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PHOSPHORUS REMOVAL IN EXTENDED AERATION PLANTS

This study is devoted to the removal of phosphorus by biological activated sludge alone. The experiments were carried out in large laboratory scale (model units) and two packaged plants. In all three cases the values of main activated sludge parameters were:

- aeration time — over 1 d,
- sludge loading — about 0.1 kg BOD_5/kg MLSS·d,
- MLSS concentration — about 6.0 kg/m³.

The obtained results of phosphorus removal were described by the following relations:

$$\frac{100 P_{rem}}{COD_{rem}} = 328 \left(\frac{COD}{P}\right)^{-1.38}, \tag{1}$$

$$\eta_P = 537 \left(\frac{COD}{P}\right)^{-0.5}, \tag{2}$$

$$\eta_P = 37.7 + 49.7 \log O_P \tag{3}$$

which have been found for COD:P rations in raw sewage from 50:1 to 313:1.

1. INTRODUCTION

Phosphorus removal from wastewater is usually connected with chemical precipitation which may be applied to different locations of sewage treatment process. However, it is well known that phosphorus can also be removed in biological way alone. Up today the mechanism of biological phosphorus removal has not been well defined. There are two main trends in literature, which do not exclude themselves. According to the first one, phosphorus removal occurs by the chemical precipitation caused by some metal ions present in sewage, mainly calcium. The second one states that phosphorus is removed in biochemical processes exclusively. The results obtained in various plants cover a wide range of 20–95 percent, providing that the process is very complicated and depends on various factors. The influence of some of them was already investigated, but mainly in laboratory tests, with artificial sewage and pure bacterial cultures or with conventional activated sludge.

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CARBERRY and TENNEY [1] have reported that amount of dissolved oxygen and aeration rate are the significant factors controlling phosphorus removal. Optimum aeration rate was 315 cm^3 air/min dm^3. WITHEROW [6] have found that phosphorus removal does not occur at all when DO levels in aeration basin range within 0.2–0.4 mg/dm^3. When DO levels were brought up to 1.5 or even up to 5.3 mg/dm^3 the removal efficiency increased to 70 percent.

Dissolved oxygen level and aeration rate are moreover responsible for the release of phosphates from sludge, and consequently for increased phosphorus amount in effluent [3], [6]. According to HULCHER, RANDALL, KING [3] the release rate is strongly inhibited by high F: M ratios.

The best effect of phosphorus removal was obtained by MORGAN and FRUH [4] for COD:P ratio of 220: 1. It has been determined for artificial sewage, pure cultures and sludge loading of 2 kg COD/kg VSS day. STALL and SHERRARD [6] found the maximum phosphorus removal efficiency (72.9 percent) at COD:P ratio of 126.5:1 for artificial wastewater and sludge loading of 0.34–1.00 kg COD/kg VSS day. They have also stated that the removal efficiency increases with increasing the COD: P ratio or the decreasing mean cell residence time.

The efficiency of phosphorus removal depends essentially on the ability of activated sludge to incorporate this element [1], [4], [6]. A typical activated sludge contains on the average 2–3 % of phosphates with respect to organic dry weight. Under specific conditions this content may increase up to 6 or even 8 percent (so called "luxury uptake") [1], [4], [6]. It results in higher efficiency of phosphorus removal reaching even 95 percent.

According to some investigators [3], [6], the efficiency of phosphorus removal does not depend on aeration time, MLSS concentration and pH value.

The purpose of this paper was to find experimentally a relationship between the amount of raw sewage's substrates (COD, P) and the efficiency of phosphorus removal in the extended aeration system.

2. DISCUSSION OF THE RESULTS

The investigations were carried out in the model units and in two small packaged plants at Rakoniewice and Oleśnica, from July to November 1977 and in June and July 1978. Influent, effluent and the aeration basin were controlled at least once a week by following determining BOD_5, COD, total phosphorus, total nitrogen, total suspended solids and volatile suspended solids. Besides these tests the rate of wastewater and amount of excess sludge were measured. The plant at Oleśnica received wastewater from household, alcohol distillery, slaughter; cow sheds, and piggeries and at Rakoniewice from the winery, gaswork, slaughter, the dairy and household. The investigations in the model units were carried out on wastewater from the city of Poznań. Table 1 shows the most important indices of the wastewater quality and main parameters of activated sludge process. The amount of the total phosphorus in the influent received by the model unit was twice lower than in

Table 1

The most important features characterizing quality of sewage and main activated sludge parameters
Najważniejsze wskaźniki charakteryzujące jakość ścieków oraz podstawowe parametry procesu osadu czynnego

