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## MODERN TRENDS IN PLANTS DESIGN FOR THE REMOVAL OF NUTRIENTS FROM SEWAGE\*\*\*

An analysis of the world development trends in the biological removal of nitrogen and phosphorus from wastewater has been presented. Emphasis was placed on the modern biological removal methods based on the activated sludge biomass. The methods include: denitrification following biooxidation and nitrification, preliminary denitrification, two stage total denitrification conducted ahead and after the denitrification and simultaneous nitrification and denitrification in one tank. The method of combined removal of nitrogen and phosphorus in modified sludge process is presented. The advantages and disadvantages of particular methods efficiencies obtained are also included.

### 1. FOREWORD

The new Italian law (Bill No. 139 of May 10, 1976 "Rules for water pollution control"), requires all wastewater treatment plants to achieve total nitrogen and phosphorus removals down to  $10 \text{ mg/dm}^3$  and  $0.5 \text{ mg/dm}^3$ , respectively. The regulation concerns direct discharges into lakes or the indirect ones into rivers less than 10 km distant from coastline. Analogous consideration are made in the special law for water protection of the lagoon of Venice. Although the new law concerns primarily industrial wastewaters regional authorities have issued basically the same standards for all types of discharges.

Hence, designers of new treatment plants for both industrial and domestic wastewaters have to consider denitrification and phosphorus removal, whereas the existing plants shall have to be modified accordingly.

### 2. DENITRIFICATION

In spite of only a few applications of sewage denitrification facilities found in our country, the plant designers and potential purchasers have adequate experimental and full scale data to warrant full process reliability.

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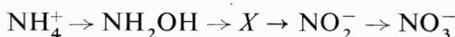
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Basically, two systems of denitrification are used: the chemical-physical and the biological. The former comprises breakpoint-chlorination, ion exchange, air stripping with prior pH raising, and ammonia transformation to chloramines with subsequent absorption on activated carbon. All these unit processes usually constitute tertiary treatment following the conventional biological treatment. Successful full-scale applications of these processes are rare due to high initial and operating costs in some cases and by plant design and operation difficulties in others.

### 2.1. DENITRIFICATION ON SUSPENDED CULTURES

Biological denitrification of sewage on suspended cultures has received the utmost attention and has been widely applied on full-scale. As known, nitrogen removal is obtained by nitrification followed by denitrification.

#### a) Nitrification



#### b) Denitrification (dissimilatory and assimilatory)



The biochemical mechanism of nitrification develops through the following steps: formation of hydroxylamine, of nitrites, and even before of a compound ( $X$ ), found in the assimilatory denitrification, too, which must be still studied for an exact identification. One of the most probable hypothesis is the formation of nitrosyl ( $\text{NOH}$ ) or of the relating dimer ( $\text{N}_2\text{O}_2\text{H}_2$ ).

Of the two processes for nitrate reduction, the assimilatory one (biomass production) is rather ineffective for nitrogen removal, so that when speaking of denitrification it is understood that the dissimilative process is considered. As a matter of fact, the sludge growth coefficient is supposed to approximately equal 0.4 mg VSS/mg  $\text{NO}_3\text{-N}$  [3]. In the hypothesis of a content of about 10% of nitrogen in the organic matter, it has been calculated that 0.04 mg N is assimilated per mg of  $\text{NO}_3\text{-N}$  removed. That is, only 4% is removed by assimilation, whereas nitrate reduction to gaseous nitrogen constitutes the predominant removal.

For the occurrence of the (dissimilatory) denitrification process, the simultaneous presence of a biodegradable organic substance is required which may act as oxygen acceptor (i.e. as an electron donor according to the wider concept of oxidation processes). For example, by taking methanol as a source of carbon, which moreover exhibits one of the highest denitrification rates, the denitrification reaction, apart from the intermediate compounds, may be written as follows:



A consumption of 2.5 mg  $\text{CH}_3\text{OH}/\text{mg NO}_3\text{-N}$ , assimilation inclusive, is calculated for this reaction.

The use of methanol or of another supplementary source of carbon involves rather high operating costs, which unfortunately are unavoidable with a number of industrial wastes of the inorganic type. In the case of sewage, denitrification may be conveniently carried out by taking advantage of the high content of biodegradable organic matter, even if the process rate is much lower as shown in fig. 1 [4]. In the practice, the advantages derived from the operating costs savings greatly predominate over the disadvantage of the increased dimensioning of the denitrification stage to the extent that the use of methal for sewage denitrification seems unjustified.

As a possible source of biodegradable organic matter, fig. 1 also reports the endogenous carbon, namely the very biomass that, as will be seen hereinafter, acquires some meaning in the post-denitrification process. In any case, the reduced denitrification rate of this process may be noticed since now.

