Oxidation ditch: Prevention and control of filamentous sludge

I wish to report on further research with the oxidation ditch on the premises of our Institute at Delft. I do this also in the name of my colleague Mr. B. A. Heide, who will continue this research in the future.

In principle, there are three types of oxidation ditches as represented by the lay-outs shown in figures 1a, 1b and 1c. The first time we encountered the problem of filamentous sludge was in an oxidation ditch of type 1c in 1961/1962.

After prolonged investigations, it appeared

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that two important advantages could be attained by changing from lay-out 1c to the original lay-out 1a. These were:

1. the sludge index would drop from 500-600 to about 100-150, and
2. 90 % of the nitrogen present in the raw sewage would be removed.

In order to understand how such an improvement in the sludge index could be effected by changing from a continuous supply of sewage to an intermittent supply, a theory was developed concerning the growth of Escherichia coli in filamentous form. This theory seemed quite in agreement wit the results obtained. Later, the theory was proved false through the research of my colleague, Eikelboom.

In practice, is was repeatedly confirmed, however, that the sludge index was

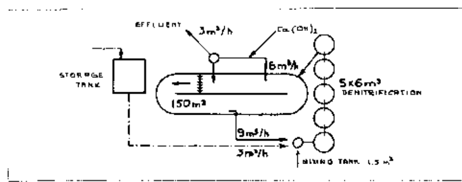


Figure 2 - Present situation oxidation ditch Zuidpolder (for 600 inhabitants).

improved by a change from a continuous sewage supply to an intermittent one.

The original theory has been replaced by the following simple hypothesis: 'intermittent nutrition and, consequently, the temporarily high concentration of nutrients are apparently favourable for the development of the flocculent bacteria; with a continuous supply of sewage, during which the concentration of nutrients remains low, the growth of filamentous bacteria, with their larger contact area with the environment, is apparently promoted.

The experimental oxidation ditch of our Institute is of type 1a. It was put into operation in 1969. We did not succeed in obtaining a true oxidation ditch sludge with an index of 40-60. As is the case in many oxidation ditches a sludge index of 100-150 was attained, with now and then upward or downward variations.

Though, under normal circumstances, such a sludge presents no problems in the separation of the floc from the purified waste water, it is an unsatisfactory situation, which makes further research into the control of the sludge index necessary.

Considering that the continuous process, represented by figure 1b, is applied in most cases in practice, and that it is used without exception for large oxidation ditches, we decided, in May 1973, to continue our research on a scheme where the supply of sewage which must be purified, and the separation of activated sludge and purified effluent takes place in a continuous process. This led to the scheme of figure 2.

The sludge trap (1.8 m^2 water surface) was fitted into a final clarifier. It was estimated that this area might be loaded with 3 m^3/h, in case of a sufficiently low sludge index. With a supply of 24 x 3 m^3 of sewage with 550 ppm of dichromate COD, the load would then amount to 40 kg COD/day, or 400 inhabitant equivalents which is 80 % of the design load.

According to the scheme of figure 2, the main quantity of the floc in the oxidation ditch is permanently aerated.

By continuously bringing together the sewage (3 m^3/h) and the circuit liquor (9 m^3/h) the floc present in this liquor is provided with nutrients. The sludge then returns to the oxidation ditch heavily loaded with the waste products from the 3 m^3 of sewage. In this mixture, the oxygen demand is very high. Therefore, when there is a sufficiently high temperature and when a sufficient detention time is provided, a process of denitrification may readily proceed. We will return to this at the end of the lecture.

It soon appeared that a really good sludge index was obtained with the scheme of figure 2. This result and previous work of a group of Czech investigators put us on the track which has led to what we now regard as a major cause of the light sludge problem as we find it in the practice of the oxidation ditch system. This solution has as its basis the way in which the polluting substances present in the sewage are supplied to the activated sludge floc. The great differences existing in this respect are made clear in table I for the operating schemes in the figures 1 and 2.

In the operating schemes of figures 1b and 1c with a continuous supply of sewage, the floc is loaded with a small amount of organic pollutant at each circulation.

At the same time an equally large amount of organic material is continuously removed by assimilation and oxidation. As a result, the load level of the floc is permanently low to very low.

In the discontinuously operating scheme of fig. 1a, sewage is supplied four times a day.

After each supply the floc is highly loaded; following each loading, the organic matter

Figure 1.

