Nutrient dosage in biological treatment of wastewaters

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ABSTRACT: Discharge loads from activated-sludge treatment of wastewater can be unnecessarily high if nutrient dosages to the process are incorrect. This paper presents a method of controlling nutrient dosages based on calculation of nutrient balances and simultaneous monitoring of dissolved nutrient levels in the treated effluent. In the example cited here, a mill using this approach had very low discharge loads, with total nitrogen of 2–3.5 mg/L and total phosphorus of 0.2–0.4 mg/L. The method prevents nutrient-dosage errors arising from process disturbances such as temporary oxygen depletion or fluctuating pH. It also lowers costs by reducing nutrient overdosing and rectifies nutrient imbalances throughout the sludge residence time.

KEYWORDS: Activated sludge process, biological treatment, dosage, effluent treatment, monitoring, nutrients, waste waters.

More than 30 activated-sludge treatment plants were built in Finland in the 1980s and early 1990s. Because of the nature of Finland's waterways, low nutrient discharges were considered an important goal. However, the initial targets were not generally achieved, and phosphorus and nitrogen discharges did not begin to decline appreciably until 1989, as seen in **Fig. 1**. Nevertheless, this decrease was obtained despite a substantial simultaneous growth in production. Aside from production-process modifications, the main reason for the decline in nutrient discharges has been the introduction of new methods for nutrient dosing.

Three dosing methods have been used.

1. The traditional method is to base nutrient dosages on the organic content of the influent. The ratio of nutrient to organic content is determined empirically.
2. A second approach is to monitor the content of dissolved nutrients in the effluent and maintain the outgoing nutrients near some target level.
3. The third method seeks to minimize changes in nutrient levels in the activated-sludge plant while monitoring and controlling dissolved-nutrient levels in the effluent.

Results achieved in Finland suggest that fairly low nutrient discharge levels can be achieved using the last two methods. Calculation of nutrient balances is particularly advantageous in situations where process control is disturbed.

Nutrient balance

The nutrient balance is calculated from the nutrient amounts entering and leaving the treatment process. When additional nutrients are required, typically nitrogen, the amount needed is usually determined by monitoring the dissolved nutrient concentration in the effluent.

For dosing purposes, total nitrogen and phosphorus in the influent, effluent, and in the excess sludge are measured. The amounts are often double-checked, usually by measuring the dissolved nitrogen and phosphorus contents of the effluent as well.

Typical guidelines for dissolved nitrogen and phosphorus in effluent are 2–3 mg/L and 0.05–0.1 mg/L, respectively. Dissolved nutrients refers to the total nutrient con-

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centration after removal of suspended solids by filtration. The Finnish standard method for suspended solids filtration is to use a GF/A glass-fiber filter (Whatman) with a pore size of 1.6 µm.

For dosing purposes the nutrient balance is determined as follows:

Nutrient content of influent = nutrients in wastewater from process plus added nutrients

Nutrient discharge = nutrients discharged with effluent and nutrients discharged in excess sludge

Nutrient content of influent = Nutrient discharge

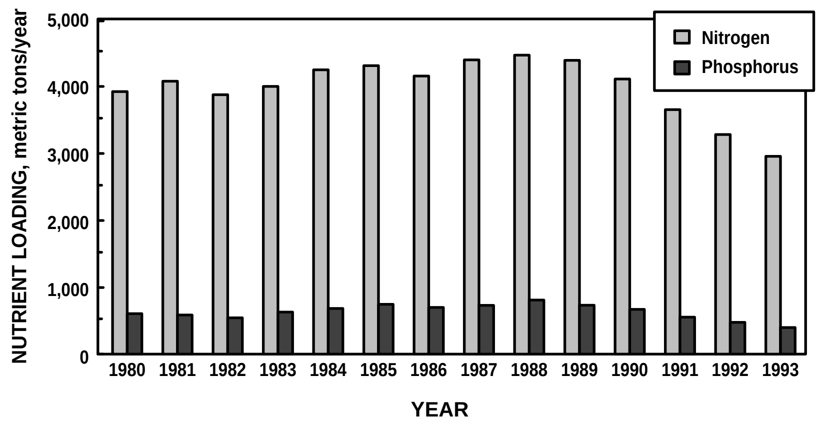
The dissolved nutrient level in the effluent can be controlled by the nutrient dosage to the process. However, it is vital to adjust the dosage correctly so that the treatment process never lacks nutrients. Phosphorus from the kraft process often exceeds the amount needed for the treatment process.

