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COMBINED NITROGEN AND PHOSPHORUS REMOVAL IN A LOW LOADED ACTIVATED SLUDGE SYSTEM OPERATING ON OXYDATION DITCH PRINCIPLES

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SUMMARY

Successfull experience in the operation of a low-loaded activated sludge system, in which a combination of nitrogen and phosphorus removal is applied, will be reported. Operating on domestic sewage the 500 P.E. plant on the experimental field of the TNO Research Institute yields even at $10^{o}C$ the following removal efficiencies of COD, N-tot and P-tot resp. $> 93\%$, $> 85\%$, and $> 85\%$. Nitrogen removal is achieved by biological denitrification, whereas phosphorus reduction is carried out in a simultaneous precipitation procedure with $Ca(OH)_2$ at slightly elevated pH values. The latter requires a Ca/P (wt/wt) ratio of ≥ 2 resulting in effluent pH values ranging from 8.4 - 8.8

1. INTRODUCTION

The oxydation ditch principle which was developed in our Institue in 1953 by Pasveer is characterized by a number of features which are well-known these days. The omission of the pre-setting tank and the sludge digestion step has been compensated for by the aerobic stabilization of the sludge within the aeration basin. The aerobic stabilization or mineralization of the sludge is achieved by a very low loading of the sludge i.e. 50 g BOD_5/kg MLSS.day resulting in a low sludge production of about 40 g sludge/P.E. day.
Corresponding with the loading level of this activated sludge system hydraulic detention times of 2-3 days are obtained.
Nowadays in Europe alone roughly 2000-3000 plants are in operation treating domestic and industrial sewage based on the oxydation ditch principles.
The practical applicability of biological denitrification in an oxydation ditch had already been demonstrated in 1964 by Pasveer (lit. 1). Based on this observation a number of patents have been granted (lit. 2), describing biological denitrification which can be obtained by alternation of the following processing steps: - mixing of influent with nitrified mixed liquor without oxygen supply - nitrification with oxygen supply - discharge of treated effluent etc.
This combination of oxydation and denitrification is called the oxydenitro process.

2. PRINCIPLES OF THE PRESENT PROCESS

Besides the high degree of BOD removal (98 - 99%) and almost complete nitrification which is obtained in the oxydation ditch, the present process includes nitrogen removal (> 85%) and phosphorus reduction (> 85%).

2.1 Nitrogen removal

The nitrogen removal is effectuated in two ways, viz:

- biological denitrification based on the oxygen requirements of the influent (denitrification I - rate: $r_{Den\ I}$)
- biological denitrification based on the endogenous respiration of the micro-organisms (denitrification II - rate: $r_{Den\ II}$)

In fact we notice here a combination of principles which have for instance been reported by Wuhrman (lit. 3) and Ludzack and Ettinger (Lit. 4). [see fig. 1]

2.2 Phosphorus removal

The application of calcium hydroxyde as a means to remove phosphorus is confined to pre-precipitation and post-precipitation procedures. When the requirements for P-removal are not too stringent i.e. when > 85% P-reduction or 2 mg P/l in the effluent are acceptable then $Ca(OH)_2$ can very well be applied in simultaneous precipitation at slightly elevated pH values (lit. 5 and 6). The calcium phosphate compounds are mainly precipitated as $Ca_5(PO_4)_3OH$-Calcium hydroxyapatite and leave the system together with the surplus sludge.

3. DESCRIPTION OF THE 500 P.E. PLANT OF TNO DELFT

The schematic lay-out of the plant is given in fig. 1. In basin 1 which is mildly stirred without oxygen supply influent is mixed with nitrified mixed liquor from basin 3 and return sludge. Nitrification and oxydation of the carbonaceous compounds of the influent take place in basin 2 and 3 at a controlled oxygen concentration of 2 mg/l. In basin 4 denitrification based on endogenous respiration is realized due to mildly stirring without oxygen supply. Post-aeration is carried out in basin 5 in which also $Ca(OH)_2$ is supplied to the system. The content of the plant without settling tank is $4 \times 37.8\ m^3 + 7.7\ m^3 = 158.9\ m^3$. Hence an influent flow of $4\ m^3/h$ means a hydraulic detention time of 40 h.

4. RESULTS AND DISCUSSION

The plant was set into operation in June 1974. The results of the period July 1974 - January 1975 will be discussed.

