1.00	G PIG **COD**

Kinetic constants used in ● i.ull.aial.

Heterotrophic bacteria.		Simulation	IAWPRC	**Wentzel**	
Growth **rate**	**(Muh)**	2.600	3.00	-	**1/D**
Particulate hydrolysis.	**(Khx)**	0.800	1.00	-	**G COD/G COD**
Soluble hydrolysis.	**(Khs)**	0.600	-	-	**M3/G COD/D**
Hydrolysis of **organic** N	**(Khnd)**	**0.500**	0.04	-	**1/D**
Decay *rata*	**(Bh)**	0.300	0.20	-	**1/D**
Monod conrt. for **COD**	**(Ksh)**	**5.000**	20.00	-	**G COD/M3**
Monod conrt. for 02	**(Koh)**	2.000	0.20	-	G **02/M3**
Monod const. for **NH4**	**(Knh)**	0.016	-	-	G **N/M3**
Monod const. for NO3	**(Knoh)**	0.400	0.50	-	**G N/M3**
Monod conrt. for COD	**(Kx)**	0.010	0.01	-	**G COD/G COD**
Monod const. dor **Ss**	**(Kss)**	**0.500**	-	-	**G COD/M3**
Frac. *of* **anoxic bact.**	**(Etag)**	0.800	0.80	-	
Anoxic hydrolyse	**(Etah)**	**0.800**	0.40	-	

Poly-P bacteria.					
Growth *rata*	**(Mup)**	2.500		1.00	**1/D**
Decay rate	**(Bp)**	0.500	-	0.03	**1/D**
Anerobic COD uptake	**(Kp1)**	4.000	-	2.00	**1/D**
Aerobic COD uptake	**(Kp2)**	**0.000**	-	-	**1/D**
Aerobic P **uptake**	**(Kp3)**	4.500	-	-	**1/D**
Hydrolysis *of* **organic** P	**(Khpd)**	1.000	-	-	**1/D**
Poly-P hydrolysis	**(Khp)**	0.000	-	-	**G P/M3**
Monod const. for **COD**	**(Ksp)**	5.000	-	0.18	**G COD/M3**
Monod const. for 02	**(Kop)**	0.750	-	0.002	G **02/M3**
Monod const. for **NH4**	**(Knp)**	0.018	-	-	G **N/M3**
Monod conrt. for **NO3**	**(Knop)**	0.400	-	1.00	**G N/M3**
Monod const. for **COD**	**(Ksrp)**	0.001	-	1.00	a **COD/M3**
Monod const. *for* **Poly-P**	**(Kpp)**	0.100	-	1.00	**G COD/M3**
Monod oonrt. for **PO4**	**(Kpop)**	0.250	-	0.10	a **P/M3**
Monod oonrt. for **COD**	**(Kspl)**	20.000	-	-	**G COD/M3**

Autotrophic bacteria.					
Growth **rate**	**(Mua)**	0.150	0.30	0.35	**1/D**
Decay **rate**	**(Ba)**	0.080	**0.15**	0.04	**1/D**
Monod conrt. for 02	**(Koa)**	0.600	0.40	0.002	**G 02/M3**
Monod const *for* **NH4**	**(Kna)**	0.500	1.00	1.00	**G N/M3**

Table 3 : **Konstants Used in** ● **imulation, chosen** by **IAWPRC, and** by **Wentzel. Many constants are incompaerable because** that **they are used differently** in **the three** models. **Tempearture = 10•deg** C.

RESULTS AND DISCUSSION

One point, which is a little tricky to deal with in the simulation is how to handle the oxygen concentration. The most simple way would be to use the measured oxygen values directly, but this would not reflect that a high oxygen concentration in the tank is a result of low biological activity. It would rather reflect that the oxygen is pumped into the tanks at high level equal to high. K_ia value. This means that a high oxygen concentration would result in higher biological activity, and not that low biological activity results in little use of oxygen and thereby higher oxygen concentration. It would be most correct to use two distinct K_ia-values which were swhitched on or of in shorter or longer periods. But this is rather difficult to simulate, because that the values of the K_ia values and the period length of operation, need to be estimated independently and at the same time. Instead it is chosen to simulate the oxygen concentration by fitting a K_ia value at every measuring point. Thus the different K_ia values then reflects the different length of the periods with a high respectively a low K_ia-value.

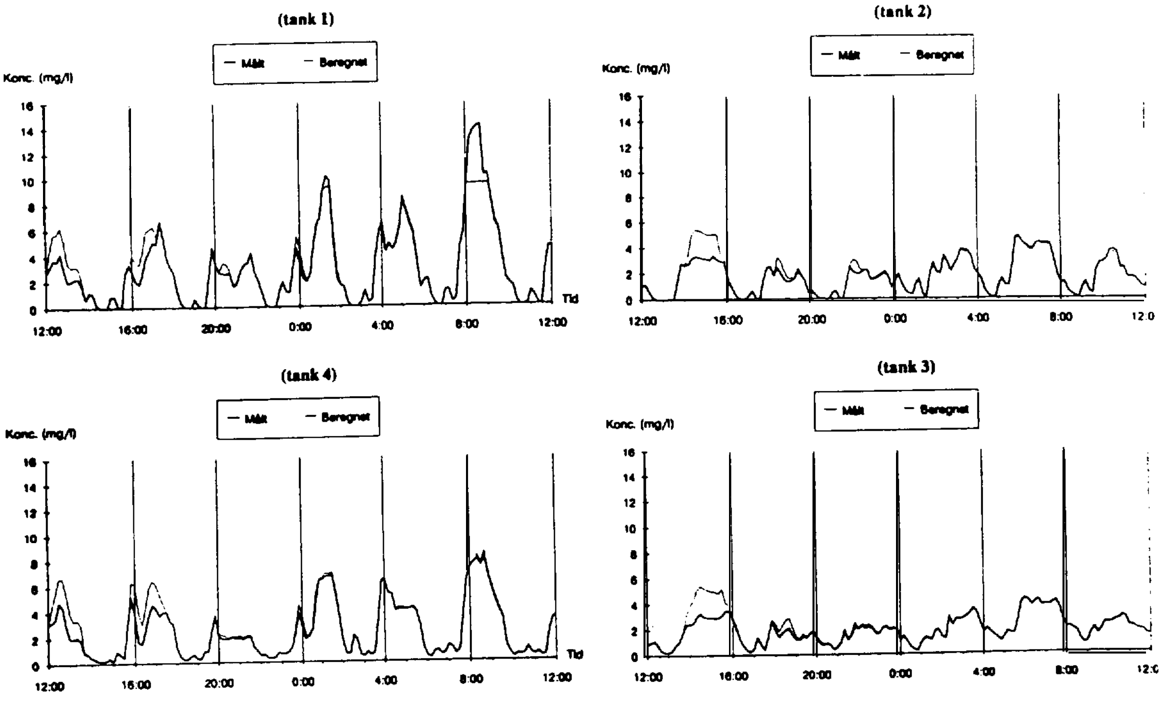


Figure 6 Oxygen concentrations in reactor 1 to 4.
Malt = Measured. Beregnet = Calculated.

In this way the simulated oxygen values naturally fit very well to the measured oxygen values as seen in figure 6.

In the next figures (figure 7, 8 and 10) the results of the simulation for ammonia, nitrate and phosphate are shown. Taking a look on ammonia it is seen that the simulation of the ammonia concentration is consistent with the measured values. From this it can be concluded which part of the model that concerns ammonia, it is possible to fit the constants, so that there is agreement between the model and the measured concentration. In this case even without changing the constants considerably compared to the IAWPRC suggestions.

