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RECENT DEVELOPMENTS IN THE TECHNOLOGY OF WASTEWATER TREATMENT

Present technological development of the wastewater treatment in the United States as well as the world over is summarized in the paper. A number of process combinations including biological, physical and chemical, which are technically feasible to produce treated wastewater effluents of varying degrees of quality, are described and the guidelines are given that enable the selection of the optimum process combination to yield the least cost, depending upon the volume and characteristics of the wastewaters and upon the availability and cost of chemicals and equipment.

NOMENCLATURE

- F/M — Biomass loading or food to microorganism ratio, g BOD₅/g MLVSS.d;
obciążenie biomasy osadu czynnego, g BZT₅/g s.m.o. d;
- COD_{inf} — Soluble COD of the activated sludge basin influent, g/m³;
— ChZT rozpuszczone w dopływie do komory osadu czynnego, g/m³;
- COD_B — Nondegradable organics generated in activated sludge process, g/m³;
biochemicznie nierozkładalne metabolity organiczne powstałe przy oczyszczaniu ścieków osadem czynnym, g/m³;
- BOD_u — Influent soluble ultimate BOD, g/m³;
całkowite rozpuszczone BZT dopływu, g/m³;
- BOD_t — Total BOD of the activated sludge effluent at any time, g/m³;
ogólne BZT odpływu z osadnika wtórnego w dowolnym czasie t, g/m³;
- BOD_a — Soluble BOD under summer operating conditions, g/m³;
BZT rozpuszczone w warunkach eksploatacyjnych pory letniej, g/m³;
- S_0 — Influent soluble substrate concentration, BOD/m³ or g COD/m³;
stężenie substratów rozpuszczonych w dopływie, g BZT/m³ lub g ChZT/m³;

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- S_{oa} – Summer average influent soluble BOD, g BOD/m³;
 średnia wartość rozpuszczonego BZT dopływu w okresie letnim, g BZT/m³;
 S_e – Effluent soluble substrate concentration, g BOD/m³ or g COD/m³;
 stężenie rozpuszczonych substratów w odpływie g BZT/m³ lub g ChZT/m³;
 N_{inf} – Influent soluble nitrogen, g N/m³;
 zawartość azotu rozpuszczonego w dopływie, g N/m³;
 P_{inf} – Influent soluble phosphorus, g P/m³;
 zawartość fosforu rozpuszczonego w dopływie, g P/m³;
 SS – Effluent suspended solids.
 Zawiesina ciała stałego w odpływie;
 X_e – Average biomass concentration in the activated sludge basin, g MLVSS/m³;
 zawartość biomasy w komorze osadu czynnego, g S.M.O./m³;
 ΔX_e – Sludge yield (in g MLVSS/d) divided by daily wastewater flow (in m³/d);
 g MLVSS/m³;
 przyrost osadu (w g s.m.o./d) podzielony przez dobowy przepływ ścieków
 (w m³/d), g s.m.o./m³;
 x – Biodegradable fraction of the mixed liquor volatile suspended solids;
 rozkładalna biochemicznie frakcja suchej masy organicznej osadu czyn-
 nego;
 B – BOD equivalent of the biodegradable fraction of effluent suspended
 solids, g BOD/g SS;
 BZT odpowiadające rozkładalnej biochemicznie frakcji zawiesin odpływu,
 g BZT/ g zawiesin;
 F – Factor for variability in product mix;
 współczynnik zmienności składu mieszaniny;
 t – Detention time, d;
 czas przetrzymania, d;
 k – rate constant biochemical reaction;
 stała szybkości reakcji biochemicznej;
 θ – Temperature coefficient;
 współczynnik temperaturowy,
 T – Temperature, K;
 temperatura, w K;
 T_a – Average summer, temperature, K;
 średnia temperatura, w K;
 MLVSS – mixed liquor volatile suspended solids, g MLVSS/m³;
 Sucha masa organiczna osadu czynnego, g S.M.O./m³;

Water quality requirements in the future will consider, in addition to BOD and suspended solids, non-degradable organics (COD or TOC), nitrogen and phosphorous, and dissolved inorganic solids. These latter substances are removed by tertiary treatment processes or in some cases by a physical-chemical process sequence which replaces or acts in combination with the biological process.

If tertiary treatment is to be considered, it is essential to optimize

the biological process in order to effect optimal performance and economics from the tertiary system.

Optimal performance from the biological process relates itself to maintaining a favorable sludge age (food to microorganisms ratio — F/M) and imposing constraints on the influent wastewater variability to avoid upsets to the process.

It has been found that effluent quality from the activated sludge process can be related to sludge age [8, 13] or F/M (Fig. 1). When the sludge age is too low, filamentous and/or dispersed growth yielding

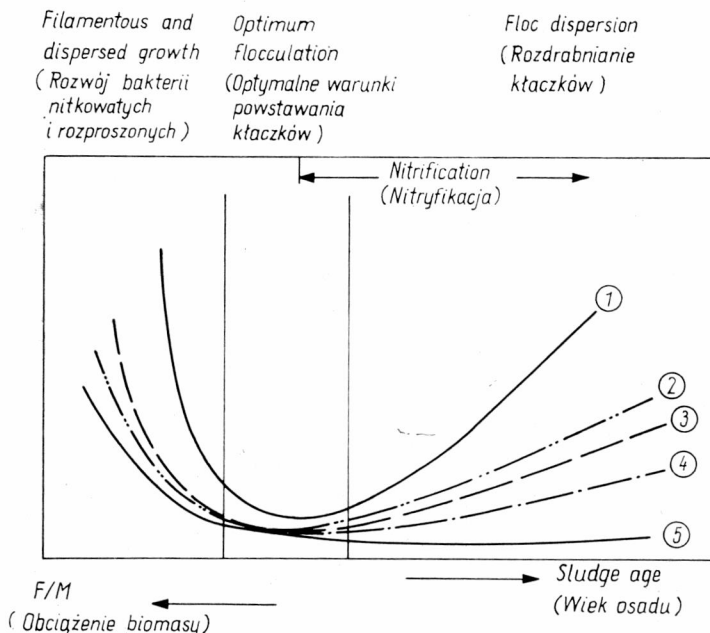


Fig. 1. Effluent characteristics as related to sludge age and F/M

1 — suspended solids, 2 — COD (dissolved), 3 — COD (total), 4 — N and P, 5 — N and P (dissolved)

Rys. 1. Zależność składu ścieków oczyszczonych od wieku osadu i obciążenia biomasy (F/M)

1 — zawiesiny, 2 — ChZT (rozpuszczone), 3 — ChZT (ogólne), 4 — azot i fosfor, 5 — (rozpuszczone).

poor settling properties and a high suspended solids carryover from the final settling tank. This in turn increases the total BOD discharged from the plant. For example, in a kraft pulp and paper mill wastewater treatment plant, the soluble and total BOD removal was 94 and 88 %

respectively at an F/M of 1.0 (based on active mass). The BOD contributed by the carryover suspended solids was 0.2 mg BOD/mg SS. Increasing the loading (F/M) to 2.0 reduced the soluble and total BOD removals to 90.5 and 76 % respectively, and increased the BOD contribution of the suspended solids to 0.5 mg BOD/mg SS. While there was only a small decrease in soluble BOD removal, the effluent deteriorated markedly due to increased carryover of suspended solids with a high active fraction.

When the sludge age becomes too high (or the F/M too low) the biological floc is oxidized and dispersed.