This balancing method is successfully being used in Finland to determine nutrient dosages in the forest industry's activated-sludge processes and aerated ponds. The method can also be used to determine dosages for anaerobic treatment. The major errors that have occurred when using this method have usually been due to analytical errors in determining the total phosphorus and nitrogen in the sludge.

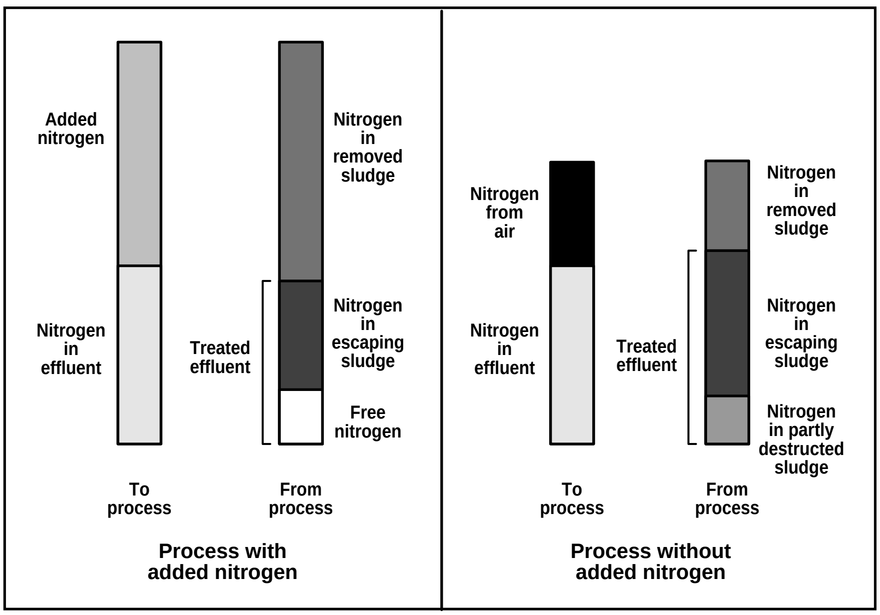
Monitoring sludge nutrient contents

Critical to nutrient balancing is understanding that the microorganism's life span is short compared with its mean cell residence time (sludge age) in the activated-sludge process and aerated pond. Microorganisms are consumed in the process, so allowances must be made for reutilization of nutrients. Phosphorus is only known to be discharged from the process with the effluent and with the excess sludge.

1. Phosphorus and nitrogen loadings for the Finnish pulp and paper industry, 1980–93



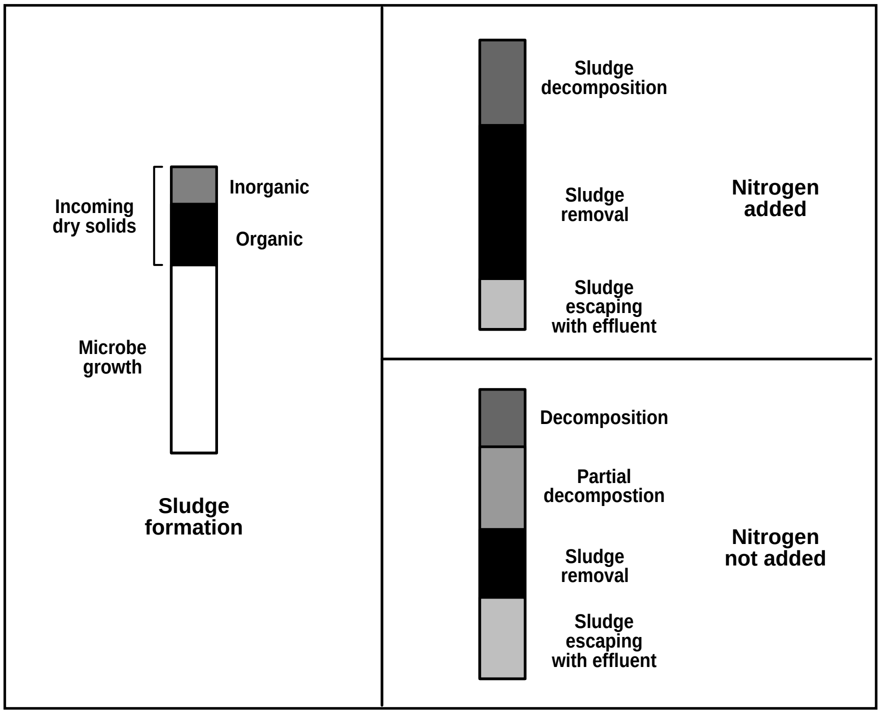
2. Nitrogen balance for activated-sludge plants with and without nitrogen addition