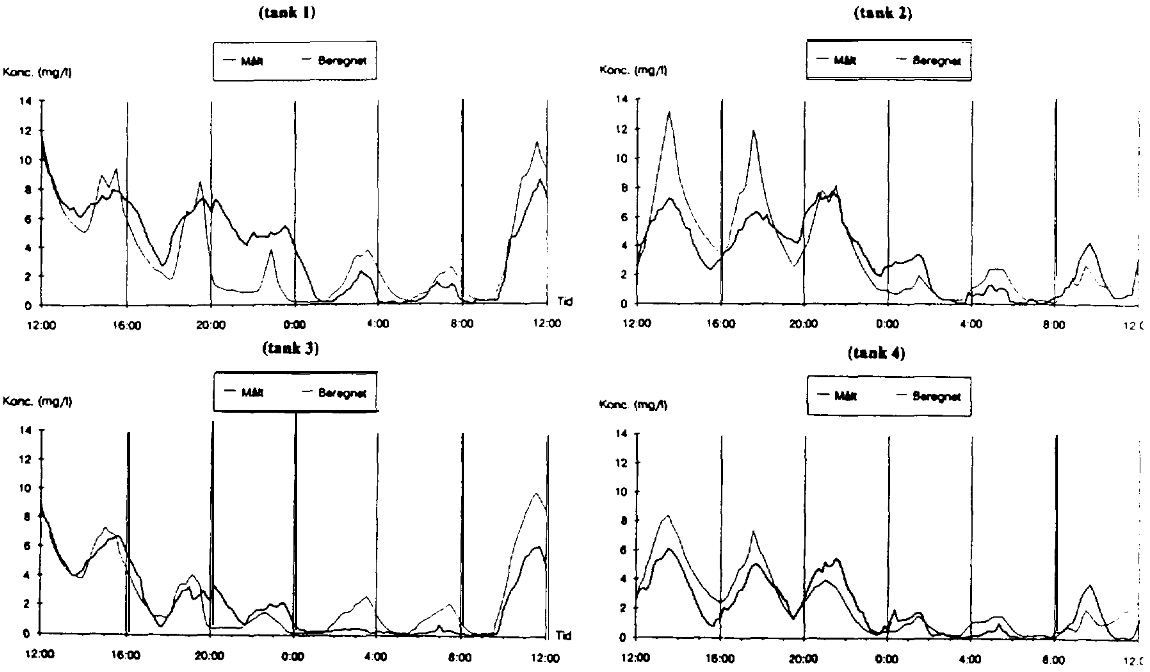


Figure 7 Ammonia concentrationin reactor 1 to 4.
Malt = Mesured. Beregnet = Calculated.

For nitrate the results is a bit different. In the first 8 hours of simulation the results are acceptable. But thereafter the results become very poor. When the measured values are near to zero in this period, the calculated values fluctuates much more, due to the alternating nature of the system, and it is not possible to calculate the very low concentration of nitrate wich occur in the measured data. The reason for this, could be connected to the very low concentration of easily degradable soluble substrate that occur in the simulation, as seen in figure 9.

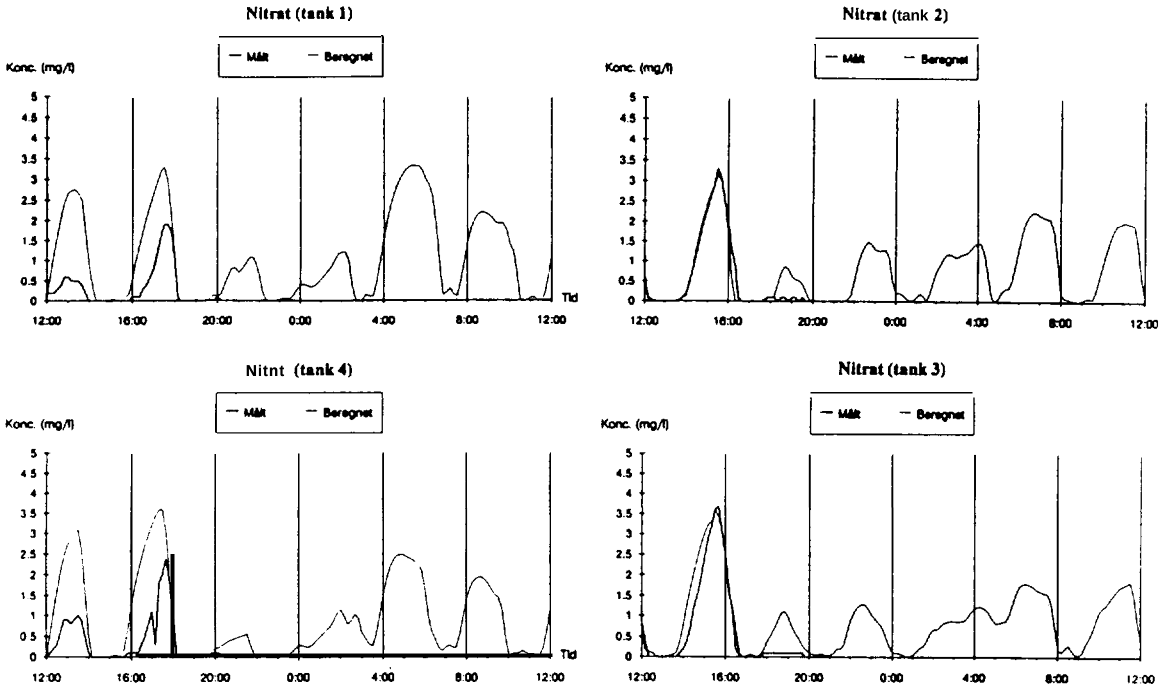


Figure 8 Nitrate concentration in reactor 1 to 4.
Malt = Mesured. Beregnet = Calculated.

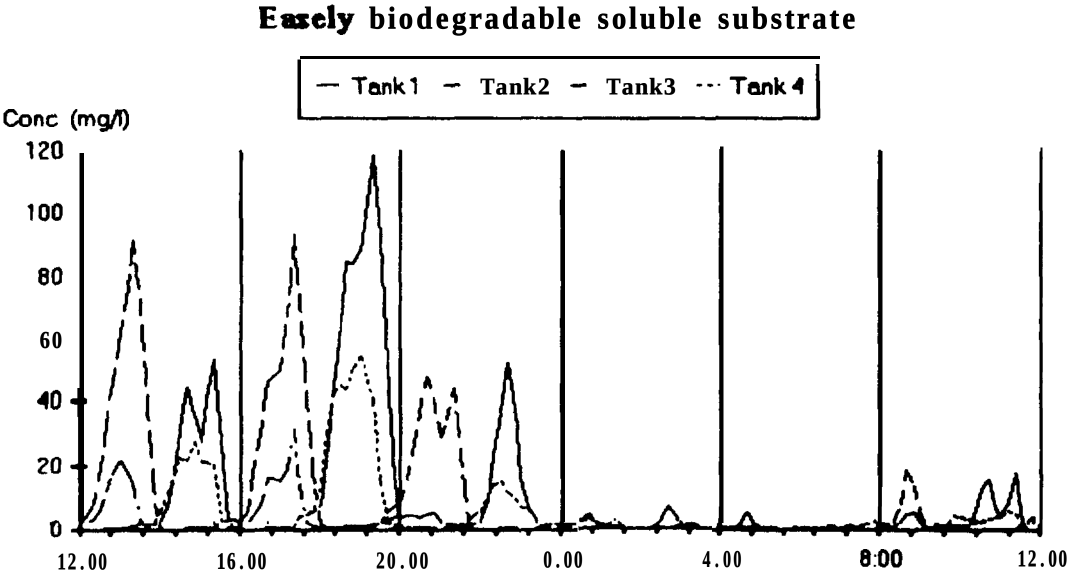


Figure 9 Calculated concentrations of easely biodegradable soluble substrate.

This lack of substrate in the simulation leads to inhibition of the simultaneous denitrification, which might not be found in the real world. It is difficult to say wheter the mesured values of nitrate or the model are wrong. The measured values might not be repesentative or the influent composition to the model might have been estimated wrong. The last could be caused by the fact that the ratio between the various wastewater components is estimated arbitrary and modelled as being constant during the diurnal variations, which might not be true.