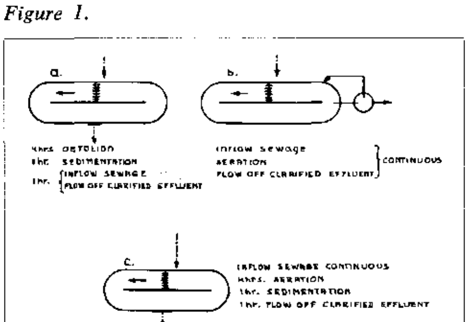


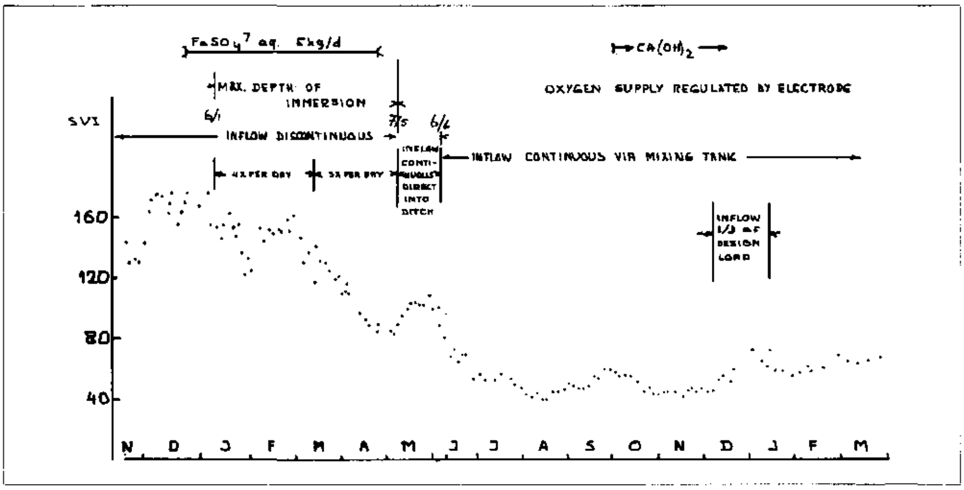
TABLE I

Inflow sewage	Continuous	Discontinuous	Continuous via mixing tank	Laboratory batch
Floc-load kg COD/kg floc/d	0.089	0.089	0.089	0.089
Length cycle	± 3.6 min.	6 hours	16.7 hrs.	24 hrs.
Number of cycles per 24 hrs.	± 400	4	1.44	1
Level of loading	very low	higher	high	high
Average g COD/kg floc	(0.22)	(22)	62	89
Sludge index	up to 500—600	usually 100—150	< 70	40—50

present is assimilated and oxidized in four hours.
In the scheme of figure 2, the floc in the 9 m^3 of mixed liquor is loaded even more heavily than in the preceding case. Here it takes about 17 hours on an average before the floc returns to the mixing tank and is reloaded with organic material from the sewage.
In the last column of table I, the situation for the so-called batch system, as is often applied in the laboratory, is presented.
In this case, the level of the floc load immediately after the new supply of nutrition is still higher than in the scheme of figure 2.
It should be emphasized that the floc loading as normally expressed in practice in grams of COD per kg of floc per day is the same in all four cases; the difference lies in the distribution of the supply of sewage over the day.
The great differences in the manner of supplying the nutrition to the floc must be of influence on the bacteriological process. Of course, it is of great interest to know how this works out in the sludge index obtained. This is shown in the figures in the lowest line of table I.
The figures speak for themselves.
The results obtained in our experimental oxidation ditch are shown in figure 3.