	Units	Oleśnica plant			Rakoniewice plant			Model plant		
		min	max	mean	min	max	mean	min	max	mean
Influent C:N:P ratio		27:6:1	117:16:1	—	19:3:1	62:5:1	—	16:3:1	94:6:1	—
Influent COD:P ratio		61:1	313:1	—	50:1	179:1	—	43:1	252:1	—
Influent total phosphorus	mg P/dm^3	7.2	20	12.4	7.3	29.4	13.9	3.4	17.5	6.5
Activated sludge loading	kg BOD_5/kg MLSS day	0.045	0.28	0.13	0.03	0.20	0.10	0.06	0.13	0.09
Aeration time	h	33.6	72	46	18	30.5	25	—	—	27
MLSS concentration	kg/m^3	1.7	6.1	4.0	6.7	9.4	7.8	2.1	3.8	2.9
Phosphorus activated sludge loading	g P/kg VSS day	1.47	3.75	2.33	0.86	2.93	2.38	1.10	3.80	1.95
Phosphorus removal efficiency, P	%	21	67	48	40	95	68	22	73	49
COD removal efficiency	%	82	98	91	87	97	92	64	96	92

the influent received by the treatment plants at Rakoniewice and Oleśnica. Nevertheless, the average loadings of sludge with phosphorus expressed as the ratio of total phosphorus to volatile suspended solids were similar (table 1).

Comparing the value of C:N:P ratio in examined wastewater with the optimum value for development of microorganisms (106:16:1) it can be stated that the former contained the excess of phosphorus. With respect to nitrogen and organic carbon the data obtained were used to examine dependences of percentage of the total phosphorus removal and the ratio of the reduced total phosphorus to reduced COD on the following factors:

— loading of the activated sludge with total phosphorus, O_P, g P/kg VSS day,

— COD:P ratio in raw wastewater,

— mean cell residence time, τ, days, and the total phosphorus to COD removed ratio.

The P_{rem}/COD_{rem} ratio was chosen to correlate the efficiencies of (η_P) phosphorus and organic compounds removal [4]. Significant correlations have been stated in only three cases (table 2). The curve $P_{rem}/COD_{rem} = f(COD/P)$ shown in figure 1 indicates that with

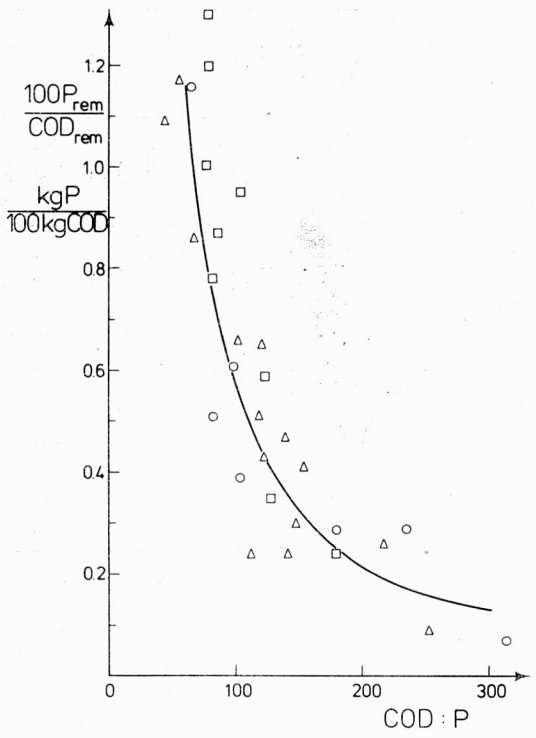

Fig. 1. P_{rem}/COD_{rem} ratio as a function of the influent COD:P ratio

o — data from the Oleśnica plant; □ — data from the Rakoniewice plant; △ — data from the model units.

Rys. 1. Zależność stosunku $P_{rem}/ChZT_{rem}$ od stosunku ChZT:P w odpływie;

o — wyniki z oczyszczalni ścieków w Oleśnicy, □ — wyniki z oczyszczalni ścieków Rakoniewicach, △ — wyniki z oczyszczalni ścieków w skali modelowej

Table 2

Equations developed from the experiments
Zestawienie zależności wyprowadzonych na podstawie badań

Relationship	Number of results	Linear correlation coefficient r_{xy}	Equation	Range of applicability	Percent level of significance
$\frac{P_{rem}}{COD_{rem}} = f\left(\frac{DOD}{P}\right)$	32	0.82	$\frac{100\,P_{rem}}{COD_{rem}} = 328\left(\frac{COD}{P}\right)^{-1.38}$	$43 < \frac{COD}{P} < 313$	1%
$\eta_P = f\left(\frac{COD}{P}\right)$	32	0.55	$\eta_P = 537\left(\frac{COD}{P}\right)^{-0.5}$	$46 < \frac{COD}{P} < 313$	1%
$\eta_P = f(O_P)$	30	0.43	$\eta_P = 37.7 + 49.7 \log O_P$	$0.86 < O_P < 3.8$	5%