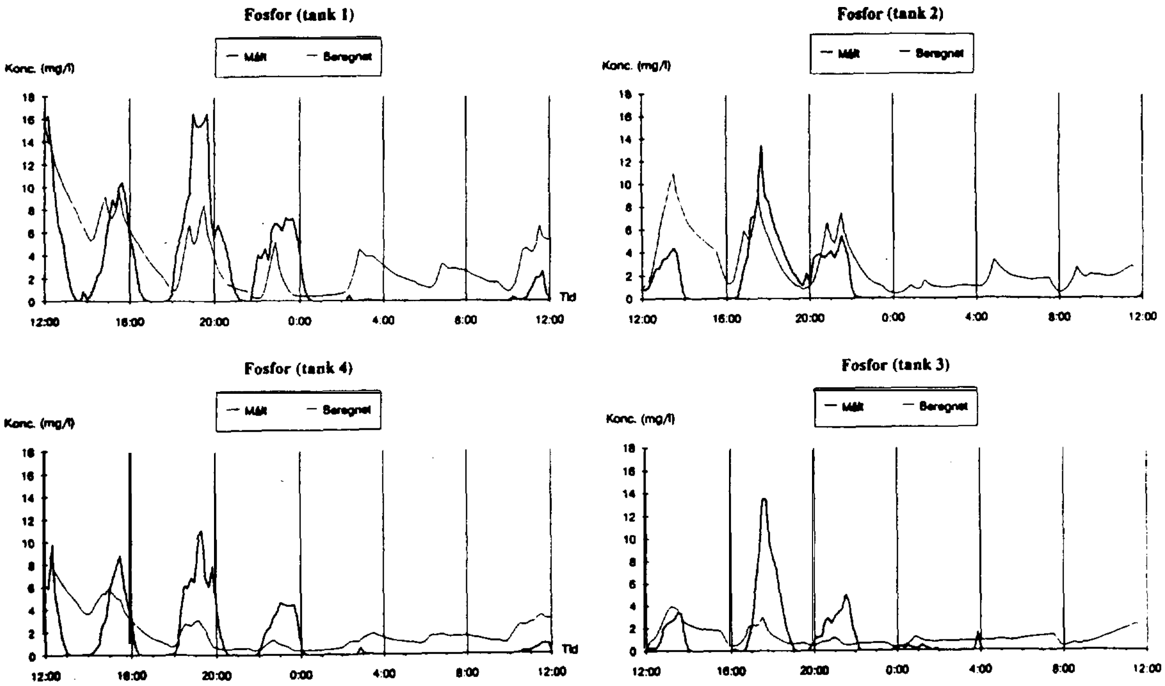


Figure 10 Phosphate concentration in reactor 1 to 4.
Målt = Mesured. Beregnet = Calculated.

The curves for the last component, phosphate, give reasonable results, but there is some discrepancy between the measured and the calculated values. Two things leap into the eyes. The high level of the calculated concentrations during the last part of the simulation, similar as for nitrate, and the slowly decrease of phosphate uptake in the aerobic zones. The first discrepancy is probably again due to the very low calculated easy degradable soluble substrate which makes it impossible for the bacteria to take up phosphate in the aerobic phases. The second discrepancy is more likely a model error caused by inflexibility of the model, caused by the reuse of constants in different processes. This might be corrected, by making the kinetic constants for substrate in the phosphate/substrate exchange processes independent of the same constants in the growth processes. The last is being tested at the moment.

CONCLUSION

A model for biological phosphorus removal is developed, as an extension to the model developed by the IAWPRC group for modelling (M.Henze et al, 1987). This model is tested against measured data from Frederiksund wastewater treatment plant to see if it was possible for the model to simulate biological phosphorus removal. Generally the model reflects the measured date very well, even so that there still are discrepancies.

Two possibilities are located, which could make a resonable explanation on these discrepancies. At first the problems are caused by inflexibility in the constants, because that some kinetic constants, in the present model, are reused intensively in different processes. Another possible explanation of the problems with fitting the observed data for nitrate and orthophosphate with the modelled could be the fact that the model is so complex that the data collected are not sufficiently detailed or representative to be used for a fitting procedure.

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STUDY ON NITROGEN REMOVAL AT THE HELSINKI WATER AND WASTEWATER AUTHORITY

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No nitrogen treatment is required at the wastewater treatment plants now in operation in Helsinki. The designs for the new central wastewater treatment plant, at present under construction at Viikinmäki, had to make the incorporation of nitrogen removal possible if future effluent quality requirements should demand this. Thus it was necessary to conduct a feasibility study on nitrogen removal on a plant scale at the Kylasaari wastewater treatment plant (300 000 P.E.). One of the Kylasaari process lines was modified for use as a study line for nitrification and denitrification.

The purpose of the study was to find out if a conventional treatment plant, using simultaneous precipitation and operating at normal loads, could be modified into a nitrogen-removal plant using the single-sludge DN-process, and what the conditions for such operation would be. The study began in the autumn of 1986 and will continue at least up to the end of 1990. The study is carried out in cooperation with the City of Espoo water and wastewater utility. The results will be used in the process designs for the Viikinmaki plant going on stream in the 1990s. The costs for modifying the study line have so far amounted to approximately FIM 300 000.

Test Set-Up

One of the twelve process lines at Kylasaari was modified for nitrification and denitrification (DN-line). Preliminary wastewater treatment - i.e. screening, grit removal, and pre-aeration - is the same throughout the plant, but the aeration basin was rebuilt as shown in Appendix 1 for a single-sludge DN-process. Denitrification takes place in the anoxic zone in the first quarter of the basin. Mechanically treated wastewater constitutes the carbon source for denitrification. The dimensioning values for the test set-up are shown in Appendix 2. Phosphorus removal as simultaneous precipitation with ferrous sulphate is again the same throughout the plant.

Propeller agitators were installed in the anoxic zone to prevent sludge settling when aeration is switched off. The fine bubble diffusers in this zone were coated with a rubber membrane to prevent aerator plate clogging when aeration is not used. An additional turbine aerator was installed in the first quarter of the basin to improve aeration capacity during nitrification start-up (Appendix 3). Nitratecontaining sludge is recirculated to the anoxic zone both as return sludge and through two anoxic zone both as return sludge and through two centrifugal pumps with fixed yields installed at the end of the aeration basin. Recirculation from secondary sedimentation depends on the recirculation pumping rhythm of the whole plant; thus the recirculation ratio cannot be altered for the DN-line alone.

The operation of the DN-line is continually monitored. In addition, samples are taken twice a week. Samples from primary sedimentation and from biological treatment are collected as daily composites. The DN-line contains continuously operating pH-meters at the beginning and end of the aeration basin, and temperature and flow monitors. Oxygen concentration is continually monitored from points at the beginning and end of the aerobic zone. The aeration regulation system keeps the oxygen concentration at 2 mg/l.

In addition to technical ferrous sulphate used for phosphorus removal, lime is added to the DN-line to compensate for loss of alkalinity. Lime ($Ca(OH)_2$) feed was introduced in May 1988.

Test Runs

The construction of the DN-line was completed in the summer of 1987, and the first test runs for nitrification start-up began in August. Nitrification got under way, but because of a drop in alkalinity (0.1-0.5 mmol/l) the process was disturbed and denitrification could not be started.

A lime feed apparatus was installed on the line and, after snow-melt peak flows had passed, nitrification was started again together with a dosage of finegrained industrial lime ($Ca(OH)_2$) in the spring of 1988. During the summer of 1988 nitrification stabilized so much with the lime feed, that the first denitrification test run could be started on July 12. This period lasted until September 30, although denitrification had to be interrupted for the period July 29-August 10 because nitrification was being intensified by using the total aeration basin capacity. The DN-test had to be interrupted when flooding due to heavy rains flushed away the sludge and halted nitrification. The results for the two denitrification phases are shown in Appendices 4, 5, and 6.

Results in 1988

Nitrification reached a level of 70 % on the average during the test period, but showed a wide range of variation. This effected the whole nitrogen removal process, as poor nitrification did not produce enough nitrate for denitrification. Clogged aerators, which made oxygen concentrations drop below the required level, and an irregularly operating lime feed were contributing factors in irregular nitrification. However, the principal reason for poor nitrification results was that sludge age could not be retained at a sufficiently high level.