4.1 Operation conditions

The plant is supplied with domestic sewage of which the relative composition of the main components COD:N:P = 100 : 10 : 3,5. The incoming sewage has an average strength of 500 mg COD/l (tabel 1).
The mean sludge loading amounted 95 g COD/kg MLSS-day or 150 g COD/kg MLVSS. day. The ash content varied between 30 - 48% depending on the temperature and the amount of calciumhydroxyde which was supplied to the system. The latter was varied in view of the P-removal investigation
The influent flow was kept at 3 m^3/h till September 1974, afterwards the average flow amounted 4 m^3/h. The recirculation flow was varied between 9 - 15 m^3/h. Since November 1974 a constant flow of 12 m^3/h was maintained.
A typical example of the operation of this plant, in which 93% of COD reduction is obtained is given in fig. 3.

4.2 Nitrogen removal

The microorganism population which is present in a sewage treatment depend on the chemical composition of the influent, the temperature and the operation conditions of the system. Also the ability to nitrify and denitrify which is reflected by the rates of nitrification and denitrification is dependent on the composition of the micro-organisms population and the afore mentioned factors. The main purpose of the operation of the plant at our Institute is to establish reliable figures for nitrification and denitrification rates which can be expected in the organic fraction of the mixed liquor volatile suspended solids (MLVSS) which is obtained with domestic sewage at the existing operation conditions at various temperatures. To this end we carry out batch experiments with the activated sludge from the system at the actual system temperature, apart from the overall observation of the nitrogen removal in the 500 P.E. plant. Once more insight is obtained in the kinetics of nitrification and denitrification the operation of this system or analogous lay-out can be optimized. The main process parameters which can be used to minimize the nitrogen content in the effluent are (i) the relativeratio of the content of the denitrification and nitrification basins (ii) recirculation ratio (iii) sludge concentration.

4.2.1 Overall nitrogen balance

In the period July 1974 - January 1975 the average N-reduction amounted 87%. The effluent contained 13% N, which was mainly N as nitrate. The nitrifcation appeared to be almost complete, even at 10°C the N-kj amounted $\leq$ 1.5-2 mg N/l in the non-filtered effluent. The N-reduction of 87% consisted of 23% for assimilation in the sludge and of 64% as overall result of denitrification I and II.

4.2.2 Rates of nitrification and denitrification

During the investigation the temperature went down from 20 to 10°C (see table 1). The rates of denitrification and nitrification were slightly influenced by the decreasing temperature, which was probably caused by the change in micro-organisms population. The decrease in rate due to the temperature drop had apparently been counterbalanced by a relative increase in denitrification ability of the sludge. This aspect is also shown in table 1, in which only a reduction from 92 to 84% in N-removal efficiency is observed going from 20°C - 10°C. In the course of the coming year we shall gain more information about the temperature influence of the reaction rates. Assuming zero kinetics we obtained between December 1974 - January 1975 at 10°C

$$r_{Den\ I} = 1.1 \text{ mg } N\text{-}NO_3/\text{g MLVSS.h}$$

$$r_{Nitr.} = 1.6 \text{ mg } N\text{-}NO_3/\text{g MLVSS.h}$$

$$r_{Den\ II} = 0.5 \text{ mg } N\text{-}NO_3/\text{g MLVSS.h}$$

Indications are found that nitrification rates strongly decrease when the N-kj concentration drops below 1-2 mg N-kj/l. The same effect was observed with denitrification when the nitrate content went down below 1-2 mg $N\text{-}NO_3$/l.
The minimum amount of recirculation flow should be just high enough to maintain a nitrate concentration of $\geq$ 2 mg $N\text{-}NO_3$/l in basin 1. Then the conversion of nitrate to nitrogen will not be hindered to a large extend by the nitrate concentration.
It can be calculated that for the mentioned rates at 10°C a minimum recirculation flow of about 8.7 m^3/h (influent : recirculation = 1 : 2,2) should be applied resulting in a 85% N-reduction. In the same way the performance of other lay-outs can be predicted. For instance when basin 1 and 2 are used for denitrifi-

cation I and denitrification II is omitted a recirculation flow of 31 m^3/h (influent : recirculation = 1 : 7.7) will also yield 85% N-reduction at 10^oC. In the case of nitrification in basins 1 and 2 and denitrification II in basin 3 and 4 (hence no recirculation) the N-reduction at 10^o can be computed at 63%.