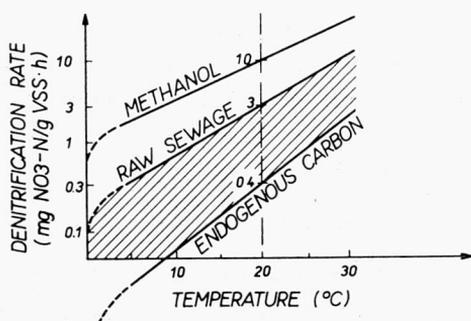


Fig. 1. Denitrification rates with suspended cultures, as a function of temperature and kind of organic substrate

The network represents the denitrification field of domestic sewages with internal carbon source, where it is actually difficult to distinguish the contributions of the two carbon sources, endogenous and biodegradable organic compounds in the raw sewage. It may be seen that through use of methanol as oxygen acceptor, the denitrification rates are more than three times as high as those allowed by the internal carbon sources [2]

Rys. 1. Szybkości denitryfikacji przy stosowaniu zawiesin kultur mikroorganizmów, jako funkcje temperatury i rodzaju podłoża organicznego

Siatka przedstawia obszar denitryfikacji ścieków miejskich przy wewnętrznym źródle węgla, gdzie trudno jest obecnie rozróżnić udział dwóch źródeł węgla w ściekach miejskich, endogenicznego i zawartego w organicznych związkach podlegających biodegradacji. Można zauważyć, że przy zastosowaniu metanolu jako akceptora tlenu tempo denitryfikacji jest ponad trzy razy większe niż osiągnięte przy zewnętrznym źródle węgla [2]

Hence by making use of internal sources of carbon, whether the raw sewage BOD or endogenous carbon, the biochemical denitrification reaction may, to a first approximation, be schematized as follows:



The organic matter consumption (assimilation inclusive) is estimated to equal about 4.5 mg BOD<sub>5</sub>/mg NO<sub>3</sub>-N. This ratio measures the lowest BOD availability in the denitrification stage for the almost complete removal of nitrogen (present in wastewater as nitrate).

## 2.2. PLANT DESIGN ALTERNATIVES

Provided that plant design alternatives must be looked for within the processes endowed with an internal source of organic carbon, the solutions shown schematically in fig. 2 may be considered as the most reliable.

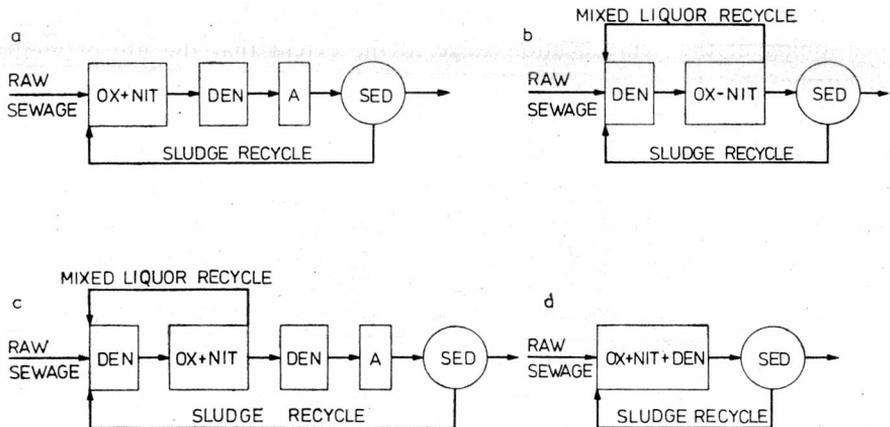


Fig. 2. Denitrification alternatives on suspended cultures that may be possible on plant level

Rys. 2. Warianty denitryfikacji na zawiesinach kultur, znajdujące zastosowanie w skali przemysłowej

a) denitryfikacje wtórne, b) denitryfikacje uprzednie, c) kompletne denitryfikacje uprzednie i wtórne, d) denitryfikacje jednoczesne  
 OX+NIT – oksydacja biologiczna z nityfikacją A – utlenianie dla ułatwienia się azotu; SED – sedimentacja osadu czynnego.

The post-denitrification process (fig. 2 a) was the first studied. Sewages derived from oxidation-nitrification stage have a low BOD content; therefore endogenous carbon is the actual carbon source for denitrification. As a consequence there are low denitrification rates and rather low efficiencies. Such drawbacks are at the basis of poor interest toward this method for full-scale applications.

In opposition to the above limitations, pre-denitrification has acquired importance (fig. 2b). On dimensioning this process, denitrification rates of 2–3 mg NO<sub>3</sub>—N ML VSS·h may be reasonably assumed compared with the 0.3–0.5 values that may be attributed to post-denitrification. The indicated values are related to the standard temperature of 20°C. For an adjustment to the real temperature, the following expression may be used

$$RD_t = RD_{20} \cdot 10^{k(t-20)}$$

where  $RD_t$  and  $RD_{20}$  represents the denitrification rates at temperatures  $t$ (°C) and 20°C, respectively,

$k$  is the temperature coefficient experimentally calculated as  $0.06^\circ\text{C}^{-1}$ .