Because of high wastewater temperatures (18-20°C) in the summer, the sludge age required is only 5-6 d, but should be 7-9 d to allow for flow variations. With present volumetric loads (0.38 kg/m^3d) this would lead to such high sludge concentrations that the sludge would not be retained in the aeration-clarification system, but would be flushed on from secondary sedimentation during peak flows. It is even more difficult to achieve nitrification in the winter and spring with low wastewater temperatures.

The problems encountered with low alkalinity levels in 1987 could be compensated with lime dosage. Periodic interruptions occurred in the lime feed, and the dose used (40 g/m^3) was calculated as an average over a long period due to the absence of fine adjustment in the feed.

Recirculation pumping of activated sludge and the carbon-to-nitrogen ratio in aeration basin influent were factors limiting denitrification. Return and recirculation pumping gave a 2.35 coefficient of recirculation, at which level denitrification would at most have reached 70 %. Complete denitrification with the carbon-to-nitrogen ratio present in the wastewater would have required a 1.5-hour detention time in denitrification. The theoretical detention time, calculated from discharges, was approximately 45 minutes. Because of complete agitation actual detention time was much less, however: tracer test showed a through time of only fifteen minutes for maximum tracer concentrations in the anoxic zone (Appendix 7).

With denitrification in progress lime demand dropped somewhat. A roughly calculated feed was 30 g/m”.

Total nitrogen reduction amounted to approximately 45 % in the test line and to approximately 20 % in the control lines.

Plans for Test Set-up Improvements

As it is of primary importance that nitrification be improved, steps had to be taken to maintain a longer activated sludge age. The alternatives available were either controlling high sludge concentrations in the aeration basin or lowering the incoming load. Lowering the load with pre-precipitation, for instance, would have interfered with nitrogen removal, as it would haved reduce the amount of carbon needed for denitrification.

A carrier material test program was planned in order to find a suitable method of controlling high sludge concentrations in the aeration basin. The support material chosen was small cubes of foam plastic in free suspension. The cubes are prevented from entering secondary sedimentation and recirculated to the beginning of the aerobic process. According to calculations, the sludge concentration need was 12 kg/m”. In order to determine the quantity of sludge on the surface of the carrier material and the amount of carrier surface necessary, test runs will first be carried out on a pilot plant scale at the test facility operated by the National Board of

Waters and the Environment as a joint project with the Board's Technical Research Bureau.

Test Runs in 1989

The plant scale test line was redesigned, and test runs continued in the summer of 1989.

Detention time in denitrification was extended by constructing baffles between the agitators in order to prevent short-circuiting and to change the flow into more of a plug flow type.

Plans were also drawn up for raising the alkalinity of the process with a feed of lime sludge residue left over from the production of lime water in the water treatment process.

Because test runs in 1988 had showed that the fine bubble aerators clogged easily, probably due to the joint effects lime, iron, and high sludge concentrations, all aerators along the test line were replaced with a type covered with a rubber membrane.

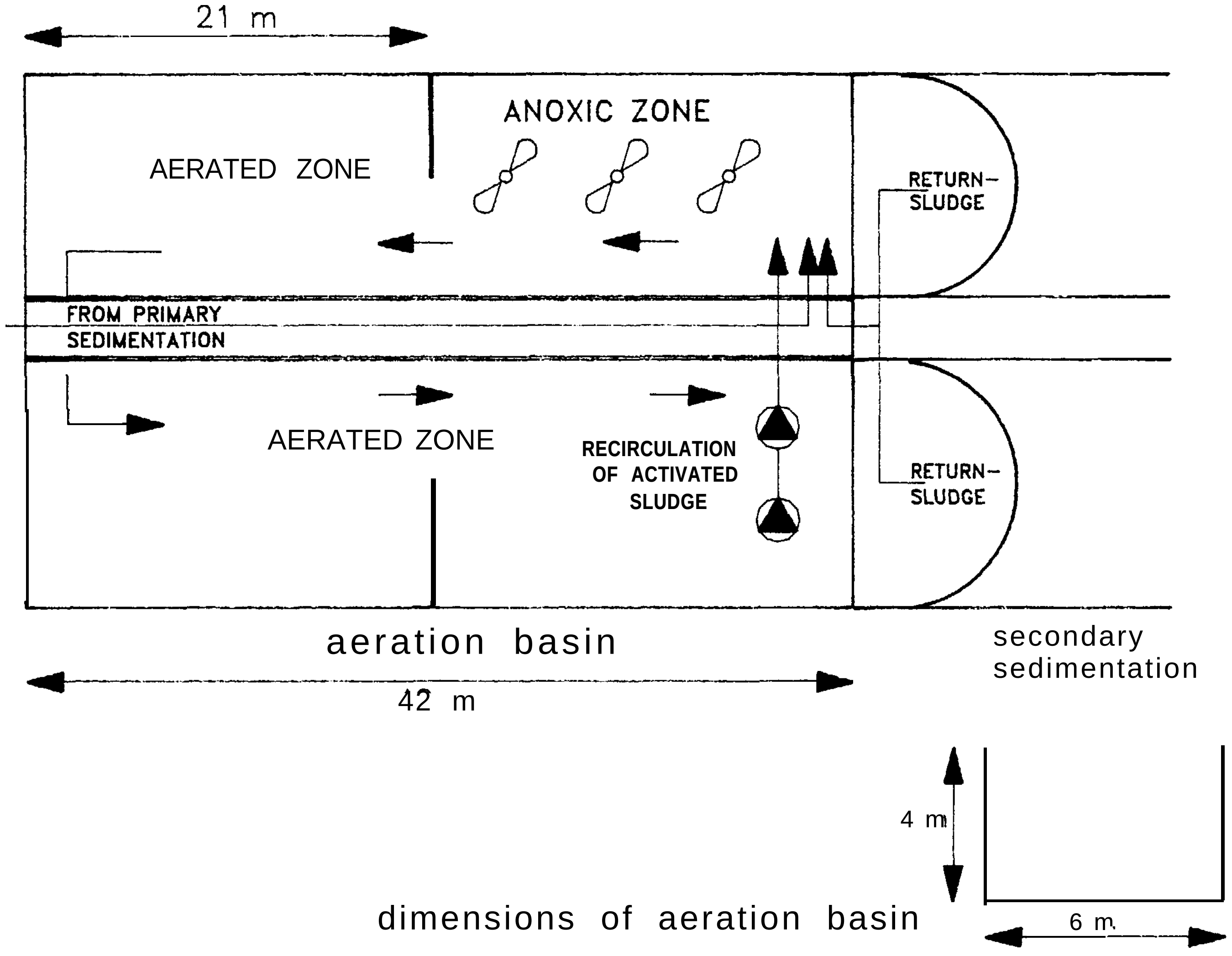
Results in 1989

The average value for nitrification reached 80 %, and the process was more stable than in 1988. Total nitrogen reduction rose to 54 % because the denitrification zone functioned better than previously. Nitrogen reduction in the control lines remained at 20 %.

There was no need to start a feed of lime sludge residue because improved denitrification prevented alkalinity from falling too much.

The results for 1989 are shown in Appendices 8, 9, and 10.