Chudoba [4] has shown that the biological oxidation of degradable organic compounds yields refractory organics as a by-product equal to 0.5–1.3 % of the original COD. By contrast, other investigators have reported residual COD values of 5–15 % of the original COD. It would appear that the residual COD after treatment bears a relationship to the F/M employed in the process. As a result, while the effluent BOD will remain relatively constant with increasing initial concentration of biodegradable substrate, the effluent COD will increase due to the increased bio-resistant products of oxidation. This phenomena results in a changing BOD_5/COD ratio through treatment. Raw biodegradable wastewaters will have a BOD_5/COD ratio of 0.5–0.7. Activated process effluents will decrease to 0.03–0.2. Chudoba showed that after very long periods of aeration, the ratio further reduced to 0.007–0.04.

The COD of the effluent will therefore be composed of bio-resistant material present in the wastewater, refractory metabolic by-products and residual compounds resulting from cell lysis and auto-oxidation. Chudoba [5] showed that the residual COD of an activated sludge effluent increased with sludge age as a result of the release of refractory organic compounds to solution. While most of the residual COD and BOD is in suspension, the soluble COD increased from about 20 g/m³ at a sludge age of 10 days and an F/M of 0.2 to 40 g/m³ at a sludge age of 50 days and an F/M of 0.082. The soluble BOD remained constant over this period. At high sludges ages, the auto-oxidation of the cell mass will release nitrogen and phosphorous back to solution. The nitrogen and phosphorous discharged in the effluent will therefore depend on the BOD/N and the BOD/P ratios in the wastewater and the sludge age in the process (see Table 1).

When considering industrial wastewaters several factors influence the attainable effluent quality. As previously mentioned for domestic sewage an optimal F/M range will exist for maximum sludge settling rate and

Table 1

Effluent qualities attainable from wastewater treatment processes treating domestic sewage (in g/m³)

Jakość odpływu przy zastosowaniu różnych procesów oczyszczania ścieków bytowo-gospodarczych (w g/m³)

Process	BOD	COD	SS	N	P
Activated Sludge					
Soluble	< 10	a	< 30	b	c
Total	< 20				
Physical-chemical ^d	5	13	5	4.6	0.15
Tertiary ^e	< 1	10	0	—	0.06
Tertiary ^f					
inf	5.8	8.0 ^g	4.4	17.4 ^h	13.5
eff	3.6	2.2	1.6	1.5	1.4

^a $COD_{inf} - (BOD_u \text{ removal}/0.92) + COD_B$ is nondegradable organics generated in process and is a function of sludge age

$COD_{inf} - (BOD_u \text{ usuwanie}/0.92) + COD_B$ w nierozkładalnych substancjach organicznych wykonywanych w procesie jako funkcje wieku osadu

^c $P_{inf} - 0.026 \times X_p/0.77 + 0.01(0.77 - x/0.77) X_p$ in which X_p is the excess volatile suspended solids and x is the biodegradable fraction of the volatile suspended solids

$P_{inf} - 0.026 \times X_p/0.77 + 0.01(0.77 - x/0.77) X_p$, gdzie X_p jest nadmiarem lotnej zawiesiny ciała stałego, x - jest biologicznie rozkładalną frakcją lotnych zawiesin ciała stałego

^d Blue Plains, Washington - lime clarification, filtration, ion exchange, carbon adsorption

Blue Plains, Washington - klarowanie wapnem, filtracja, wymiana jonowa, adsorpcja węgla

^e Lake Tahoe - chemical clarification, filtration, carbon adsorption, chlorination

Lake Tahoe - klarowanie chemiczne, filtracja, adsorpcja węgla, chlorowanie

^f Strong base anion exchange following activated sludge

Silna zasadowa wymiana anionowa zachodząca w osadzie czynnym

^g NO₃-N

^h Permanganate value

Utlenianie.

effluent quality. This range will depend on the composition of the wastewater. For example a readily degradable wastewater such as a brewery has a maximum F/M of 0.45 for settling while a complex wastewater such as a petrochemical effluent has a maximum F/M greater than 1.0. In addition to flocculation and settling the BOD removal rate as defined by Equation (1) will depend on waste composition [9]:

$$\frac{S_0 - S_e}{X_v t} = k \frac{S_e}{S_0} \quad (1)$$

The removal rate coefficient k has been found to vary from 0.05 to 1.0 for organic chemical wastewaters. The soluble effluent BOD attainable

can be computed from Equation (1). While in theory soluble BOD's in the order of 10 g/m^3 are attainable, low k 's require long retention periods (low F/M) resulting in excessive oxidation of the biomass and a high unit cost of treatment as shown in Figure 2.

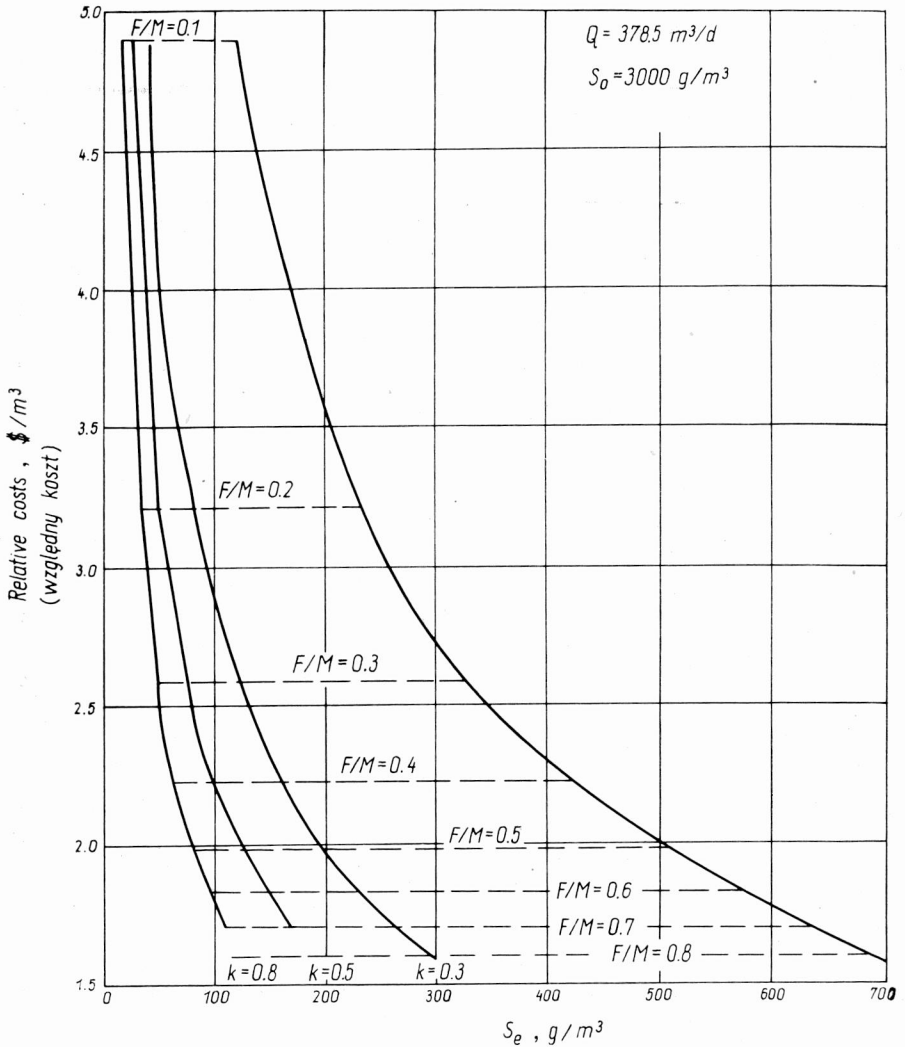


Fig. 2. Parameters affecting costs for activated sludge

Rys. 2. Parametry decydujące o koszcie oczyszczania ścieków osadem czynnym

The F/M is defined by the relationship:

$$F/M = \frac{24 S_0}{X_v t} \quad (2)$$

Combining Equations (1) and (2) yields the relationship:

$$(F/M)^{-1} k = S_0/S_e - 1.$$

Since $S_0/S_e \gg 1$ for any wastewater at a constant loading (F/M) the effluent soluble BOD is proportional to the influent BOD [5]. The effluent suspended solids will increase as the TDS of the wastewater increases. These solids are dispersed (non-settleable) and are probably due to poor flocculation at high salt levels. For example, effluent suspended solids of 20–30 g/m³ can be expected at TDS levels of less than 500 g/m³. The effluent suspended solids will increase to 60–100 g/m³ at TDS levels of 7,500 g/m³. The total BOD will increase depending on the g BOD/ g SS which in turn depends on the sludge age in the process.

1. VARIATION IN EFFLUENT QUALITY

While it is possible to estimate the average effluent quality from a secondary treatment facility as design input for tertiary treatment design, variation in secondary effluent quality can exert a profound effect on tertiary treatment performance. Variation in effluent suspended solids from secondary clarification will result from hydraulic upsets and from load variations which markedly alter the biological sludge characteristics resulting in sludge bulking. Organic upsets, slugs and spills in the case of industrial wastewaters can result in a marked increase in the BOD and COD entering the tertiary treatment system.

There are a number of control measures that can be taken in the design of a secondary wastewater treatment facility to stabilize the quality of the effluent. When industrial wastes are to be treated and there is a chance of severe spills, a monitoring station with a diversion should be considered. For example, a biological treatment facility is designed for a maximum TOC of 3,000 g/m³ after equalization. This represents a 98% probability during plant operations. It is usually due to product loss, severe spills, etc. The monitors divert the flow to a holding basin and set an alarm for plant personnel to investigate and correct the source

of pollution. After correction, the wastewater is again diverted to the equalization basin. The high strength waste in the holding basin is then metered at a constant rate to equalization.

Several investigators have shown that sludge characteristics, to a large measure, are related to the F/M . The F/M should be kept as constant as possible in order to maintain a stable process operation and a uniform quality effluent. This is best achieved by employing one or more completely mixed basins. Variations in organic loading, pH, etc., are equalized throughout the aeration basin. Optimal sludge age or F/M can be maintained by varying the recycle and hence the biomass returned to the aeration basin. If organics which are toxic in high concentration but degradable in low concentration are present in the wastewater, such as phenol, the minimum retention period in the basin is that required to reduce the concentration to a level less than the toxic threshold.

The factors which will primarily affect the effluent quality from an activated sludge plant in terms of soluble BOD are: variation in concentration, variation in product mix which results in variation in waste composition and hence the reaction coefficient, k , and variation in temperature. The total BOD will be affected by variation in effluent suspended solids. A relationship defining variation in effluent BOD has been proposed by Conway et al. [6]:

$$\text{BOD}_t = \text{BOD}_a \cdot \frac{S_0}{S_{0a}} \cdot \theta^{(T_a - T)} \cdot F + B \cdot \text{SS}.$$

An analysis of one years' operating data for the Union Carbide activated sludge plant at South Charleston, West Virginia showed a value of θ of 1.055, a maximum value of F of 1.9 and B as 0.3 g BOD/g SS. Variability in plant effluent is summarized in Table 2.

2. BIOLOGICAL PROCESS MODIFICATIONS

In recent years, a number of biological process modifications have been developed to enhance the treatment efficiency and to provide a more uniform effluent. A few of these will be mentioned here.

High purity oxygen has recently been employed in which dissolved oxygen levels in the order of 10 g/m³ are maintained in the aeration basin. Under these conditions, a more dense sludge is attained and filamentous

Table 2

Operating data for the South Charleston wastewater treatment works
1972, January through August [6]

Dane eksploatacyjne z oczyszczalni ścieków w South Charleston z okresu:
styczeń–sierpień 1972 [6]

Item	Winter	Summer
Biological system BOD ₅ data		
Average inlet BOD ₅ , g/m ³	795	645
Average effluent BOD ₅ , g/m ³	85	35
Average percent removal	89	95
Average soluble effluent BOD ₅ g/m ³ (est. from 0.33 g BOD/g solids)	43	19
Average effluent BOD ₅ (worst 20 days), g/m ³	129	41
No. of days in 90-day period BOD ₅ exceeded 1.5 × worst 20 days	6	4
Effluent suspended solids		
Average effluent SS, g/m ³	127	49
Average effluent SS (worst 20 days), g/m ³	198	73
No. of days in 90-day period SS exceeded 1.5 × worst 20 day period	4	8
Biological system COD data		
Average inlet COD, g/m ³	2176	1870
Average effluent COD, g/m ³	631	286
Average percent removal	71	85

growths substantially eliminated even at high F/M values. It is postulated that under the moderately turbulent conditions (40–60 W/m³) usually employed in the activated sludge process, only a portion of the floc is aerobic. Increasing the biological activity by establishing fully aerobic conditions require either increased dissolved oxygen levels or increased power level.

Oxygen systems employ closed aeration basins with reduced retention periods with higher mixed liquor solids levels. Highpurity oxygen is passed through several stages and absorbed by surface or submerged aerators to enhance absorption. An alternative approach uses fine bubble diffusers in open aeration basins. This is of considerable benefit under cold temperature operations since heat loss is reduced and the reaction rate maintained at a high level. In one case, treating a high strength

industrial waste, an increase in temperature in the aeration basin was observed due to the exothermic biological reaction. A cost comparison of oxygen vs. air for municipal wastewater is shown in Figure 3. Main-

Pilot plant performance

Table 3

Wyniki oczyszczania ścieków przy użyciu czystego tlenu w urządzeniach póltechnicznych

	A	B*	C	D	E	F
Retention time (Q), h	15	2.2	2.5	1.8	6.0	2.0
Recycle ratio	0.28	33	30	29	57	25
Wastewater temperature, K		308	291	291	308	298
Mixed liquor suspended solids, g/m ³	9340	6600	5200	4700	4400	5900
VSS/TSS		0.90	0.84	0.84	0.86	
Biomass loading, g BOD/g MLVSS · d	0.49	0.54	0.53	1.4	0.96	0.70
Organic loading, g BOD/m ³ · d	4330	3210	2325	5610	3690	3210
Sludge retention, d	13.5					
BOD ₅ influent, g/m ³	2670	294	242	415	915	270
effluent, g/m ³			17	12	25	35
removal, %	90	91	93	97	97	87
COD influent, g/m ³	5730	888	469	826	1640	525
effluent, g/m ³			70	99	84	117
removal, %	68	60	85	88	95	78
SS influent, g/m ³		79	314	180	465	411
effluent, g/m ³		46	22	18	65	33
removal, %			93	90	85	92
TOC soluble, g/m ³	1590					
TOC removals, %	69					
Clarifier overflow rate, m ³ /m ² · h		0.88	0.49	0.88	0.64	0.98
Clarifier mass loading, kgSS/m ² · h		6.90	3.26	6.30	4.47	7.32
Clarifier underflow concentration, %	3.6	2.8	2.0	1.5	1.3	2.8
Sludge volume index (SVI), cm ³ /g	39	47	102	82	91	47
Solids production, g/g BOD ₅ removed	0.17					
Oxygen requirement, g/g BOD ₅ removed	1.7					