4.3 Phosphorus removal

$Ca(OH)_2$ was supplied to the plant in basin 5 at varying amounts. In table 1 the weight ratio of Ca-added as $Ca(OH)_2$ and P-tot. (in influent) Ca/P (wt/wt) is given in conjunction with the obtained P-reduction and corresponding pH-values of the effluent. Moreover in fig. 3 the Ca/P ratio has been plotted against the effluent phosphorus concentration. It appears that with simultaneous precipitation P-reduction of 85-90% or effluent values of ca. 2 mg P-tot/l can be obtained at Ca/P values ≥ 7. Then the effluent will have pH values varying from 8.4 - 8.8.
Per P.E. or about 3.5 g P/day is required a quantity of 24.5 g Ca or 45 g $Ca(OH)_2$. Taking into account a price of ƒ 0,10/kg $Ca(OH)_2$ the phosphorous removal costs as far as the chemical dose is concerned amounts to only ƒ 1.65/P.E. Year.

4.4 Sludge production

The sludge which is obtained in this method has good dewatering properties as for instance is noticed on drying beds. The sludge production will increase due to the formation of $Ca_5(PO_4)_3OH$ calcium hydroxy apatite and other calcium compounds. In this process we have measured in the first 6 months of operation an average sludge production of 53 g sludge/100 g COD with 40% ash. In comparison with the normal oxydation ditch sludge production we state tentatively that an increase of about 30% should be taken into account.

5. CONCLUSIONS

After the first half year of operation of this low loaded activated sludge system the following conclusions can be drawn.

1. Apart from a high COD reduction Nitrogen elimination to a high degree can easily be obtained. At 10^oC a N-reduction of 85% and at higher temperature even much better efficiencies turn out te be realistic values for this system.
2. The processes of denitrification and nitrification can approximately be described with zero-order kinetics. However it is observed that the rate of denitrification

strongly slows down below 1-2 mg $N\text{-}NO_3/l$. Also the rate of nitrification drops quickly below 1-2 mg N-Kj/l.

3. Phosphorus removal with $Ca(OH)_2$ in a simultaneous precipitation step is a simple and cheap method te eliminated >85% P. To this end a Ca/P (wt/wt) ratio of ≥ 7 should be applied resulting in effluent pH values ranging from 8.4 - 8.8. The corresponding increase in sludge production amounts about 50%.

Literature

1. PASVEER A.(1964) über den Oxydationsgraben. Schw.Zeitschr. f. Hydrologie XXVI, 446 - 485.

2. See for instance: CAN 956.733, BEL. 773.449.

3. WUHRMANN K. (1964) Stickstoff und Phosphorelimination, Ergebnisse von Versuchen in technischen Massstab. Schw.Zeitschr. f . Hydrologie XXVI, 520 - 528.

4. LUDZACK F.J. and ETTINGER H.B. (1962) Controlling operation to minimize activated sludge effluent nitrogen. J.Wat.Poll.Control Fed. 34, 920-931.

5. FERGUSON J.F., JENKINS D, and EASTMAN J (1973) Calcium phosphate precipitation at slightly alkaline pH value. J.Wat.Poll. Control Fed., 45, 620 - 631.

6. PASVEER A. and HEIDE B.A. (1974) Oxidation ditch: Prevention and Control of filamentous sludge. H_2O 7, 373 - 377.

TABLE 1

Overall Results of the 500 P.E. Plant (Period July 1974-Febr. 1975) *)