In the pre-denitrification process, the nitrates reduced to gaseous nitrogen are contained in recycle flows (sludge and oxidized mixed liquor), the nitrogen in the raw sewage essentially being ammonia and organic nitrogen. A low-loaded oxidation process with activa-

ted sludges may be expected to cause about 20% nitrogen removal by assimilation. In the hypothesis to operate with a recycle rate of 100% (e.g. with the recycle sludge only and by excluding the oxidized mixed liquor recirculation), a nitrogen removal of 50% over residual nitrogen is attained at the most. To conclude, the actual overall removal should equal approx. 60%. Higher removal efficiencies may be obtained by increasing recirculation, preferably of the oxidized mixed-liquor, in order to avoid solid overloadings in the sedimentation stage. However, in order to obtain efficiencies above 85%, overall recirculation ratios higher than 5 are required.

An interesting full-scale application of pre-denitrification, is offered by the plant at Rye Meads, which originally operated as conventional activated sludge plant (plug-flow type) and which was subsequently to attain a higher efficiency of nitrogen removal. To that purpose aeration was stopped in the initial section of the activated sludge plant, with a volume equalling 25% the total volume, and slow stirrers were set up in it with the purpose to maintain biological sludge in suspension. The sludge recirculation was kept at 100%. With an operating sludge loading of about 0.15 kg BOD<sub>5</sub>/kg ML SS per day, average daily results shown in table 1 were obtained.

Table 1

Average daily results obtained at the Rye Meads plant, England, respectively, by the conventional plant and that adjusted to obtain pre-denitrification.

Average sludge loading: F/M = 0,15 kg BOD<sub>5</sub>/kg ML SS per day [3]

Przeciętne dzienne wyniki w Rye Meads (Anglia) przy zastosowaniu oczyszczarki konwencjonalnej oraz dostosowanej do wstępnej denitrifikacji. Przeciętne obciążenie osadu F/M = 0,15 kg BZT<sub>5</sub>/kg ML zawiesin dziennie

| Parameter   | Influent<br>biological<br>treatment | Effluent              |                   |
|---|-------------------------------------|-----------------------|-------------------|
|   |                                     | conventional<br>plant | modified<br>plant |
| – BOD <sub>5</sub> mg O <sub>2</sub> /dm <sup>3</sup> | 205                                 | 7.3                   | 8.4               |
| – COD mg O <sub>2</sub> /dm <sup>3</sup>              | 375                                 | 38                    | 49                |
| – NH <sub>3</sub> mg N/dm <sup>3</sup>                | 34.5                                | 0.4                   | 0.4               |
| – TKN mg N/dm <sup>3</sup>                            | 48.8                                | 2.3                   | 2.8               |
| – TN mg N/dm <sup>3</sup>                             | 48.8                                | 40.4                  | 21.2              |
| – SS mg/dm <sup>3</sup>                               | 103                                 | 7.6                   | 16.5              |

Such a 50% increase in total nitrogen removal, yielded the receiving River Lee waters, used as potable water supply nitrogen content below 11 mg/dm<sup>3</sup>, i.e. the limit for drinking water recommended by the World Health Organization to prevent infantile cyanosis.

When a more complete nitrogen removal is required, instead of disproportionately increasing recirculation in pre-denitrification, it is convenient to perform complete denitrification, as shown in fig. 2c. The recirculation flows of both oxidized mixed-liquor and sludge constitute the key variables for process dimensioning. According to calculations related to the technical and economical profitability, the oxidized mixed-liquor recircula-

tion must be of the order of 250–350% of the average raw sewage flow, whereas — due to the above reasons — the recirculation sludge should be kept within 100–150%. The final aeration is exclusively done to volatilize the nitrogen and to avoid sludge flotation in the final clarifier.

The nitrification stage is calculated on the basis of a nitrification rate of 150–250 mg N/g NVSS·h (at 20°C), where NVSS is the fraction of mixed liquor volatile (ML NSS) constituted by nitrifying bacteria. Estimating the nitrifying bacteria concentration at 1–2% in the activated sludge under nitrification condition, the nitrification rate referred to ML VSS may be conservatively evaluated to be 1.5–2 mg N/g ML VSS·h (at 20°C). The adjustment to temperatures below 20°C may be made by the expression:

$$RN_t = RN_{20} 10^{k(t-20)}$$

where

$RN_t$  and  $RN_{20}$  — nitrification rates at temperatures  $t$  and 20°C, respectively,  
 $k$  — temperature constant equalling  $0.05(^{\circ}\text{C})^{-1}$ .

The nitrification rates correspond the sludge loading and at 0.12–0.17 kg BOD<sub>5</sub>/kg ML SS·d some 90% NH<sub>3</sub> nitrification is found for domestic sewage at 16°C. Smaller sludge loading should be applied when larger nitrogen removals are required.