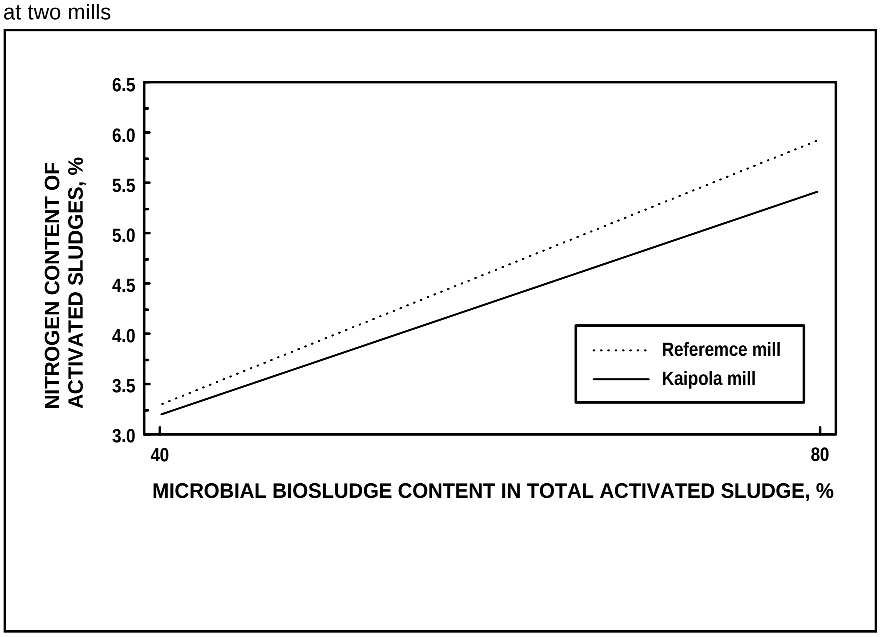
Nitrogen discharge is slightly more complex.

In the aerobic treatment of forest-industry wastewaters, it has been shown that if the dissolved nitrogen in the effluent does not exceed 1.5–2 mg/L, microorganisms will obtain nitrogen from the air. This accelerates degradation of biological sludge and leads to increases in effluent chemical oxygen demand (COD), suspended solids, and nutrient discharge. These trends are apparent in **Figs. 2 and 3**.

3. Sludge formation and removal with and without nitrogen addition



4. Nitrogen content of activated sludge as a function of sludge microbial content for sludges at two mills



The nitrogen and phosphorus contents of activated sludge appear to depend mainly on the amount of biomass in the sludge. **Figure 4** shows the results for nitrogen achieved in 1993–94 at United Paper Mills, Kaipola. Biosludge content was calculated from the plant's COD removal, sludge age, and temperature, the last of which affects the sludge decomposition rate. The factors used to calculate biosludge content were determined from measurements made at the plant.Comparisons with results obtained at other plants have shown some significant differences in sludge phosphorus contents. As seen in Fig. 4, the differences in nitrogen contents are smaller.

Nutrient dosage can also be determined without monitoring the nutrient balance, but instead monitoring dissolved nutrients in the treated effluent. However, this approach has caused process disturbances. The main cause was that dissolved nutrient in the treated effluent increased for reasons other than overdosage. Possible causes of error could be oxygen deficiency in aeration, abnormal pH, or influent containing mineral oil toxic to microorganisms.

Mill example

United Paper Mills Ltd., Kaipola, produces 550,000 tons/year of wood-containing printing paper. The mill has a two-line activated-sludge plant. The two lines were constructed at different times.

The aeration basin uses bottom aerators. The basin in the front sections has aerated selectors. The plant has a volumetric loading capacity of 0.8–1 kg BOD_7/m^3/day and a sludge loading of 0.2 kg BOD_7 per kilogram of sludge per day. (BOD_7 is a measure of the biochemical oxygen demand over seven days.) The secondary clarifier has a surface loading of 0.6 $m^3/m^2/h$.