In figure 3, the course of the sludge index in the experimental oxidation ditch is represented from 1st November 1972 on. During the period from 15th December 1972 to 25th April 1973, a daily amount of 5 kg of ferrosulfate ($FeSO_4 . 7 aq$) was supplied. From 10th January 1973 up to and including the 6th of May 1973, it was attempted to supply as much oxygen as possible by aeration at an economically disadvantageous maximum immersion depth. On March 12, 1973, we changed from a 6-hour cycle with a 4-times a day sewage supply and 4 times 4 = 16 aeration hours, to an 8-hour cycle with a 3-times a day sewage supply and 3 times 6 = 18 aeration hours which further increased the oxygen supply.
The considerable improvement in the sludge index during the month of March and April 1973 may be the result of the three factors mentioned; namely, the supply of ferrosulfate, the high oxygen input, and since March 12, the change in the distribution of the supply of sewage over the day (3 times instead of 4 times a day). A definite conclusion as to the influence of the three factors cannot be made. The period of time is reported in order to show the history of the floc in the ditch prior to the May 7th when we changed from the operating scheme of figure 1a, to that of figure 1b.
After May 7th, the sewage was continuously supplied directly into the ditch. The oxygen supply was — and is — regulated in such a way that the oxygen content in the whole ditch constantly amounts to 2 ppm. After this change, the sludge index increased to about 110. As a consequence, there was an insufficient separation of the floc from the purified effluent until the first model of the scheme in figure 2 came into operation on 6th June 1973. In three weeks time, the sludge index dropped below 60 and has remained low ever since. It is the first time that we succeeded in bringing the sludge index of our experimental oxidation ditch to the desired low level and keeping it here for such a long time. None of the efforts expended during the nearly four years of operation of scheme 1a had had such a good result.
In the period from the beginning of December 1973 to mid-January 1974, a small increase in the sludge index was observed. During this period, the daily COD was decreased to 34 % of the standard load, while conducting an experiment on sludge production at a very low floc load. This decrease in daily COD also resulted in a decrease in the level of floc load in the mixing tank to 1/3 of that prior to the beginning of December. On 14th January 1974, the daily COD was again brought up to 40 kg a day.
From these results, we must conclude that there apparently is a connection between the load level of the floc obtained during the mixing process and the sludge index.
As already mentioned, this load level should not be confused with the rate of floc loading expressed as g COD/kg floc/d. When the load level is low, the environment is favourable for the development of filamentous bacteria; as the load level increases, the filamentous bacteria diminish and the sludge index improves.
The foregoing results are supported by the work of the previously mentioned Czech investigators Chudoba c.s. which was published in the August and October 1973 issues of Water Research. They investigated the influence of the hydraulic conditions on the sludge index by comparing complete mixing with that of different situations with tanks in series (see figure 4).

Figure 3.



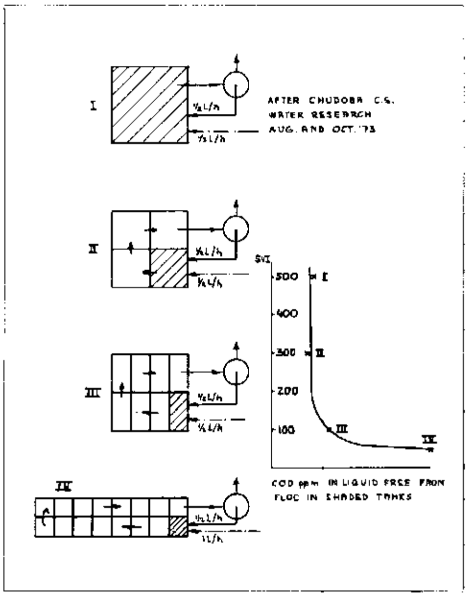


Figure 4.

In these investigations, the circumstances with regard to a number of factors differ greatly from those in our oxidation ditch. The Czech investigators work with small laboratory set-ups, the average floc load in g COD/kg floc/d is 6 to 10 times that in the oxidation ditch. The oxygen content in all four set-ups is maintained at 2 ppm; consequently, there is no denitrification.

The waste used consists of a mixture of peptone and starch.
In figure 4 I, return sludge and waste are brought into the 4 liter complete mixing tank.
As in the scheme of figure 1b, the result is a permanently low load level of the sludge. As in scheme 1b, the amount of nutrient which is continuously supplied, equals the amount which is continuously assimilated and dissimilated.
In figures 4 II, 4 III, and 4 IV, return sludge and waste are brought together in smaller tanks (1, ½, and ¼ liter, respectively). Because of the smaller amounts of floc and the relatively short detention times, especially in the last case, the dissimilative action of the bacteria is limited. As a result, the level of load on the floc is higher as the tanks are smaller (shaded area).
The sludge indexes obtained in set-ups I, II, III, and IV are 517, 300, 91, and 51, respectively.
Chudoba and collaborators have repeatedly shown that the sludge index changes when the sludge is transferred from set-up I to set-up IV, or vice versa and adjusts itself after a long or somewhat shorter lapse of time (months or weeks) to the level corresponding with the new situation.
On the basis of these results, Chudoba et al. concluded, just as we did that a higher concentration of nutrients is apparently favourable for the flocculating bacteria, whereas a lower concentration of nutrients may promote the growth of the filamentous bacteria. The Prague investigators attribute the considerably better sludge index found in the set-ups III en IV to the higher concentration of nutrients in the liquid around the floc found in the first compartments, represented by the shaded areas in figures 4 III and 4 IV.