Only few full-scale pre-denitrification and complete denitrification (pre-and post-denitrification plants are in operation, and although they yield satisfactory reproducible performance simultaneous denitrification has already gained much wider applications. It is carried out in closed-circuit activated sludge basins in which the mixed liquor is aerated and simultaneously circulated fixed turbine surface aerators or alternatively by brush rotors (fig. 3). On circulating, the mixed liquor alternatively passes through highly aerated zones (downstream of the aerators) and oxygen-depleted zones (upstream of the aerators), where, respectively, nitrification and denitrification occur. In practice, complete denitrification (fig. 2 c) occurs with the difference that the alternation of aerated and anoxic zones repeats several times, i.e. as many time as is the number of the operating aerators. A number of plants of this type already operate in Holland where aeration and circulation are induced by vertical-axis fixed turbines and operated at sludge loading of 0.05 kg BOD<sub>5</sub>/kg ML SS·d. The advantages offered by such a solution essentially consist in the high operating stability, high BOD removal, low excess sludge production with high degree of stabilization and good dewaterability and simultaneous nitrogen removal by biological denitrification. This last feature is interesting, since annual taxes on all treated effluent discharges to surface waters in Holland are based on the amount of residual BOD<sub>5</sub> and TKN as well as on flowrate.

Due to low sludge loadings, no separate sludge stabilization is required. No primary clarifiers are used similarly to all schemes reported for denitrification processes. The main reason is to avoid any decrease in the carbonaceous BOD contribution later badly needed for denitrification.

The above mentioned advantages achieved by these plants — in comparison with the conventional systems — are offset by the higher power consumption for extended aeration

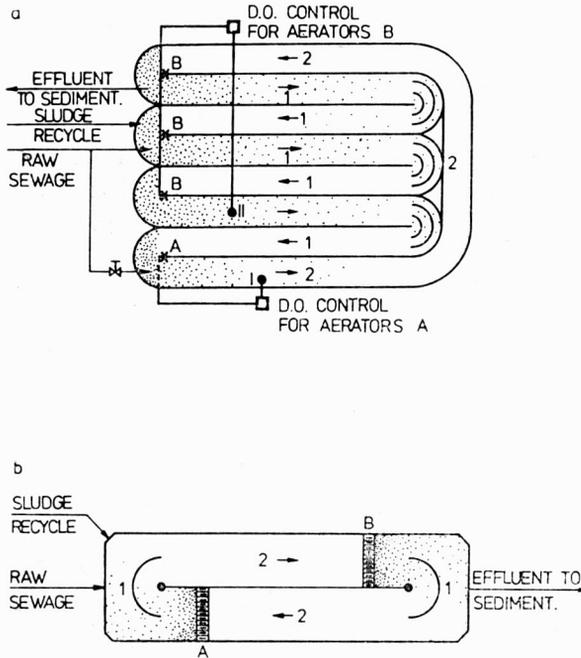


Fig. 3. Biological stage of plants with simultaneous denitrifications

a) turbine-type surface aerators, b) brush-type surface aerators.

In both cases, the mixed liquor is subjected to circulatory motion through oxygen-rich and anoxic zones where nitrification and denitrification process, respectively, occur

Rys. 3. Etap biologicznego oczyszczania z jednoczesną denitryfikacją

a) napowietrzacze powierzchniowe typu turbinowego, b) napowietrzacze powierzchniowe typu siatkowego.

W obu przypadkach mieszanina odcieku jest puszczona w obieg i krąży po strefach bogatych i ubogich w tlen, gdzie zachodzą odpowiednie procesy nityfikacji i denitryfikacji

1 — strefa bogata w tlen, 2 — strefa uboga w tlen

and larger volume of tanks due to the increased overall volume required to achieve denitrification. In any case, in the design phase, care should be taken that the BOD load in the oxidation stage be extensively limited by BOD<sub>5</sub> removal through denitrification. At the other hand the higher power consumption is reduced by the biochemical reuse — in the denitrification stage — of oxygen present in nitrates, for the BOD<sub>5</sub> oxidation.

Comparing the various alternative plant systems for nitrogen removal it appears that complete denitrification system is better than the simultaneous one due to the optimal dimensioning of the whole process. Actually, since the oxidation and denitrification areas are well characterized and distinct, a reliable evaluation of the results must be done based on determination of the denitrification and nitrification rates for each process phase. On the other hand simultaneous denitrification foresees several intermediate denitrification stages, each having a different nitrogen removal rate, which ranges from the highest value (pre-denitrification) to the lowest one (post-denitrification or endogenous denitrification). That is why an accurate dimensioning can be hardly done, being further compli-

cated by the continuous change in the extent of both aerated and anoxic areas following the variability of raw sewage composition.

As a direct consequence, the results obtained are less convincing than those supplied by complete denitrification plants, of equal size.

An advantage offered by simultaneous denitrification is the plant simplicity as slow stirrers are not required in the denitrification basins as well as no external recirculation of the mixed liquor is needed; the process having such a configuration that inner recirculation takes place. Furthermore the system has considerable operating flexibility, and yields itself to control — either automatical (through dissolved oxygen probes) or manual — and by regulating the submergence of aerators the extension of both aerated and anaerobic areas can be adjusted. Among the peculiar characteristics of the simultaneous process, mention should be made of the high stability toward overloadings and inputs of toxic or inhibitory compounds. The particular sensitivity of nitrifying bacteria towards compounds causing inhibitory effects on the bacterial flora of activated sludge is experienced. Table 2 shows the molar concentration of a series of compounds causing a 75% inhibitory effect on the activity of nitrifying bacteria.