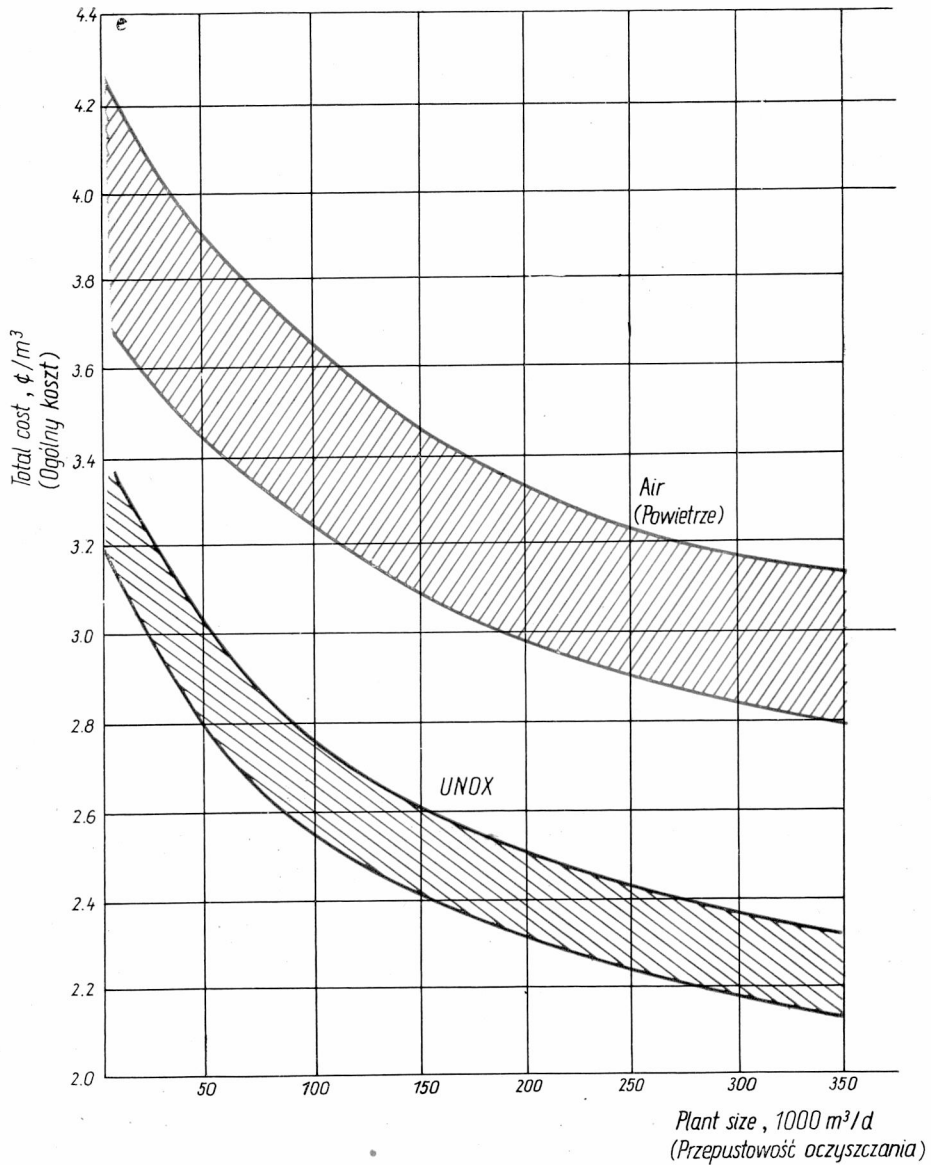
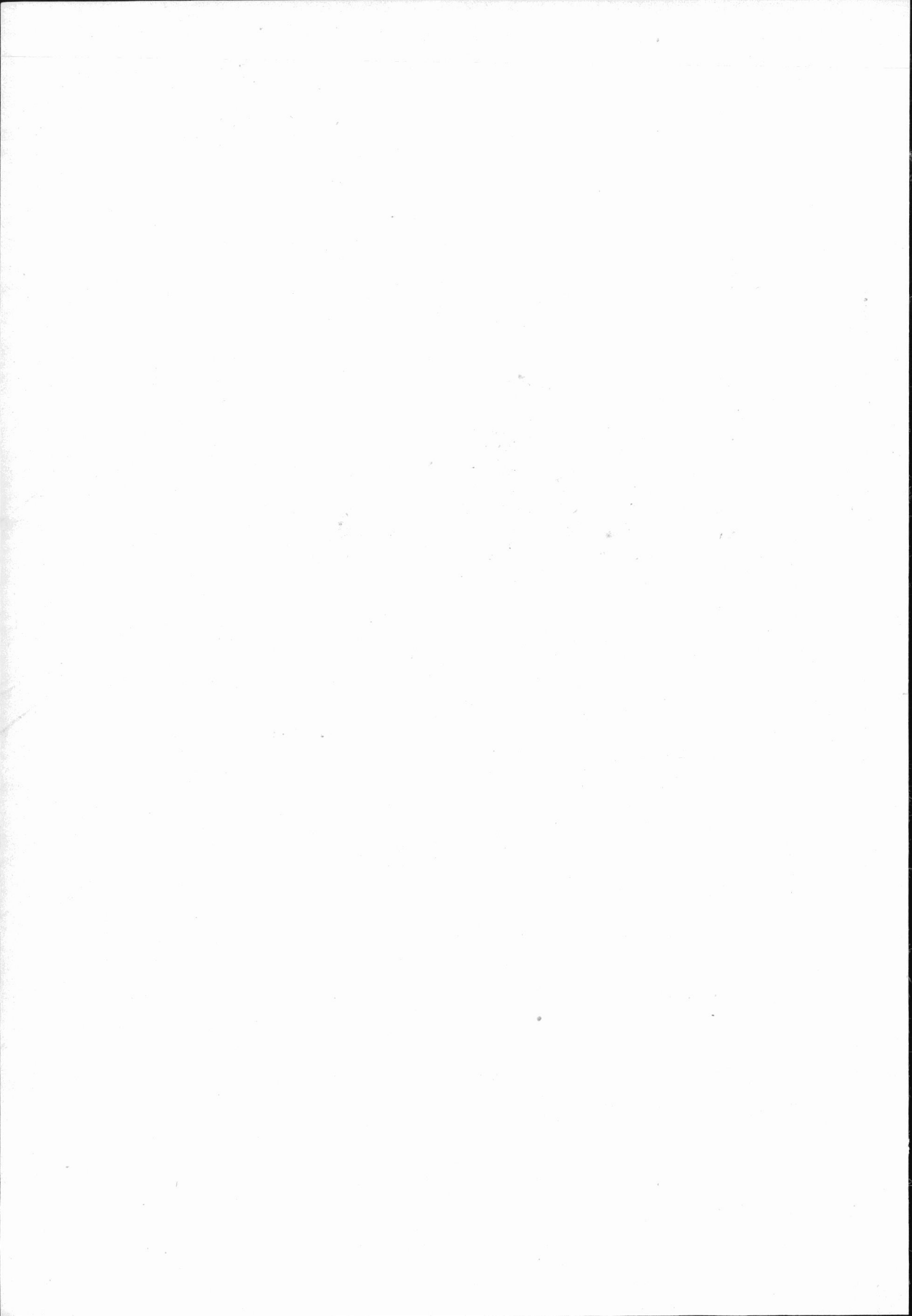