Date 1974	Temp. °C	COD mg/l			N-tot mg/l			P-tot mg/l			Ca/p wt/wt	pH Effluent	Influent m³/h	Recirculation m³/h
		Influent	Effluent	% Reduction	Influent	Effluent	% Reduction	Influent	Effluent	% Reduction				
29.7	20	436	48	89	41.0	3.2	92	–	14.7		–	7.70	3.0	9
12.8	22	467	37	92	39.2	8.0	80	24.7	12.0		–	7.70	3.1	9
19.8	21	405	40	90	39.3	4.0	90	10.0	9.7		**)	7.70	3.0	9
26.8	20	448	36	92	38.7	4.7	88	20.7	5.3		–	8.90	2.9	12
2.9	18	375	28	93	42.2	5.1	88	19.0	3.7	81	6.5	8.80	2.9	12
9.9	18	373	35	91	44.5	5.0	89	21.3	3.7	83	5.5	8.65	3.0	15
16.9	18	476	21	96	51.4	4.2	92	18.3	1.9	90	8.1	8.90	3.3	15
23.9	18	495	30	94	62.9	5.1	92	18.7					3.7	15
30.9	17	365	31	92	35.2	2.9	92	15.3	2.6	83	8.4	8.50	3.9	15
7.10	16	350	28	92	36.8	3.6	90	20.0	3.9	81	3.5	8.20	3.9	15
14.10	16	413	32	92	42.3	3.8	91	10.3	4.1	60	6.9	8.40	3.8	15
21.10	16	538	33	94	49.0	6.2	87	14.3	4.8	66	5.1	8.30	3.7	15
28.10	13	369	21	94	36.8	6.2	83	10.7	1.8	83	6.2	8.85	4.1	15
4.11	12	367	35	90	39.8	6.8	83	12.3	4.1	67	5.8	8.60	3.8	15
11.11	12	504	26	95	49.6	7.0	86		4.8			8.20	3.9	12
18.11	12	495	36	93	43.6	4.7	89	11.3	5.7	50	6.2	8.15	3.9	12
25.11	11	488	28	94	43.1	5.7	87	13.0	5.4	58	5.2	8.30	4.0	12
2.12	10	501	23	95	43.4	7.8	82	11.0	2.0	82	10.4	8.65	4.1	12
9.12	11	474	25	95	50.6	8.0	84	14.7	1.6	89	7.7	8.60	4.4	12
16.12	9	748	36	95	46.5	10.5	77	11.7	2.0	83	11.2	8.45	3.8	12
6.1.75	10	1321	35	97	50.1	5.1	92	34.0	5.7	83	4.5	8.40	3.3	12
13.1	10	525	38	93	54.9	8.9	84	15.7	1.8	89	8.1	8.45	3.9	12
20.1	10	568	42	93	57.3	9.3	84	18.0	1.8	85	9.1	8.50	4.6	12

* Effluent samples were analysed without prior filtration

**14.8.75 $Ca(OH)_2$ supply starts

FIG. 1: 500 P.E. Plant of TNO Delft

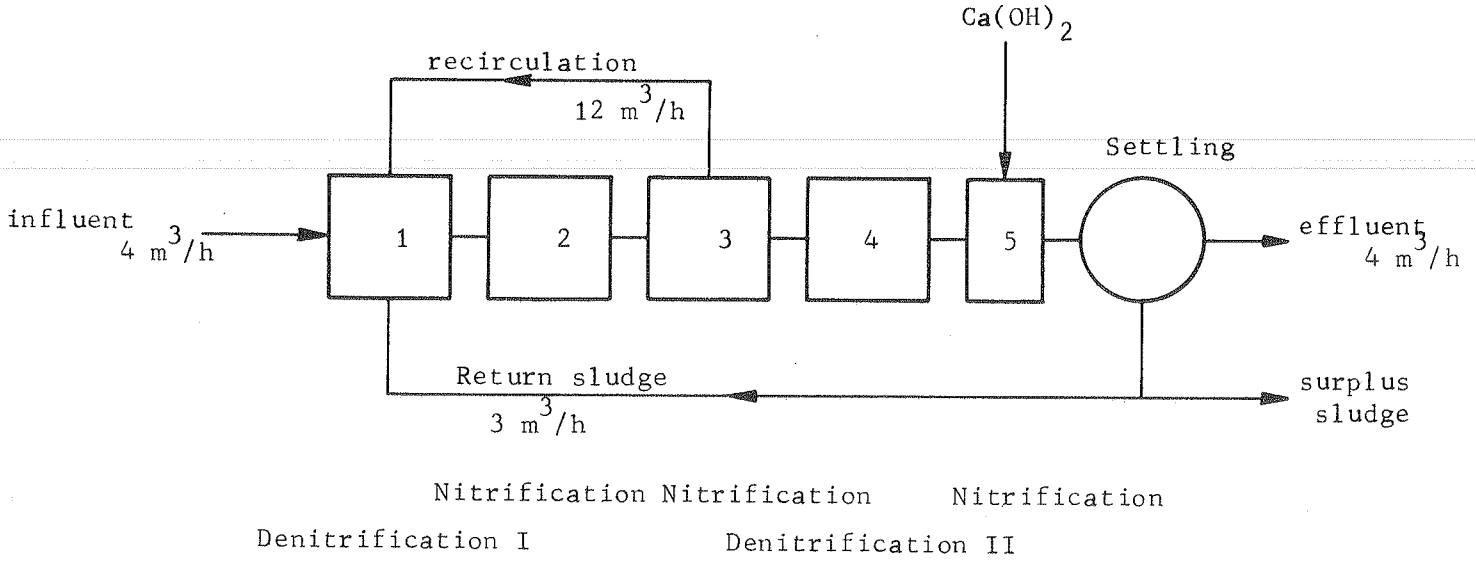

FIG. 2. Typical Example of Operation of this System (2.12.1974 - 10°C)