Table 2

Molar concentrations of a series of compounds, at which a 75% inhibition of the nitrifying bacteria has been determined  
Stężenie molowe serii związków przy których określono 75% hamowania bakterii nitryfikujących

| Compound          | Concentrations<br>(mols/dm <sup>3</sup> ) |
|-------------------|---|
| Thiourea          | $1.0 \cdot 10^{-6}$                       |
| Thioacetamide     | $7.0 \cdot 10^{-6}$                       |
| Thiosemicarbazide | $2.0 \cdot 10^{-6}$                       |
| Phenol            | $6.0 \cdot 10^{-5}$                       |
| Aniline           | $8.3 \cdot 10^{-5}$                       |
| Sodium cyanide    | $2.4 \cdot 10^{-5}$                       |
| Ethanol           | $5.0 \cdot 10^{-2}$                       |
| Acetone           | $3.5 \cdot 10^{-2}$                       |
| Chloroform        | $1.5 \cdot 10^{-4}$                       |

Very little is known of the influence of toxic compounds on the denitrifying bacterial flora; early data indicate a lower sensitivity as compared with that of the nitrifying one. The above considerations indicate the effects that combining domestic and industrial wastewaters, may have on the correct performance of a biological plant with denitrification.

Temperature is another important factor here. As to the denitrification processes ( $k = 0.06^\circ\text{C}^{-1}$ ), each  $5^\circ\text{C}$  decrease in temperature corresponds to a process rate decrease

of 50%, while about 44% is assumed for the nitrification processes. As demonstrated, pH may also considerably affect, the activity of nitrifying and denitrifying bacteria (as clearly shown in figs. 4 and 5, at pH < 7). In simultaneous denitrification systems, the raw sewage is diluted and dispersed with the recirculation flow hence, the effects of inhibitory substances are considerably diminished.

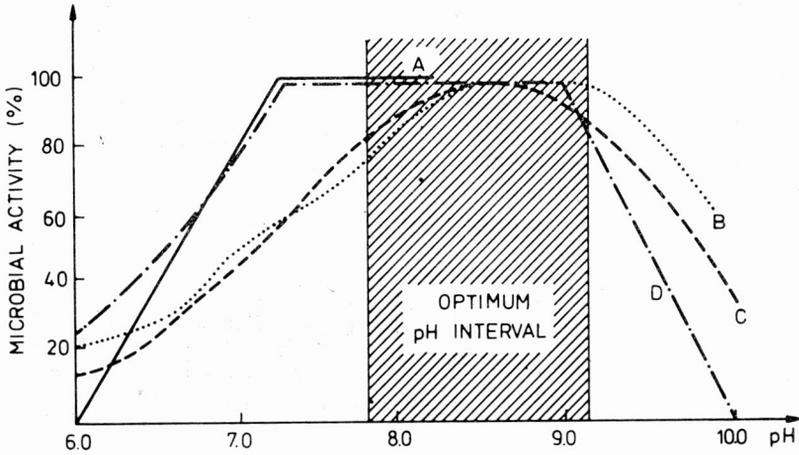


Fig. 4. pH effect on the activity of nitrifying bacteria according to different authors

The optimal field ranges between pH 7.8 and 9.1. Considerable reductions in activity are found at pH lower than about 7.2 [8], [9], [10], [7]

Rys. 4. Wpływ pH na aktywność bakterii nityfikacyjnych według różnych autorów

Optymalny zakres waha się od 7,8 do 9,1. Stwierdzono, że przy pH < 7,2 aktywność znacznie się zmniejsza. [8], [9], [10], [7]

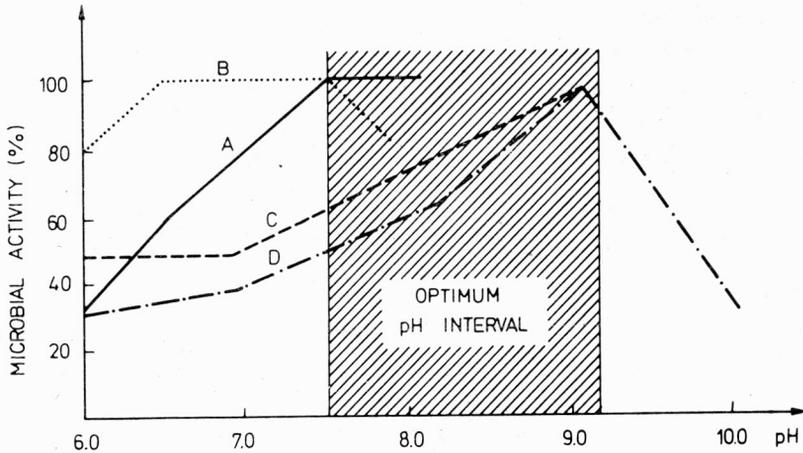


Fig. 5. pH effect on the activity of denitrifying bacteria according to different authors. The optimal field ranges between pH 7.5 and 9.1; [8], [9], [10], [7]

Rys. 5. Wpływ pH na aktywność bakterii denityfikacyjnych według różnych autorów. Optymalny zakres pH w granicach od 7,5 do 9,1; [8], [9], [10], [7]

The correct operation of simultaneous denitrification plants — especially those of high capacity — the oxygenation power must be automatically controlled by the aerator submergence via monitoring signals sent by the automatically cleaned oxygen probes, placed along the final section of the aerated zone where oxygen concentration is of the order of 1.5–2 ppm. Oxygenation control may be also conveniently integrated by the automatic halting of some aeration units. In this case, the mixed liquor must be kept circulating at a sufficient rate to avoid sludge sedimentation.