KYLÄSAARI DN-process

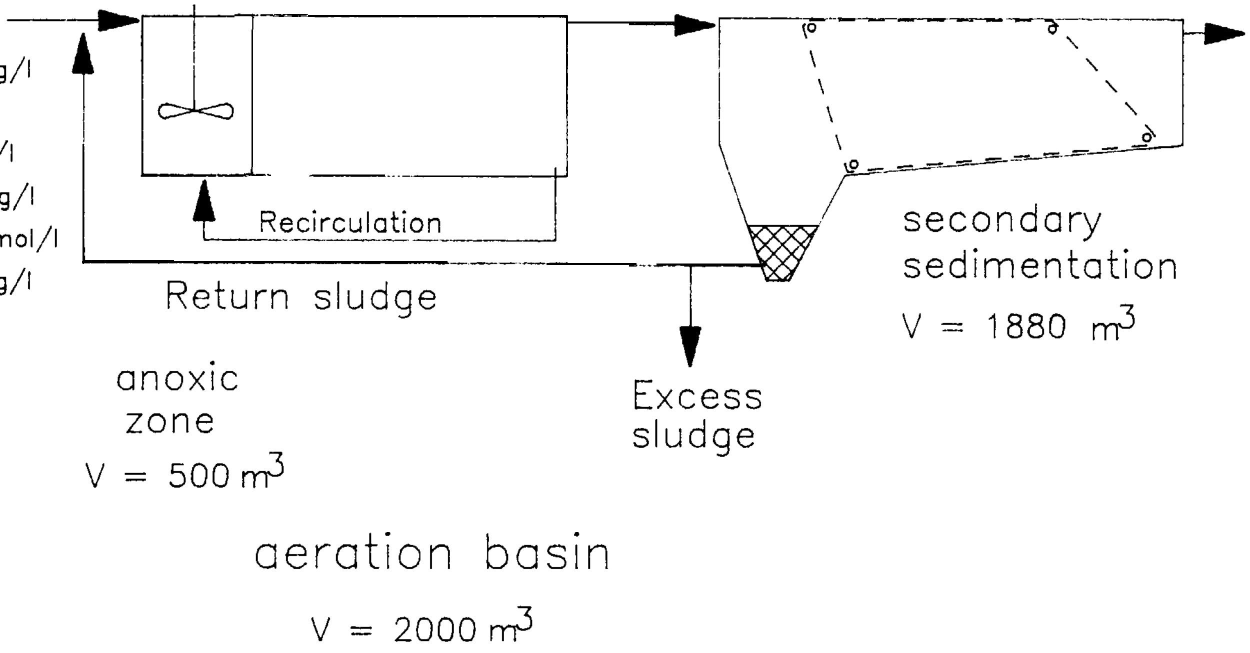


KYLÄSAARI DN-process

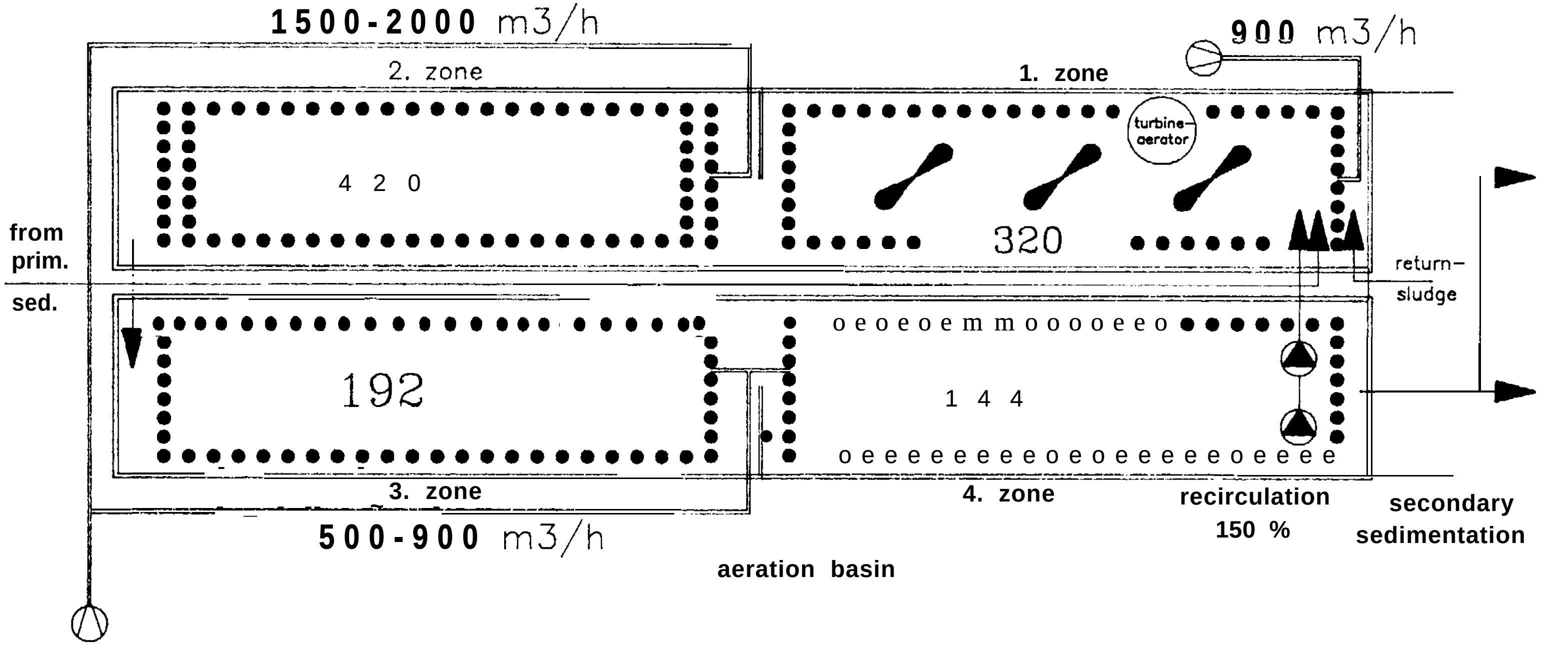
Influent

$Q = 7500–11000\ m^3/d$

BOD_7 = 70–110 mg/l
SS = 70–130 mg/l
tot–N = 30–45 mg/l
NH_4–N = 25–35 mg/l
alkal. = 2,5–3,5 mmol/l
tot–P = 3,5–4,5 mg/l



KYLÄSAARI DN-process



Membrane aerators

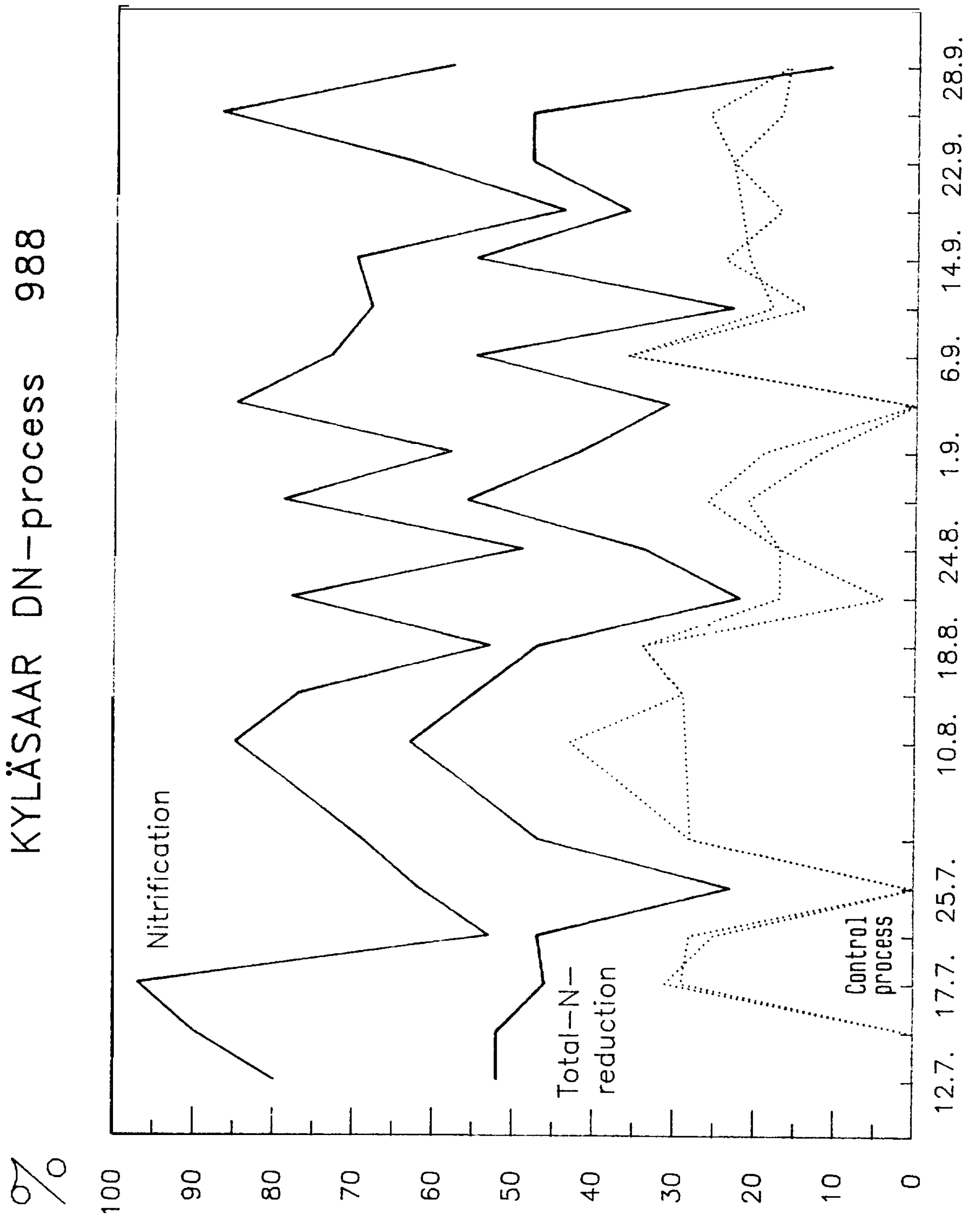
1. zone 500 m3, 0,088 m2/m2, 2,8 m3/h **aerator** $P_{mix} = 4,5$ W/m3