In this respect, their ideas may be somewhat different from ours to some extent. It is a fact that the bacteria are in and on the floc and that the organic matter supplied is to a large extent adsorbed on the floc surface and — by enzymatic action — is even assimilated in the floc within a short lapse of time. We think it probable that it is the situation at the floc surface during the process of mixing of waste and mixed liquor which is decisive for the ratio of flocculent and filamentous bacteria in the system. In an experiment in the laboratory, it was shown that in the situation represented by the scheme in fig. 2, where 3 m^3 of sewage are mixed with 9 m^3 of mixed liquor, 75 % of the organic matter present in the sewage is adsorbed into or adsorbed to the floc in a few minutes.
The difference in opinion with the Czech investigators would not be so important,

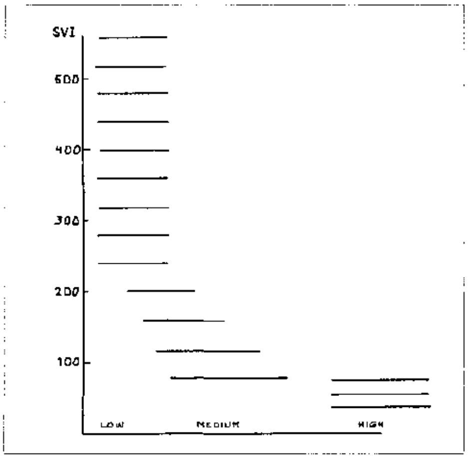


Figure 5 - Level of load on floc during or at end of mixing process.

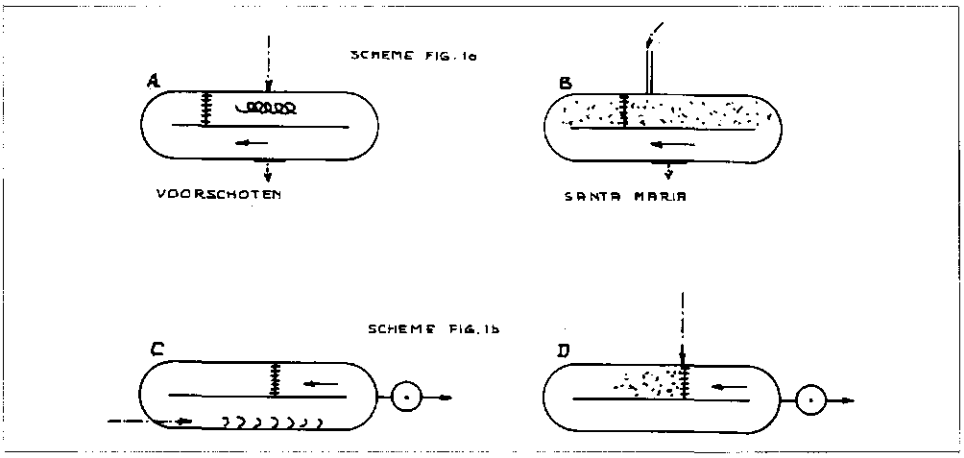
for the time being, for there certainly is a relationship between adsorbed and non-adsorbed nutrition, were it not for the fact that the Czech investigators added the conclusion to their opinion that it is of importance to maintain a concentration gradient on nutrition in the liquid around the floc over a number of tanks.
The results obtained so far show that a small mixing installation will suffice.
The rapid rate of the adsorption process ensures that a high load level of the floc is attained in a mixing process in only a few minutes time. As will be shown further on, this seems to be confirmed by experiences in practice.

What has been discussed so far, is summarized in figure 5. It proved not to be possible to indicate the load level by figures. This will become clear when we consider that the load level is determined by a number of factors which can seldom be known with sufficient exactness in their totality. These factors are the following:

a. the amount and concentration of the sewage which takes part in the mixing process;
b. the amount and concentration of the sludge mixture (mixed liquor or return sludge) which actually takes part in the mixing process;
c. the amount of organic matter which is oxidized during the mixing process.