Examples of full-scale activated sludge plants with simultaneous denitrification should include the Winterswijk plant, Holland, equipped with turbine aerators and the plant at Wien Blumental, equipped with brush-type aerators.

The Winterswijk plant serves 77,000 population equivalents (PE) of which some 53,000 PE are contributed by industry. At the sludge loading  $F/M = 0.05$  kg BOD<sub>5</sub>/kg MLSS·d, with 3 aerators operating — the plant yielded (Aug. 30–Aug 21, 1974) 98.9% BOD<sub>5</sub> removal (from 354 down to 4 mg O<sub>2</sub>/dm<sup>3</sup> in the effluent) and some 90.9% total nitrogen removal (from 63 to 5.7 mg N/dm<sup>3</sup>).

The Vienna Blumental plant [12] with 200,000 inhabitants has 24 rotor brushes installed — of which 12 are operating. The results, at  $F/M = 0.11$  kg BOD<sub>5</sub>/kg MLSS·d, are 95% BOD<sub>5</sub> removal and 88% total nitrogen removal (effluent of 4 mg N/dm<sup>3</sup>). At  $F/M = 0.13$  kg BOD<sub>5</sub>/kg MLSS·d these values are 93% for BOD<sub>5</sub> and 82% for N<sub>tot</sub> (effluent 4 mg N/dm<sup>3</sup>). The power consumption was 0.82–0.93 kWh/kg BOD<sub>5</sub> removed.

Interestingly, the power consumption at the Vienna plant is only slightly above (10–15%) that of a conventional activated sludge ( $F/M = 0.3$  kg BOD<sub>5</sub>/kg MLSS·d; OC/load = 1.6 kg O<sub>2</sub>/kg BOD<sub>5</sub>). As already mentioned it is the consequence of the oxygen recovery from nitrates for an aerobic biodegradation of the organic matter and for their concomitant reduction to gaseous nitrogen. However, by also taking into account the amount of BOD<sub>5</sub> removed in the primary sedimentation stage of a conventional plant (about 25%), the highest energy consumption should be of the order of 30%. Higher consumptions (up to 70%) may be expected when the plant with simultaneous denitrification is run with very low sludge loadings in order to achieve a higher degree of sludge stabilization and a higher nitrification and denitrification efficiency.

### 3. PHOSPHORUS REMOVAL

Phosphorus removal from sewage is generally obtained by chemical precipitation. Any possible discussion on this long tested process may exclusively concern the choice among the alternative methods (pre-treatment, simultaneous treatment, post-treatment) that may be realized on a real scale as an integrating part of the conventional biological treatment.

On weighing the pros and cons of all methods, the chemical pre-treatment appears the most convenient from the economic standpoint since it allows considerable reductions in the BOD<sub>5</sub> load (of the order of about 60%) on the subsequent biological treatment.

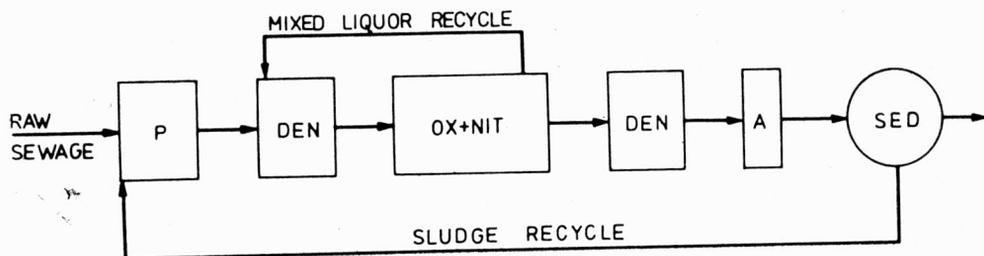


Fig. 6. Layout of activated sludge treatment with biological removal of nitrogen and phosphorus P — anaerobic phase for phosphorus release, DEN — denitrification, OX+NIT biological oxidation with nitrification, A — aeration for nitrogen volatilization, SED — activated sludge sedimentator

Rys. 6. Schemat oczyszczania osadem czynnym z biologicznym usuwaniem azotu i fosforu — faza bez-tlenowa dla uwalnienia fosforu, DEN — denitryfikacja, OX+NIT — utlenianie z nitryfikacją, A — napowietrzanie dla uwolnienia azotu, SED — sedymentator osadu czynnego

The phosphorus removal efficiency may be evaluated at about 90%. The method, which is largely applied in the Scandinavian countries, presents some applicative limits: the phosphorus removal must be adjusted to the phosphorus needs for the bacterial flora of the biological stage. The difficulty of strictly controlling this requirement, conditions the final result of the chemical-biological treatment; hence final concentrations of residual phosphorus below 0.5 ppm can hardly be obtained.