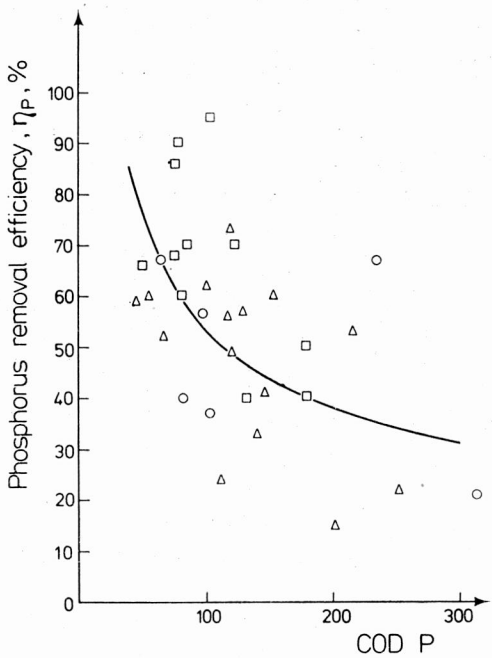

Fig. 2. Phosphorus removal efficiency as a function of the influent COD:P ratio

o – data from the Oleśnica plant; □ – date from the Rakoniewice plant; △ – data from the model units

Rys. 2. Zależność stopnia obniżenia fosforu od stosunku ChZT:P w dopływie;

o – wyniki z oczyszczalni ścieków w Oleśnicy, □ – wyniki z oczyszczalni ścieków w Rakoniewicach, △ – z oczyszczalni ścieków w skali modelowej

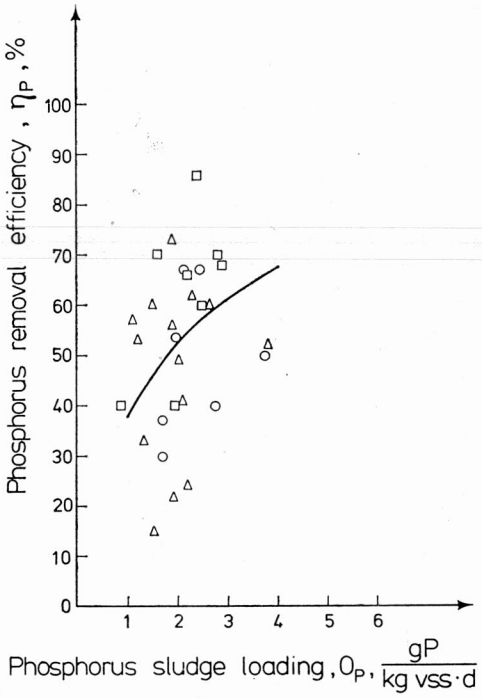

Fig. 3. Phosphorus removal efficiency as a function of the phosphorus sludge loading
o – data from the Oleśnica plant; data from the Rakoniewice plant; △ – data from the model plant

Rys. 3. Zależność stopnia obniżenia fosforu od obciążenia suchej masy organicznej osadu ładunkiem fosforu
o – wyniki z oczyszczalni ścieków w Oleśnicy, □ – wyniki z oczyszczalni ścieków w Rakoniewicach, △ – wyniki z oczyszczalni ścieków w skali modelowej

the increasing raw sewage COD:P ratio the ratio of P_{rem}/COD_{rem} decreases. Moreover, for the values of COD:P less than 150:1, thus in deficiency of carbon compounds, the amounts of phosphorus removed rise rapidly (P_{rem}/COD_{rem} ratio increases). The fact that the P_{rem}/COD_{rem} ratio increases, at relatively high value of COD removed confirms the character of the above mentioned relationship. If the values of COD:P are then 150:1 the P_{rem}/COD_{rem} quotient decreases slowly. Figure 2 indicates also that when the COD:P ratio in wastewater increases the efficiency of phosphorus removal decreases. The rate of phosphorus removal efficiency increase more rapidly within the range of the decreasing values of COD:P (below 150:1) than within the range of higher values. The curve in figure 3 shows that the higher phosphorus sludge loading results in increased efficiency of phosphorus removal. Although the character of this relationship is rather unexpected it does not contradict curves shown in figures 1 and 2. Hence, it seems that phosphorus can be better removed biologically from the wastewater if it is in excess. It should be noted however, that the character of correlations derived has been stated within a limited range of O_P values shown in table 2.