Fig. 3. Cost comparison of oxygen versus air for biological treatment of the municipal wastewater

Rys. 3. Porównanie kosztów napowietrzania i natleniania przy biologicznym oczyszczaniu ścieków miejskich



	A	B*	C	D	E	F
g SS/g BOD ₅ removed:						
Accumulation		0.41	1.37	0.67	0.32	0.56
For Disposal		0.26	1.27	0.64	0.27	0.40
g O ₂ /g BOD ₅ removed		1.46	0.88	0.85	0.96	1.02
g O ₂ /g COD removed		0.73	0.45	0.42	0.56	0.55
COD/BOD ₅ ratio		3.0	2.0	2.0	1.8	1.9
SRT		5.9		1.1	3.2	

* Mixed liquor temperature 297 K to 301 K; biosolids 93 % volatile.

Temperatura cieczy w komorze 297–301 K, zawartość ciał lotnych w biomacie – 93 %.

- A – Petrochemical wastewater, Ścieki petrochemiczne,
 B – Pulp and paper mill waste, Ścieki celulozowo-papiernicze,
 C – Fruit cannery waste during canning season, Ścieki z fabryki konserw warzywnych podczas sezonu
 D – Meat packing, cereal, starch and syrup and grain processing waste, Ścieki z produkcji konserw mięsnych, z przemysłu zbożowego i ziemniaczanego,
 E – Brewery wastewater, Ścieki z browarów,
 F – Textile and poultry processing wastewater Ścieki z przemysłu tekstylnego.

taining low effluent BOD levels during winter operation favors the oxygen system due to the high heat loss in the air system. In some cases, the high levels of CO₂ generated in the process have resulted in a loss of efficiency. The selection of an oxygen vs. air system should be made based on an economic comparison under specific operating conditions. Performance data from several oxygen systems is shown in Table 3. Enhancement of process efficiency has been achieved by the addition of powdered activated carbon to the aeration tank [1]. Several benefits have been observed relative to plant performance, namely, a decrease in effluent BOD, COD, and color, an improvement in sludge settling properties, and a reduction in foaming in the aeration basin. Carbon

Table 4

Effect of powdered activated carbon on activated sludge process performance for a mixed municipal and textil dye wastewater

Wpływ pylistego węgla aktywnego na przebieg oczyszczania mieszaniny ścieków miejskich i farbiarskich osadem czynnym

Influent BOD, g/m ³	140–185	
Aeration detention, h	2.2	
	Act. sludge	Act. sludge & carbon
BOD removal, %	72	89
Effluent SS, g/m ³	26	19
Effluent color, APHA units	248	179

Carbon dosage 20 g/m³; 500–600 g/m³ in 2800 g/m³ MLVSS.

Dawka wapna 20 g/m³; 500–600 g/m³ w 2800 g/m³ suchej masy organicznej.

dosages in the order of 30–100 mg/l have been employed. Regeneration of the carbon is a distinct possibility in many cases. Reported performance data is summarized in Table 4.

3. BIOLOGICAL NITROGEN REMOVAL

Biological removal of nitrogen is attained first by oxidizing ammonia nitrogen to nitrate followed by denitrification to nitrogen gas. This can be achieved by one of several modes of process operation. Both BOD removal and nitrification can be achieved in a single aeration basin providing that the sludge age be sufficient for the critical temperature of operation and the dissolved oxygen level be sufficiently high to insure unrestricted nitrification. Denitrification is achieved in a subsequent step either through nitrate reduction, through endogenous respiration in a mixed basin [3], the addition of methanol as a carbon source to increase the denitrification rate in the basin [3], or through upflow denitrification filters with the addition of methanol. If nitrification is achieved in the biological process, nitrogen removed by columnal denitrification is feasible. In this process, a carbon source such as methanol is added to the feed to the column. The methanol theoretical dosage has been estimated by McCarty [3] as 2.5 g/m³ methanol per g/m³ NO₃-N [24]. (Additional methanol as a dosage of 0.87 g/m³ per g of dissolved oxygen is required if oxygen is present in the feed.) In excess of 90% reduction of NO₃-N has been achieved in columns with retention periods as low as 5–15 min. at 293 K [24]. Alternatively, the BOD removal and nitrification steps can be arranged in two stages where the first stage is optimized (by F/M) for BOD removal and the second stage optimized (by sludge age) for nitrification. Such two-stage arrangement of the process can result in a substantial reduction in total aeration requirements, although two varieties of final clarifiers and return sludge pumping systems are required. The third stage can be one of the denitrification stages described above or a modification thereof. The advantage of the two-stage process relates to improved overall effluent quality and a greater degree of process control.

Two recent process modifications have achieved nitrification and denitrification in a single process sequence. Operation in Vienna [12] has achieved nitrification and denitrification in a single basin at an overall loading (F/M) to the process of 0.11. Reported data is shown in Table 5.

The mode of operation is such that the dissolved oxygen is alternatively 1–2 g/m³ through the aerator and anoxic or zero prior to the aerator. Under these conditions, denitrification occurs concurrently with BOD removal in the basin thereby achieving a high rate of denitrification.

Table 5

Nitrogen removal at Blumental, Vienna

Usuwanie azotu w oczyszczalni Blumental w Wiedniu

	Raw Sewage g/m ³	Effluent g/m ³	Removal %
BOD	257	13	95
COD	475	50	90
TOC	153	14	91
TKN	13.8	0.4	
NH ₃ –N	21.4	3.8	
NO ₂ –N	0.2	0	
NO ₃ –N	35.7	4.2	88

Operating Conditions: Temp. 291 K; Detn. 8.5 h; F/M 0.11.

Warunki eksploatacyjne: temperatura 291 K; czas przetrzymania 8,5 h; obciążenie osadu 0,11 g/BZT₅/g s.m.d

A process developed in South Africa [2] employs alternative nitrification and denitrification steps with a high recycle of nitrified sewage to an initial anoxic stage for high rate denitrification. Overall nitrogen removals in excess of 90% have been reported. The various nitrification and denitrification processes are shown in Figure 4.

Phosphorous can be removed in the primary treatment or in a tertiary step by precipitation with lime, alum or ferric chloride. Phosphorous can also be removed by the addition of chemicals (aluminum or iron salts) near the outlet of the aeration basin or at a point between the aeration section and the final clarifier. A total phosphorous residual of 0.19 g/m³ PO₄ with a 94.8% BOD removal has been reported by precipitation with alum in the activated sludge process. While the quantity of excess sludge from the biological process will increase due to the additional chemical sludge, there is very little increase in excess sludge volume due to the increased density of the combined sludge. The combined sludge has been reported to be more readily dewaterable.