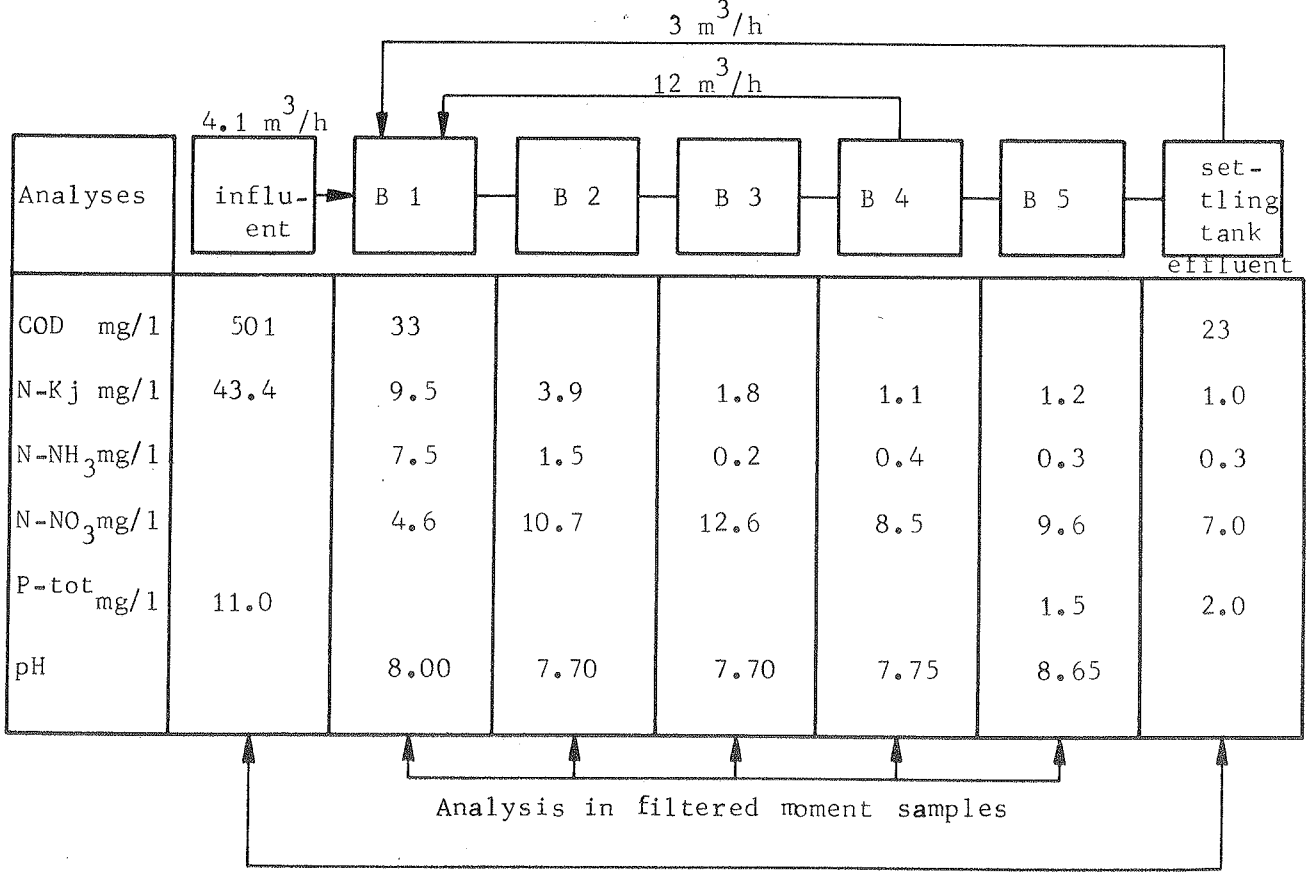

FIG. 3. Relation between Ca/P Ratio and P-Conc. in non-filtered effluent