On account of the uncertainty regarding the exact value of one or more of these factors, it is impossible to state the load level exactly, except for one or two cases (batchsystem and scheme of fig. 2).
The indication low, high, or medium must suffice. When the load level is low, during the process of mixing, growth of filamentous bacteria and a high sludge index may be expected, whereas, when the load level is high, the filamentous bacteria diminish and a good sludge index is obtained. Between these, there lies an area where smaller differences in the load level are of yet great importance for the sludge index. Especially the middle area is of great importance for the practice of sewage purification by means of the oxidation ditch. Here a difference in load level of limited magnitude may mean the occurence or nonoccurence of difficulties in the separation of floc and purified effluent.
Some examples will illustrate this:
In the discontinuous system of figure 1a, we find great differences. In the oxidation ditch at Voorschoten, figure 6A, the situation is such that, when the sewage is pumped into the ditch, it is mixed up with a relatively limited amount of floc present on the bottom of the ditch in the vicinity of the inlet. This results in a load level which is certainly higher than in the example of figure 6B (situation in the oxidation ditch of the Psychiatric Institution Sancta Maria) where the influent is supplied via a gutter which ends immediatily above the water surface of the ditch.
The influent spreads over a large area of the ditch without being mixed with the sludge settled on the bottom of the ditch.

Figure 6.



At the beginning of the following aeration period, the influent is mixed with a large part of the floc in the ditch, resulting in a low level of load on the floc. In agreement with the above, the oxidation ditch at Voorschoten and that at the Psychiatric Institution Sancta Maria show a clear difference in sludge index; namely, 40-60 and 100-150, respectively.
In the oxidation ditches of the type fig. 1b, differences in the load level, and as a result in sludge index, may also be expected because of differences in the mixing situation of the influent with the mixed liquor, as indicated in figure 6C and 6D.

It was at this point of our investigation that Mr. Teerink of the Water Board of Rhineland, unaware of our research asked us if we could explain a phenomenon occuring in the oxidation ditch 'Rijndijk' at Hazerswoude. Here the low sludge index rapidly increased when the returnsludge was temporarily brought directly into the circuit, instead of being pumped to the pump pit, which is the normal procedure for this ditch. It will be understood that Mr. Teerink's observation is in complete agreement with the foregoing; in fact, the change indicated means a move from scheme fig. 2 towards scheme fig. 1b.
Mr. Teerink's question resulted in a visit to the water Board of Rhineland in order to find out whether there exists a relationship between the manner of supply of sewage and the sludge index in the oxidation ditches under supervision of the Board. The results are shown in Table II.
From this survey it appears that, in the ditches with scheme 1b, a good sludge index is attained in those cases where sewage and return sludge are mixed before being brought into the ditch. On the other hand, the sludge index is bad where sewage and return sludge are brought separately into the ditch. In ditches with a discontinuous operating process, the result varies.

In agreement with the foregoing, we further found that, in our experimental oxidation ditch, the index rose from 66 to 130, within two-weeks time after a change from scheme fig. 2 to scheme fig 1b. In the reverse situation it seems to take a much longer time before the sludge will get in good condition again. As a result of this, we may say that it really looks that in the application of the intermittently high floc load a determining factor by which the sludge index can be controlled has been found. When the index is not as desired in existing oxidation ditches, an improvement may be often achieved by relatively simple means: i.e. by mixing the sewage with return sludge or with mixed liquor before introducing it into the ditch.

Oxidation ditch name	type	Return sludge	Sludge-index
Zoeterwoude 'Hoge Rijndijk'	1b	Mixed with sewage in pumppit	35— 50
Nieuwkoop	1b		30— 45
Hazerswoude 'Rijndijk'	1b		60—100
Langeraar	1b	Direct into ditch	160—235
Koudekerk a/d Rijn	1b		140—260
Woubrugge	1b		100—200 mostly >150
Voorschoten	1a		40— 60
Rijnsaters-woude	1c		35— 55
Rijpwetering	1c		200
Kaagdorp	1c		200—400

TABLE II - *Oxidation ditches water board of Rijnland.*

In cases where an oxidation ditch has to be altered, extended, or newly designed, it is of importance to consider the insight gained.
In addition to the level of load during the process of mixing of sewage and floc, there certainly are other factors which may have an influence on the sludge index, such as the average floc load over the day (see mr. Rensinks paper), the composition of the waste, and the oxygen input. The phenomenon of the light sludge as a whole is a problem of great complexity.