When considering phosphorous removal in the biological process it is necessary to have:

- a) a low sludge age to minimize phosphorous feedback to the system;

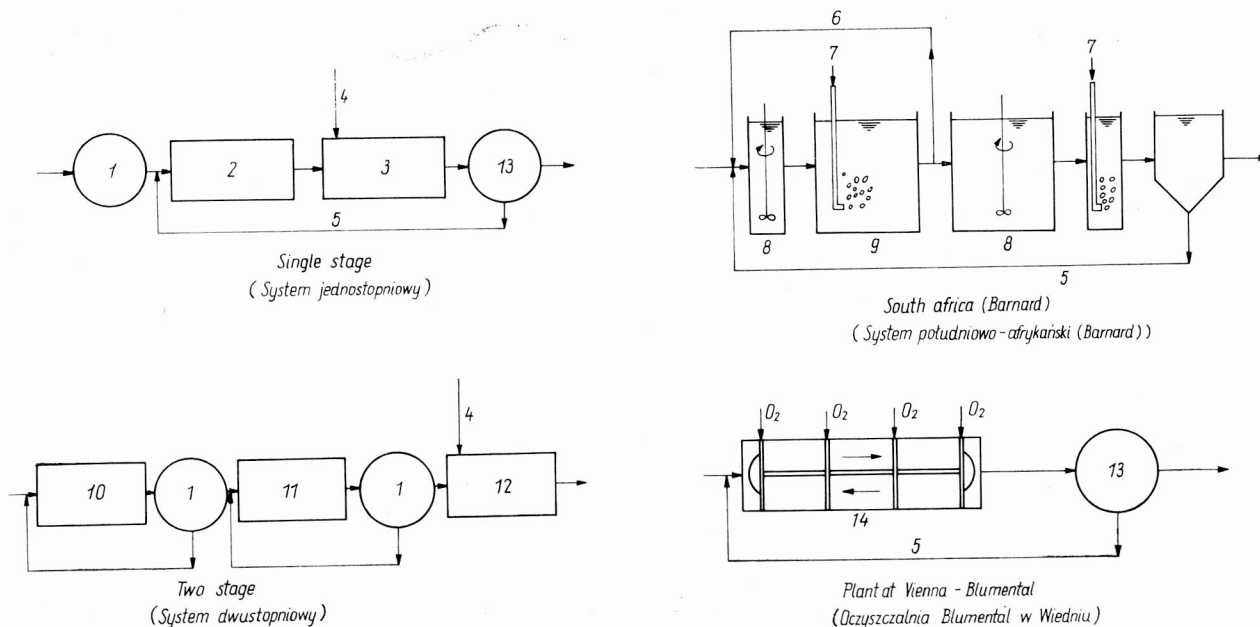


Fig. 4. Nitrogen removal processes: 1 – (primary) settling tank, 2 – BOD removal and nitrification, 3 – denitrification (basin of filter), 4 – methanol, 5 – sludge recycling, 6 – mixed liquor recycle (4 : 1), 7 – air, 8 – anaerobic, 9 – aerobic, 10 – BOD removal, F/M optimized, 11 – nitrification, 12 – denitrification filter, 13 – secondary settling tank, 14 – aeration basin

Rys. 4. Procesy usuwania azotu

1 – osadnik wstępny, 2 – usuwanie BZT i nitryfikacja, 3 – denitryfikacja (komora lub złoże), 4 – metanol, 5 – recyrkulacja osadu, 6 – stopień recyrkulacji osadu (4 : 1), 7 – powietrze, 8 – komora anaerobowa, 9 – komora aerobowa, 10 – usuwanie BZT przy optymalnym F/M , 11 – nitryfikacja, 12 – złoże denitryfikacyjne, 13 – osadnik wtórny, 14 – komora napowietrzania

- b) proper selection of the chemical addition point and dosage level;
- c) efficient solids-liquid separation.

In the process the soluble phosphorous is converted to an insoluble form by complexing with metallic ions in addition to microbial phosphorous-assimilation. The precipitated phosphorous is incorporated in the sludge mass and removed in the clarification step. Goodman [15] has shown that a chemical dosage in the range of 1.75–2.25:1 on a molar basis of Al : P is sufficient to remove 90 % of the total phosphorous entering the system.

Sludge age is significant because high sludge ages result in floc dispersion and loss of phosphate as fine particulates as well as feedback of phosphorous to solution through endogenous metabolism.

Improved overall phosphorous removal in the system can be achieved by the addition of synthetic organic polyelectrolytes for particle agglomeration prior to the final clarifier or modifying the final clarifier to a sludge blanket type of device.

4. PHYSICAL-CHEMICAL PROCESSES

When effluent qualities superior to those obtainable by biological treatment are required, additional (tertiary) or a non-biological process (physical-chemical) treatment must be employed. Physical-chemical treatment (Figure 5) employs coagulation with lime, alum or ferric chloride

Table 6

Performance of PCT plants treating domestic sewage

Wyniki oczyszczania ścieków bytowo-gospodarczych w oczyszczalniach chemicznych

Location	Coagulant	COD		BOD		SS		P	
		in	out	in	out	in	out	in	out
		g/m ³		g/m ³		g/m ³		g/m ³	
Cleveland	Iron	500	41	288	29	213	20	6.2	0.4
	Lime, pH 10.5	498	69	244	41	199	22	4.9	0.8
	Lime, pH 12	536	48	182	35	144	6	5.3	0.2
Pomona	Iron	357	27	—	—	178	19	11.9	1.6
	Alum	285	29	—	—	183	9	10.4	1.0
Lebanon	Lime	257	29	98	6	110	2	8	2.0
Blue Plains	Lime	305	13	122	5.3	158	4.6	8.4	0.1