The chemical treatment simultaneous with the biological one involves quite low additional investment costs and, as opposed to primary precipitation, it does not arouse problems concerned with the sufficient phosphorus availability for activated sludge. However it yields poorer efficiency mainly because of the conveyance of chemical precipitates in the supernatant of the final sedimentation. As an estimate, it seems justified to expect final residual phosphorus concentrations ranging from 0.5 to 1 ppm for both the chemical pre-treatment and the simultaneous treatment.

The effect of chemical precipitates on the activity of activated sludge and on the anaerobic flora of digestors is not such as to considerably affect the process efficiency even if the microbiological equilibrium is partly modified. In fact, an improvement of the sludge volume index is generally observed in the simultaneous treatment due to the disappearance of filamentous microorganisms, whereas in experimental runs of anaerobic digestion of chemical (based on  $Al^{+++}$ ) and organic sludges, a process slow-down has been observed.

In respect to other methods, the chemical post-precipitation offers evident technical advantages — higher BOD removals and suspended solids below  $0.5 \text{ mg/dm}^3$  may be expected. The limits of this method essentially consist in the higher amount of reagent required, higher sludge production and a much higher investment capital than is needed for pre-treatment and simultaneous treatment.

Among all developments achieved in the field of sewage purification technology, much interest has been recently aroused by the biological method for phosphorus removal. Pilot-plant research works, which were later confirmed in full scale, have shown that, under particular conditions, the biomass of activated sludge systems can uptake much

(2.5 wt. — % as  $\text{PO}_4$  in respect to volatile solids) [1], [17]. This phenomenon, generally higher phosphorus quantities than would follow from commonly occurring concentrations reported in the literature as "luxury uptake" takes place when the sludge, previously subjected to anaerobic conditions, is aerated in the presence of the nutrient substrate. In the anaerobic phase, the polyphosphatase enzyme is believed to catalyse the phosphorus release from bacterial cells thus causing an internal unbalance later made up for in the aerobic phase, by phosphorus accumulation as polyphosphate granules. The major role in phosphorus removal seems to be played by facultative denitrifying bacteria [11], [13].

One of the conclusions from reported research is that phosphorus release is bound to the absence of both dissolved oxygen and of nitrates. Hence as essential condition for process commencement is that the sewage is subjected to complete denitrification. Activated sludge systems, capable of performing the biological phosphorus removal, operate according to the scheme illustrated in fig. [15], [16].

The anaerobic area dimensioned for a retention time of about 2 hrs. Phosphorus adsorption, which already starts in the anoxic pre-denitrification area, is completed in the aerated zone.

In South Africa, where the most significant research work in the field has been carried out, full-scale plants are already being built. The Goudkoppies plant (Johannesburg, about 250,000 PE capacity) and the modified plants at Olifantsvlei and Alexandra (Johannesburg) should be mentioned.

The interest aroused by this innovative process has promoted analogous initiatives in other countries. In Italy full-scale and demonstration plants are either in the design or in the construction phase. Wider documentation on the reproducibility of the results and the minimum phosphorus concentrations attainable is still required before universal application of the process.

Finally, novel nutrient removal treatment trains should be mentioned. In Italy the feasibility of a process comprising of lime treatment, ammonia stripping and medium — high load biological treatment is being presently investigated in an experimental plant scale.

#### REFERENCES

- [1] AZAD H. S., BORCHARDT J. A., *Variations in phosphorus uptake by algae*, Environ. Sci. Technol. Vol., 4 (1970), p. 437.
- [2] BALTEY D. A., PHIL M., THOMAS E. V., *The removal of inorganic nitrogen from sewage effluents by biological denitrification*, Water Research Centre (Stevenage Laboratory), Reprint, 1976.
- [3] CHRISTENSEN M. H., HARREMOES P., *A literature review of biological denitrification of sewage — Conference on nitrogen as a water pollutant — Copenhagen, 18–20th August 1975*.
- [4] CHRISTENSEN M. H., HARREMOES P., *Nitrification and denitrification in wastewater treatment*, Contribution to "Water Pollution Microbiology", Vol. 2, Ed. Mitchell, Copenhagen, August 1976.
- [5] CLAYFIELD G. W., *Respiration and denitrification studies on laboratory and works activated sludge*, Water Pollution Control, 1974, 73.
- [6] DOWNING A. L., KNOWLES G., *Population dynamics in biological treatment plants*, 3rd IAWPR Conf., Munich 1966.