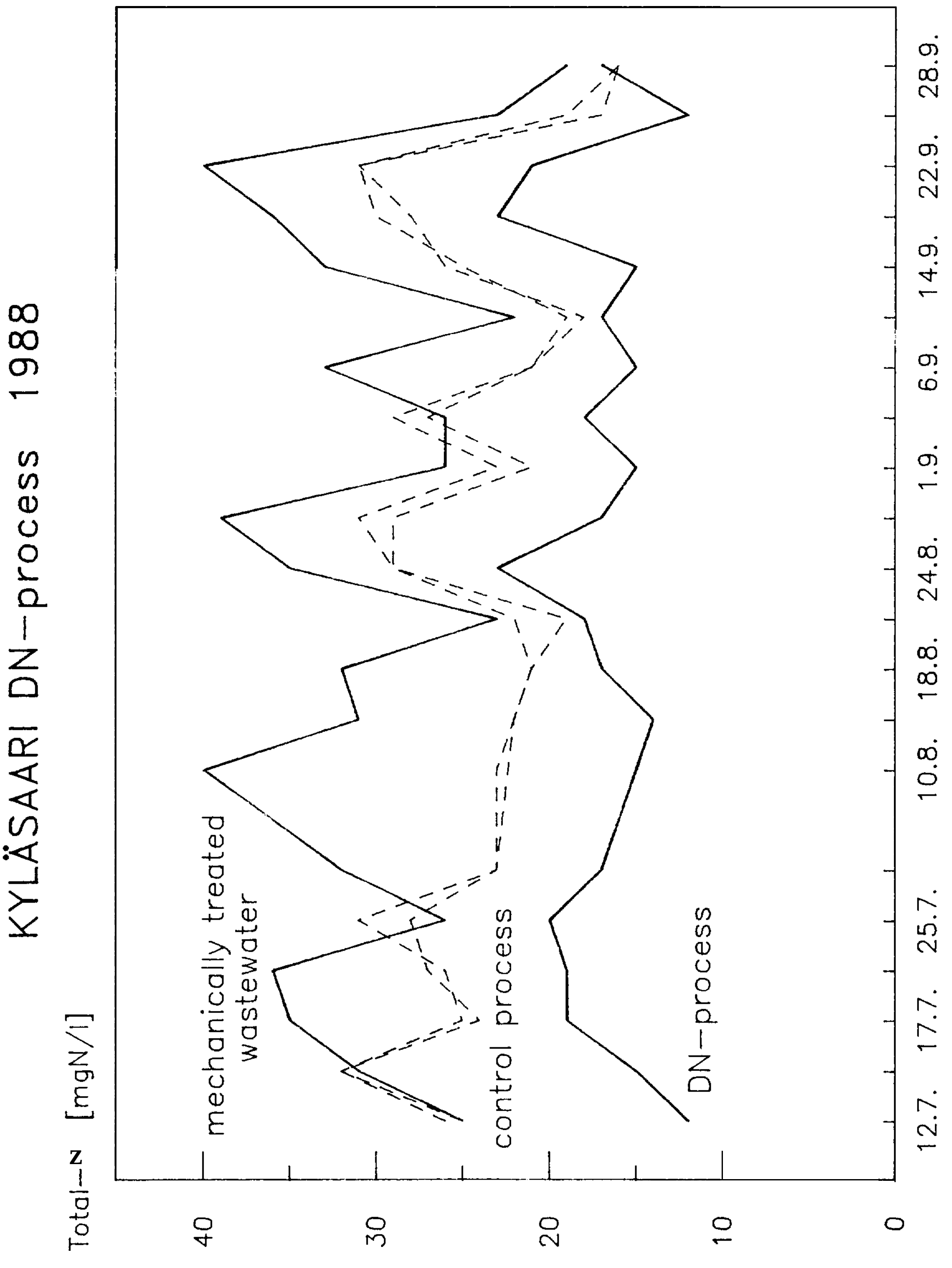
2. zone 500 m3, 0,1**15** m2/m2, 3,6–4,8 m3/h **aerator**

3. zone 500 m3, 0,053 m2/m2, 1,5–2,7 m3/h **aerator**

4. zone 500 m3, 0,039 m2/m2, 1,5–2,7 m3/h **aerator**

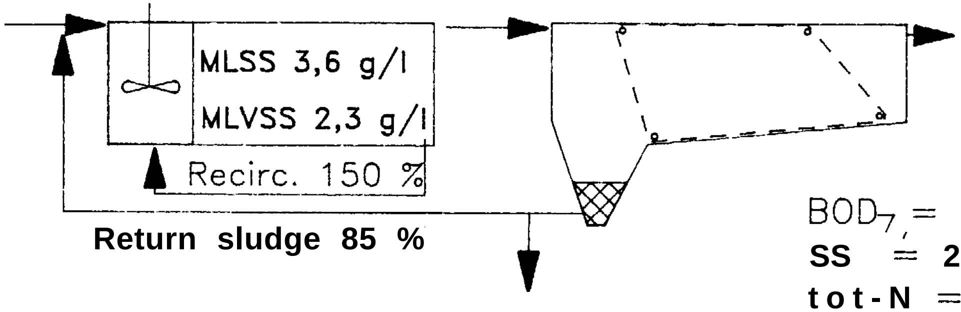
Appendix 4


KYLÄSAAR DN-process 988
%
100
90
80
70
60
50
40
30
20
10
0
12.7.
17.7.
25.7.
10.8.
18.8.
24.8.
1.9.
6.9.
14.9.
22.9.
28.9.
Nitrification
Total-N-reduction
Control process


KYLÄSAARI DN–process 1988
Total–N [mgN/l]
0
10
20
30
40
12.7.
17.7.
25.7.
10.8.
18.8.
24.8.
1.9.
6.9.
14.9.
22.9.
28.9.
mechanically treated wastewater
control process
DN–process