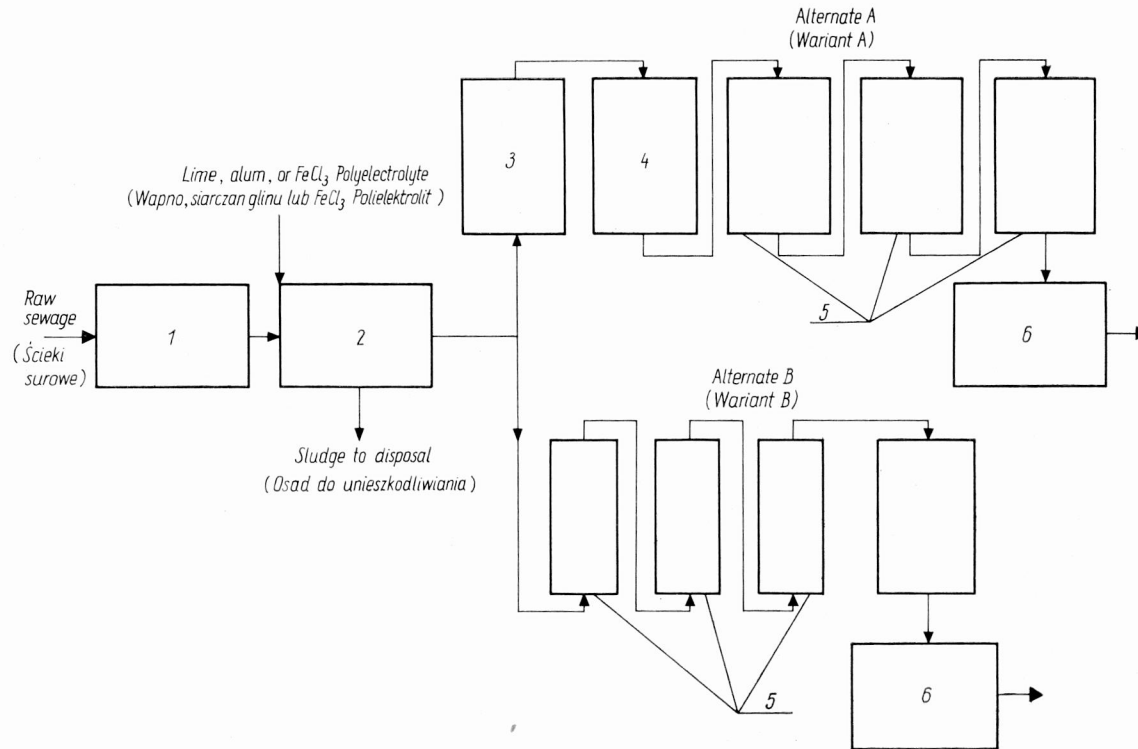


Fig. 5. Physical-chemical treatment alternatives (not including sludge disposal); 1 – preliminary treatment, 2 – chemical coagulation, 3 – recarbonization (if high lime dosage used), 4 – mixed media filters, 5 – carbon adsorbent, 6 – disinfection
 Rys. 5. Warianty fizykochemicznego oczyszczania ścieków surowych (bez przeróbki osadów): 1 – wstępne oczyszczanie, 2 – koagulacja, 3 – rekarbonizacja przy wysokiej dawce wapnia, 4 – filtry wielowarstwowe, 5 – kolumny adsorpcyjne z węglem aktywnym, 6 – dezynfekcja

followed by carbon adsorption and filtration. The physical-chemical process is particularly suited to domestic wastewaters in which the major part of the BOD is present in suspended and colloidal form which is readily removed in the coagulation step. The choice of coagulant depends in part on the characteristics of the sewage, primarily the alkalinity which affects the dosage. For low or moderate alkalinity sewages, lime has been preferred for application in the United States. Performance data for a number of plants is summarized in Table 6 [10].

Several factors need to be considered in the selection of a physical-chemical process. When lime is used as a coagulant improved clarification and phosphorous removal have been reported in the presence of magnesium above pH 10.5 [25]. The magnesium hydroxide is a highly effective flocculent for removal of finely dispersed particles including phosphorous. The presence of magnesium, however, decreases the sludge dewatering characteristics. The problem is overcome by recarbonation of the chemically precipitated sludge to solubilize the magnesium. The solubilized magnesium can be recycled for reuse in the initial coagulation step.

Since biodegradable organics are present in the wastewater applied to the carbon columns biological activity will result. Normal column operation will produce anaerobic activity resulting in H_2S formation. Injection of oxygen will produce facultative or aerobic activity. When the BOD applied to the columns is low ($<50 \text{ g/m}^3$) biological growth poses little problem and enhances the efficiency of the bed through biological regeneration of the carbon. Weber [26] has reported an increase in carbon capacity from 0.5 g COD/g C to greater than 1 g COD/g C due to facultative biological activity in the carbon bed. In order to minimize head loss, upflow expanded bed adsorbers are usually employed. When the BOD is high, extensive biological activity reduces the capacity of the carbon due to slime coating and greatly increases the head loss [11].

The dewatering and disposal of sludge is a major consideration in P-C processes. Sludge quantities and thickening and dewatering characteristics are summarized in reference [20]. It is technically feasible to recover lime by two stage centrifugation and alum by acidification however, practical and economic application is yet to be demonstrated. Powdered activated carbon has been applied in a two-stage counter-current process on a pilot scale for the treatment of domestic sewage [22]. Carbon slurry concentrations in the reactor clarifiers are maintained at 1.5–2.0%. A sludge age of less than two days is maintained to avoid anaerobic activity in the basins. The carbon is regenerated in a fluidized bed incinerator.

Table 7

Refinery wastewater treatment results

Wyniki oczyszczania ścieków rafineryjnych

Parameter	API Separator g/m ³	Biotreated g/m ³	Carbon treated g/m ³	Bio-Carbon treated g/m ³
BOD ₅	97	7	48	3
COD	234	98	103	26
TOC	56	30	14	7
Oil & Grease	29	10	10	7
Phenols	3.4	0.01	0.004	0.001
Chromium	2.2	0.9	0.2	0.2
Copper	0.5	0.1	0.03	0.05
Iron	2.2	3.0	0.3	0.9
Lead	0.2	0.2	0.2	0.2
Zinc	0.7	0.4	0.08	0.15
Sulphide	33	0.2	39	0.2
Ammonia	28	27	28	27
Cyanides	0.25	0.2	0.2	0.2
Turbidity*	26	17	11	5
Color**	30	15	15	1

* Turbidity given in Jackson Turbidity Units
Zmętnienie w jednostkach Jacksona

** Color given in Color Units
Barwa w jednostkach barwy

Greater than 90% recovery of the carbon has been reported.

One deficiency of the P-C process is that it does not remove ammonia nitrogen. Alternatives for removing ammonia include air stripping, chlorination and ion exchange. Air stripping has not been an effective solution due to deposition of calcium carbonate in the tower and the high temperature dependence on absorption efficiency. Breakpoint chlorination over a pH range of 5-8 will convert the NH₃-N to N₂ with small amounts of NO₃ and NCl₃ being formed. A Cl:NH₃-N of 8:120 has been found for municipal wastewaters with a NH₃-N concentration of 20 g/m³ (not including other oxidizable organics which may be present). Dechlorination can be achieved through the activated carbon columns. It should be noted that this process increases the chloride content of the effluent [21].

Ammonia nitrogen can be removed using a selective ion exchange resin, chlinoptilolite [19]. The resin is regenerated with sodium or calcium at high pH. The resin can be recovered by air stripping the ammonia and reused.

Table 8

Performance data for physical-chemical treatment of a refinery effluent

Wyniki fizykochemicznego oczyszczania ścieków rafineryjnych

Parameter	Sand filter inlet g/m ³	Activated carbon inlet g/m ³	% Red.	Activated carbon outlet g/m ³	% Red.
SS	69	21	70	12	43
Oil	67	35	47	7	79
COD	391	242	38	97	60
TOC	107	82	23	36	56
BOD ₅	131	103	21	19	82
FSUOD	217	—	—	26	—
Phenol	4.53	4.94	—	0.038	99.2

Physical-chemical treatment has been applied to some industrial wastewaters [14]. A major consideration is the fact that many low molecular weight, soluble organics are not removed in a carbon bed and hence incomplete BOD removal results. Pilot plant studies were conducted on a petroleum refinery effluent comparing biological, P-C and tertiary treatment of the API separator effluent [23]. The results are summarized in Table 7. It is interesting to note the low BOD removal from the P-C system and the increase in sulphides through the carbon beds. The carbon columns, either as a P-C treatment or a tertiary treatment are relatively efficient for the removal of heavy metals. One full scale P-C plant has been installed in the United States at the BP Refinery at Marcus Hook, Pennsylvania. This plant employs a pulsed bed adsorber following oil separation and filtration. Performance data after three months operation is shown in Table 8.