3. CONCLUSIONS

The relationship described by the equation (2) is contradictory to that obtained by STALL and SHERARD [6]. In the latter case the authors performed their investigations on synthetic wastewater at high loadings of activated sludge, low MLSS concentration and short aeration time, which in our research was performed under conditions of food starvation, (low loading of activated sludge) and long aeration time. It seems probably that under such conditions phosphorus contained in wastewater is maximally utilised by microorganisms present in activated sludge. The higher was the phosphorus content in the influent the higher was its removal efficiency. This observation has been confirmed by the relations (1) and (3) derived successively. In the expression $P_{rem}/COD_{rem} = f(COD/P)$ connects the ability of activated sludge to remove both organic and phosphorus compound.

The efficiency of phosphorus removal achieved in our investigations, being relatively high if compared to literature data, can be also due to sorption of phosphorus and its enmeshing in activated sludge flocs. From quantitative viewpoint, it may be of some importance at high MLSS concentrations in aeration tank.

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USUWANIE FOSFORU W OCZYSZCZALNIACH Z OSADEM CZYNNYM O PRZEDŁUŻONYM CZASIE NAPOWIETRZANIA

Artykuł poświęcono usuwaniu fosforu w oczyszczalniach ścieków z nisko obciążonym osadem czynnym o przedłużonym czasie napowietrzania, bez dodawania koagulantów. Celem pracy było znalezienie i opisanie zależności między ilością doprowadzanych do procesu substratów a efektem usuwania fosforu przez osad czynny. Badania prowadzono w skali modelowej oraz technicznej (na dwóch małych zblokowanych oczyszczalniach ścieków typu Bioblok).

Osad czynny pracował przy następujących parametrach:

- obciążenie osadu — ok. 0,1 kg BZT_5/kg sm·d,
- czas napowietrzania ścieków — powyżej 24 h,
- koncentracja osadu w komorze — około 6,0 kg/m^3.

Uzyskane wyniki pozwoliły na opisanie wspomnianych zależności następującymi równaniami:

$$\frac{100P_{zred}}{ChZT_{zred}} = 328\left(\frac{ChZT}{P}\right)^{-1,38} \quad \text{dla } 43 < \frac{ChZT}{P} < 313,$$

$$\eta_P = 53\left(\frac{ChZT}{P}\right)^{-0,5} \quad \text{dla } 46 < \frac{ChZT}{P} < 313$$

$$\eta_P = 37,7+49,7 \lg O_P \quad \text{dla } 0,86 < O_P < 3,8.$$

ZUR PHOSPHORELIMINIERUNG DURCH LANGZEITBELÜFTUNG

Besprochen wird die Phosphoreliminierung mittels schwach belastetem Belebtschlamm in Langzeitbelüftungsanlagen ohne Zugabe von Fällmitteln. Gesucht wurde nach dem Zusammenhang zwischen der zugeführten Substratmenge und der Phosphor-Abbaurate durch den Belebtschlamm. Geforscht wurde sowohl im Labormaßstab wie auf zwei volltechnischen Kompaktanlagen (Typ Bioblok).

Die grundlegenden Betriebsparameter waren:

Schlammbelastung	ca. 0,1 kg BSB_5/kg TS.d,
Belüftungszeit	mehr als 24 h,
Schlammkonzentration	ca. 6,0 kg TS/m³.

Die empirischen Formeln lauten wie folgt:

$$\frac{100P_{red}}{CSB} = 328\left(\frac{CSB}{P}\right)^{-1,38}, \text{ bei } 43 < \frac{CSB}{P} < 313,$$

$$\eta_P = 53\left(\frac{CSB}{P}\right)^{-0,5}, \text{ bei } 46 < \frac{CSB}{P} < 313,$$

$$\eta_P = 37,7+49,7 \lg O_P, \text{ bei } 0,86 < O_P < 3,8.$$

УДАЛЕНИЕ ФОСФОРА НА ОЧИСТНЫХ СТАНЦИЯХ С АКТИВНЫМ ИЛОМ ПРОДЛЕННОЙ АЭРАЦИИ

Статья посвящена удалению фосфора на станциях для очистки сточных вод с низконагруженным активным илом продленной аэрации, без введения коагуляторов. Цель работы заключалась в построении формул для зависимости между количеством подвергаемых процессу субстратов и результатами удаления фосфора активным илом. Испытания проводились в модельном и техническом масштабах. Активный ил работал при следующих параметрах: нагрузка осадка — ок. 0,1 кг $БСК_5$/кг см; время аэрации — более 24 ч; концентрация осадка в камере — ок. 6,0 кг/м³. Благодаря полученным результатам стало возможным описание упомянутых зависимостей с помощью соответствующих уравнений.