For two years, the mill based its nutrient dosage on the nutrient-balance method. This method of process operation was improved by installing an advanced control (expert) system. The control system involves measuring nutrient balances as a function of time. The system then corrects imbalances (over- or under-dosage) over a period of time corresponding to the sludge age. The aim is to avoid the unnecessary fluctuations in nutrient dosage that, in most cases, result from analytical error.

Nutrients in the influent, added nutrients, and nutrients in the effluent (January 1992 through May 1993) are shown in **Figs. 5 and 6** for phosphorous and nitrogen, respectively. It can be seen that nutrient discharges have decreased. The nitrogen feed has been reduced by about 65%, and the phosphorus feed is now very low or zero.

Nutrient processing has eliminated process disturbances. Dissolved BOD in the treated wastewater has been zero to 5 mg/L, which demonstrates the benefits of the biological process. The low phosphorus and nitrogen levels have not given rise to any obvious process disturbances, such as growth of filamentous microorganisms.

Nutrient control in future wastewater treatment

The nutrient dosages needed for treatment of kraft process wastewaters is changing. The increased use of extended cooking and oxygen delignification has reduced the phosphorus discharged from bleaching. This means that phosphorus discharges from more kraft mills can be controlled with the nutrient-balance method.

The use of nitrogen-containing chelating agents in hydrogen peroxide and ozone bleaching is becoming more common. The biodegradable portion of these chelators is put to use in the treatment plant.

The nutrient-balance method appears quite useful in controlling nutrient discharges. The phosphorus content in untreated wastewater is often high enough to make further addition unnecessary. The forest industry can continue to reduce nutrient discharges by further reducing suspended solids using flotation and filtration.

Conclusions

Use of the nutrient-balance method in the forest industry's activated-sludge processes and aeration basins and facultative ponds has produced several benefits:

- Reductions in nutrient discharge from the treatment system
- Fewer process disturbances (No disturbances have occurred because of low nutrient levels.)
- Decreased nutrient consumption and, consequently, lower costs.

The nutrient-balance method for dosage can be used on a daily basis by proper monitoring of nutrients. The nutrient balance should be corrected not once but throughout the entire sludge residence time.

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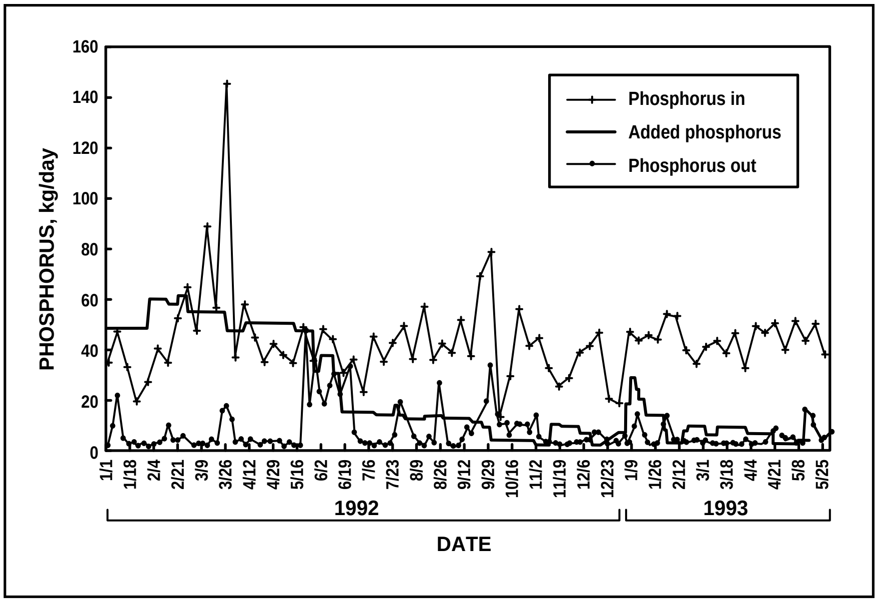
5. Phosphorus addition and phosphorus loading of the activated-sludge plant between January 1992 and May 1993



6. Nitrogen addition and nitrogen loading of the activated-sludge plant between January 1992 and May 1993