KYLÄSAARI DN-process 1988

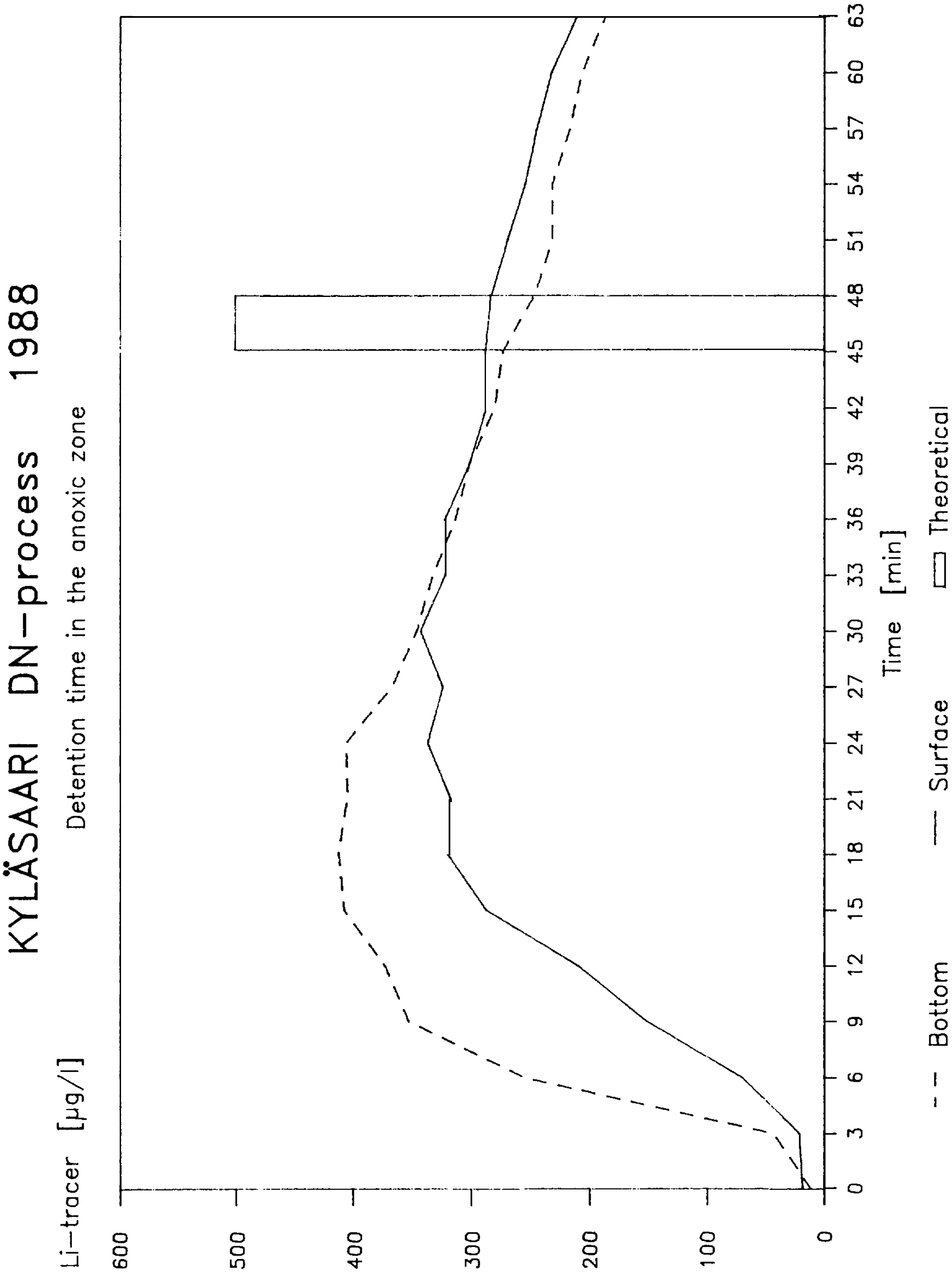
Q = 8600 m^3/d
BOD7 = **90** mg/l
SS = 100 mg/l
tot-N = **31** mg/l
NH_4–N = 27 mg/l
alkal. = 2,9 mmol/l



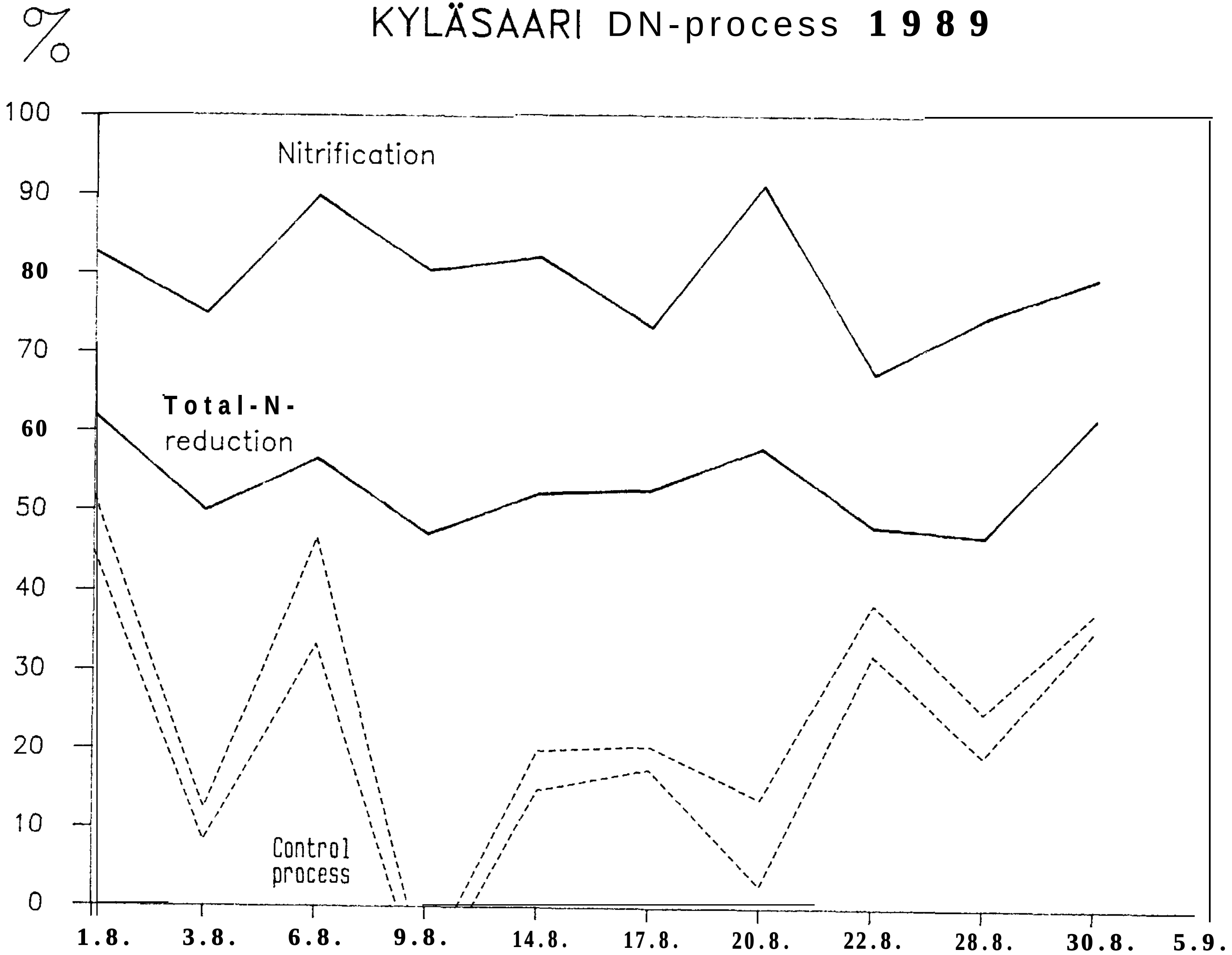
BOD_7 = **9** mg/l
SS = **28** mg/l
tot-N = **17** mg/l
NH_4–N = 9 mg/l
NO_3–N = 6 mg/l
N-red. = **45** %
alkal. = 2,1 mmol/l

Temperature = **21** °C
Sludge age = **6 d**
Detention time = **4.2** h
F / M = 0.11 kgBOD/kgMLSSd
Volumetric loading = **0.37** kgBOD/m^3d
BOD/N = **2.8**
Ca-dose = **30** gCa/m^3
Nitrification **rate** = **54** gN/kgMLVSS(aer)d
Denitrification rate = **68** gN/kgMLVSS(anox)d (20 % of nitrogen in excess sludge)