Mr. President, Ladies, and Gentlemen, this would be the end of our lecture on the prevention and control of filamentous sludge in oxidation ditches if we did not owe you some further explanation concerning the operation scheme as it is now applied in our experimental oxidation ditch as indicated in fig. 2. The mixture of sewage and mixed liquor (ratio 1 : 3) leaving the mixing tank after an average detention time of 7½ minutes flows through the denitrification unit. In the present situations, this unit takes 1/6 of the volume of the oxidation ditch (300 l per inhabitant).

In this scheme, a nitrogen removal of 80 % can be achieved theoretically, if:

1. the nitrification process in the ditch is complete;
2. the amount of nitrate supplied to the denitrification unit is reduced completely;
3. 20 % of the nitrogen of the raw sewage is assimilated into bacterial protoplasm.

According to preliminary results, it appears that in the summer it will be possible to attain an 80 % nitrogen removal. A still higher percentage of removal might be achieved by reducing the oxygen supply to the oxidation ditch to some extent.
During winter time, it is more difficult to achieve a good result. In the present arrangement where the contents of the circular tanks are constantly stirred, at a temperature of 6 to 8 °C, no more than 50 % removal of the nitrogen is achieved. At these low temperatures, it is possibly not practical to maintain a zero oxygen content in a part of the ditch because of the danger of incomplete nitrification.
The research on nitrogen removal will be continued when a new oxydenitro plant is put into operation, within a month or two.
In the scheme of figure 2, it is furthermore indicated that lime (whitewash) is supplied to the mixed liquor on the way to the clarifier. The aim of this is to achieve removal of phosphates.
Mr. Karper will give a lecture on this subject tomorrow. This new method of phosphate removal will do not be dealt with in his lecture. This is indeed a new method. It is based on a laboratory investigation by Ferguson, Jenkins, and Eastman which was published in the April 1973 issue of the Journal of the Water Pollution Control Federation.
In this research, it was shown that phosphate can be removed with $Ca(OH)_2$ at a pH much below the value of 11.0-11.5 which has been regarded as necessary.
It proves to be possible to precipitate the

TABLE III - *Phosphate removal with $Ca(OH)_2$ at pH 8.5 - 9 (preliminary results).*

Period 1974	$Ca(OH)_2$ kg/d	Influent * p-total ppm	Effluent * p-total ppm	** COD ppm	% removed
29/1— 4/2	16	19	3	60	84.2
5/2—11/2	16	26	3.8	57	85.4
12/2—18/2	16	24	3.5	50	85.4
19/2—25/2	16	26.7	4.9	64	81.7
26/2— 4/3	16	27.3			
5/3—11/3	16	24.1	7.1	62	70.6
12/3—18/3	16	18.8	3.7	72	80.3
19/3—25/3	16	18.3	1.7	32	90.7
26/3— 1/4	16	20.7	3.3	49	84.—

* Continuous sampling.
** Inclusive some flocs.

phosphate as calcium hydroxyapatite at a pH between 7.5 and 9.0 if sufficient cores of calcium hydroxyapatite ($Ca_5(PO_4)_3OH$), formed during an incubation period, are present in the liquid. These cores are always present in high numbers in the sludge of our oxidation ditch.
By supplying the whitewash to the mixed liquor on its way from the ditch to the clarifier, a pH (for example, of 8.8) may be achieved which is a full unit higher than when the $Ca(OH)_2$ is supplied to the oxidation ditch.
In the present situation, 6 of 7 kg of the 16 kg of $Ca(OH)_2$ supplied per day are needed for neutralisation of the nondenitrified nitric acid.
When 16 kg of $Ca(OH)_2$ per day are supplied for 400 inhabitants, the costs amount to about *f* 1.75 per inhabitant per year (100 kg $Ca(OH)_2$ - *f* 12.—).

These costs can possibly be decreased by partly replacing the calcium hydroxide by waste caustic soda produced by some industrial works.
How encouraging the results with the method of phosphate removal are is shown in Table III. The investigated influent and effluent samples were obtained by continuous sampling.
It must be considered that the effluent of our small final clarifier will always contain some bacterial floc. On account of this, the phosphorus content of the effluent is somewhat increased (bij about 1 ppm).

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