- [7] EDHOLM L., HULTMAN B., LÖWEN M., SVEN-NILSSON E., *Närsaltreduction. Fortsatta Försök Over denitrification kinetic (Nutrient reduction. Continued studies on denitrification)*, KTH Publ. 70: 1, Stockholm 1970.
- [8] VAN DER GEEST A. T., WITVOET W. C., *Nitrification and denitrification in carrousel systems*, Progress in Water Technology, Vol. 8 (1977), Issue 4/5.
- [9] HUANG C. S., HOPSON N. E., *Temperature and pH effect on the biological nitrification process* — Presented: Ann. Winter Meeting, N.Y. WPCA, New York City, Jan. 1974.
- [10] IDE T., TOHYA Y., SUZUKI Y., MATSUO, OSANAI M., *Removal of nitrogen and phosphorus in waste treatment*, Pachec 72, Session 10-3, 1972.
- [11] MARDSEN M., MARAIS G. V. R., *Role of the primary anoxic reactor in denitrification and biological phosphorus removal*, Research Report § 19, July 1976, University of Cape Town, South Africa.
- [12] MATSCHE N. F., SPATZIERER G., *Austrian plant knocks out nitrogen*, Wastewater Treatment, January 1975.
- [13] MCLAREN A. R., WOOD R. J., *Effective phosphorus removal from sewage by biological means*, Water S.A., Vol. 47(1976), pp. 47-50.
- [14] MULBARGER G. C., *Nitrification and denitrification in activated sludge system*, Journal Water Pollution Control Federation, Vol. 43 (1971), p. 2059.
- [15] OSBORN D. W., NUCHOLS H. A., *Optimization of the activated sludge process for the biological removal of phosphorus*, International Conference on advanced treatment and reclamation of wastewater.
- [16] SAWYER C. N., WILD H. E., MC MAHON T. C., *Nitrification and denitrification facilities*, E.P.A. Technology Transfer Seminar Publication, EPA 1973.
- [17] SHINDALA A., *Nitrogen and phosphorus removal from wastewater, Part I.*, *Water Sewage Works*, June 1972.

#### NOWE KIERUNKI W PROJEKTOWANIU OCZYSZCZALNI DO USUWANIA SUBSTANCJI BIOCHEMICZNYCH ZE ŚCIEKÓW

W pracy przedstawiono syntetyczną analizę światowych tendencji rozwojowych w zakresie usuwania związków azotu i fosforu ze ścieków w drodze biologicznej. Główną uwagę poświęcono omówieniu nowoczesnych metod biologicznego usuwania azotu w środowisku wodnym w mieszaninie z biomasą osadu czynnego. Omówiono metody: denitryfikacji wtórnej po utlenianiu i nityfikacji, denitryfikacji wstępnej, całkowitej denitryfikacji prowadzonej w 2 stopniach przed i po nityfikacji oraz metodę denitryfikacji symultanicznej prowadzonej w jednej komorze z nityfikacją. Omówiono także metodę połączonego usuwania azotu wraz z fosforem w procesie zmodyfikowanego osadu czynnego. Podano wady i zalety poszczególnych metod, uzyskiwane wyniki oraz wytyczne do ich stosowania.

#### MODERNE TRENDE IN DER PROJEKTIERUNG VON ABWASSER-REINIGUNGSANLAGEN VERBUNDEN MIT DEM ENTZUG VON BIOGENEN STOFFEN

Der Beitrag beinhaltet eine synthetische Analyse der Tendenzen die zum Entfernen von Stickstoff und Phosphor auf dem biologischen Weg dienen. Besonderes Augenmerk ist der Besprechung der Stickstoffbeseitigung aus dem Abwasser mittels Belebtschlamm gewidmet. Beschrieben werden: die sekundäre Denitrifikation nach Oxydation und Nitrifikation, die primäre Denitrifikation, die zweistufige Denitrifikation (vorgenommen vor und nach der Nitrifikation) sowie das Simultanverfahren, das im Nitrifikationsbecken vorgeht. Danach wird die Methode der gemeinsamen Beseitigung von Stickstoff und Phosphor im modifizierten Belebtschlammverfahren erläutert. Dargelegt werden die Vorzüge und Nachteile der genannten Methoden, erreichbare Resultate sowie Richtlinien für deren Anwendung.

## НОВЕЙШИЕ ТЕНДЕНЦИИ В ПРОЕКТИРОВАНИИ ОЧИСТНЫХ СТАНЦИЙ С ТОЧКИ ЗРЕНИЯ УДАЛЕНИЯ БИОХИМИЧЕСКИХ ВЕЩЕСТВ ИЗ СТОЧНЫХ ВОД

В работе представлен связный анализ тенденций в технике удаления соединений азота и фосфора биологическим путем из сточных вод. Главное внимание уделено обсуждению новейших методов биологического удаления азота в водной среде в смеси с биомассой активного осадка. Обсуждены методы: вторичной денитрификации после окисления и нитрификации; предварительной денитрификации; полной денитрификации, производимой на двух ступенях: до и после нитрификации; денитрификации, проводимой в одной камере с нитрификацией. Обсужден также метод совместного удаления азота и фосфора при процессе модифицированного активного осадка. Приведены преимущества и недостатки отдельных методов, а также получаемые результаты. Даются указания относительно применения методов.