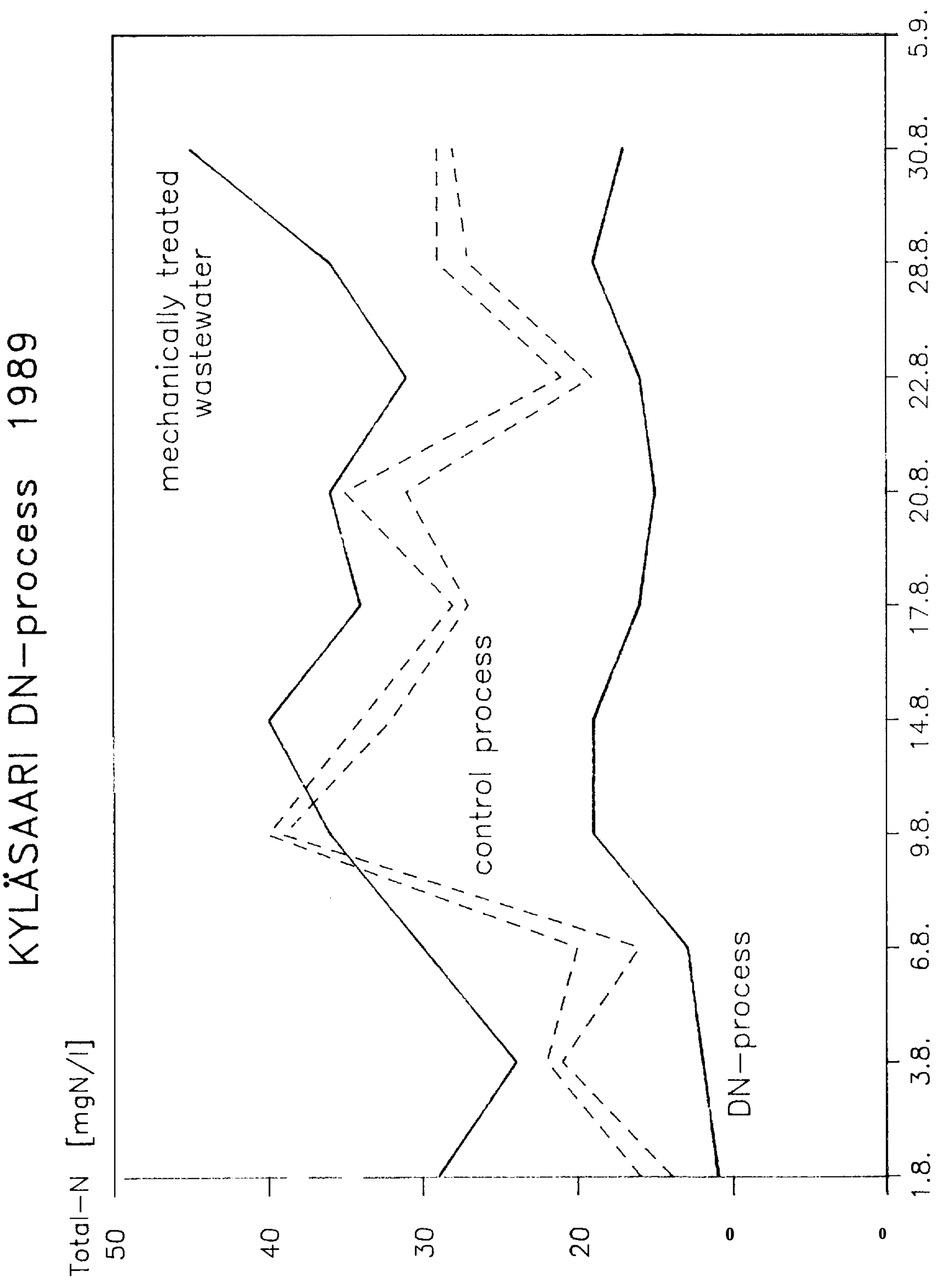
Appendix 7


KYLÄSAARI DN-process 1988
Detention time in the anoxic zone
Li-tracer [µg/l]
600
500
400
300
200
100
0
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51
54
57
60
63
Time [min]
- - Bottom
—— Surface
▭ Theoretical

KYLÄSAARI DN-process 1989

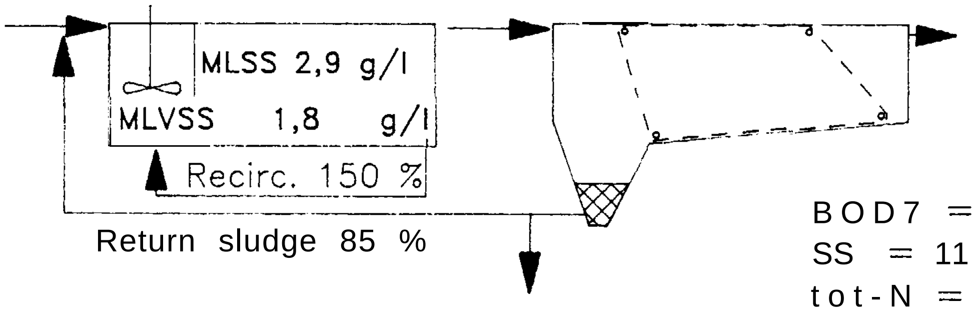


Appendix 8


KYLÄSAARI DN-process 1989
Total-N [mgN/l]
50
40
30
20
0
0
1.8.
3.8.
6.8.
9.8.
14.8.
17.8.
20.8.
22.8.
28.8.
30.8.
5.9.
mechanically treated wastewater
control process
DN-process

KYLÄSAARI DN-process 1989

Q = 7800 m^3/d
BOD_7 = 80 mg/l
SS = 100 mg/l
tot-N = 34 mg/l
NH_4-N = 27 mg/l
alkal. = 3,0 mmol/l



BOD7 = 4 mg/l
SS = 11 mg/l
tot-N = 16 mg/l
NH_4-N = 7 mg/l
NO_3-N = 7 mg/l
N-red. = 54 %
alkal. = 1,2 mmol/l

Temperature = 21 °C
Sludge age = 5 d
Detention time = 4.7 h
F / M = 0.11 kgBOD/kgMLSSd
Volumetric loading = 0.31 $kgBOD/m^3d$
BOD/N = 2.4
Ca-dose = 0 gCa/m^3
Nitrification rate = 77 gN/kgMLVSS(aer)d
Denitrification rate = 1 17 gN/kgMLVSS(anox)d (20 % of nitrogen in excess sludge)

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BALTIC SEA ENVIRONMENT PROCEEDINGS

No. 1 JOINT ACTIVITIES OF THE BALTIC SEA STATES WITHIN THE FRAMEWORK OF THE CONVENTION ON THE PROTECTION OF THE MARINE ENVIRONMENT OF THE BALTIC SEA AREA 1974-1978
(1979)*

No. 2 REPORT OF THE INTERIM COMMISSION (IC) TO THE BALTIC MARINE ENVIRONMENT PROTECTION COMMISSION
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No. 3 ACTIVITIES OF THE COMMISSION 1980
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No. 5A ASSESSMENT OF THE EFFECTS OF POLLUTION ON THE NATURAL RESOURCES OF THE BALTIC SEA, 1980
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PART A-1: OVERALL CONCLUSIONS
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No. 16 WATER BALANCE OF THE BALTIC SEA
A Regional Cooperation Project of the Baltic Sea States; International Summary Report
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No. **17A** FIRST PERIODIC ASSESSMENT OF THE STATE OF THE MARINE ENVIRONMENT OF THE BALTIC SEA AREA, 1980-1985; GENERAL CONCLUSIONS
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No. 31 THREE YEARS OBSERVATIONS OF THE LEVELS OF SOME RADIONUCLIDES IN THE BALTIC SEA AFTER THE CHERNOBYL ACCIDENT
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