5. TERTIARY TREATMENT

Upgrading effluent quality, particularly in the case of industrial wastewaters will be achieved in most instances by adding treatment modules to secondary biological plants. This may include but not be limited to filtration (with or without chemical addition) followed by carbon adsorption. Phosphorous can effectively be removed by coagulation

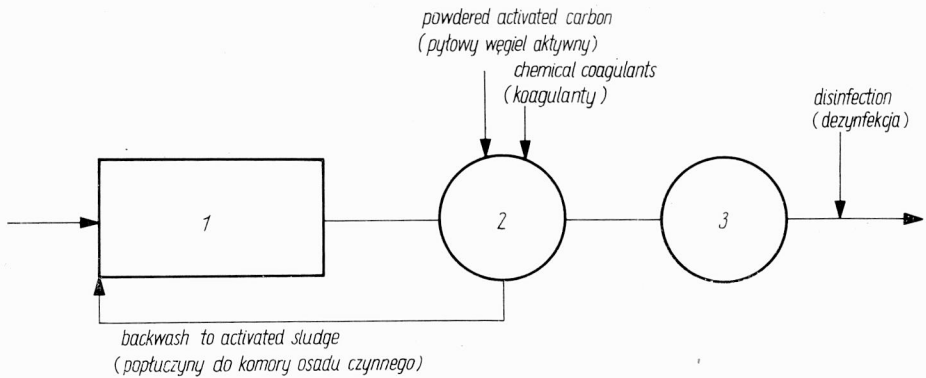


Fig. 6. Tertiary treatment alternatives. Carbon regeneration, sludge handling and nitrogen removal not shown

Rys. 6. Schemat fizykochemicznego oczyszczania ścieków oczyszczonych biologicznie (nie uwzględnia regeneracji węgla, przeróbki osadu i usuwania azotu)

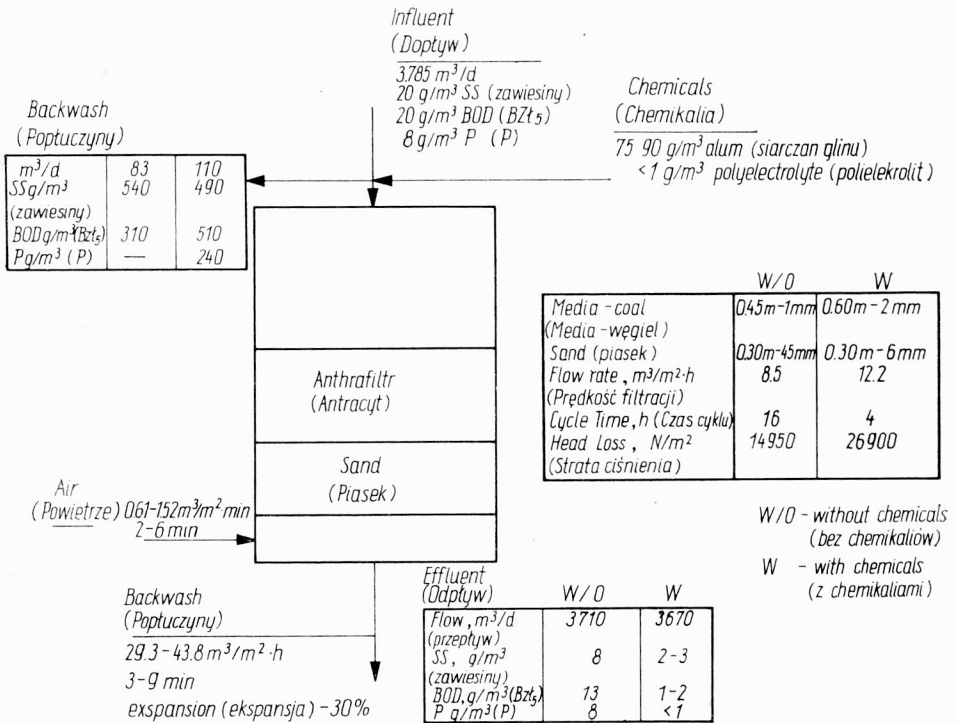


Fig. 7. Filtration of activated sludge effluent

Rys. 7. Filtracja ścieków oczyszczonych w procesie osadu czynnego

prior to filtration with alum. Variants such as the use of powdered activated carbon may also be employed, as shown in Figure 6. An advantage of powdered carbon to the filter is that it serves as a polishing adsorbent in the filter and can then be backwashed to the aeration tank for further adsorption. Carbon dosage may vary from 20–50 g/m³. Filtration opera-

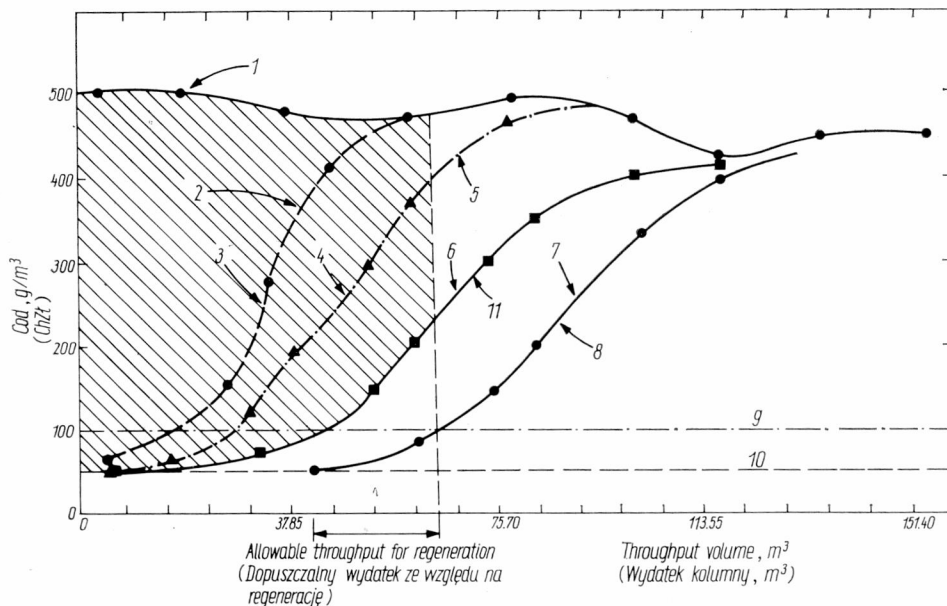


Fig. 8. Breakthrough curves from continuous-flow studies;

1 – influent COD, 2 – effluent COD, 3 – column 1, 4 – column 2, 5 – effluent COD, 6 – column 3, 7 – column 4, 8 – effluent COD, 9 – design breakthrough = 100 g/m³, 10 – apparent residual = 60 g/m³

Note: Cross-hatched area indicates COD removal capacity of three columns operated in series

Rys. 8. Krzywe przebicia uzyskane z badań przy ciągłym przepływie:

1 – ChZT dopływu, 2 – ChZT odpływu, 3 – kolumna 1, 4 – kolumna 2, 5 – ChZT odpływu, 6 – kolumna 3, 7 – kolumna 4, 8 – ChZT odpływu, 9 – założone przebicie = 100 g/m³, 10 – widoczna pozostałość = 60 g/m³

Uwaga: Zakreskowane pole oznacza pojemność sorpcyjną ChZT trzech szeregowo pracujących kolumn.

tion and performance for tertiary treatment is shown in Figure 7. Granular carbon columns are employed to remove residual BOD, COD and color. The carbon columns will also serve to remove small quantities of phenol and heavy metals remaining after biological treatment. Since most of the degradable organics (BOD) have been removed in the biological process, biological activity in the carbon columns should not cause operational difficulties. The nature of the breakthrough curve for most secondary

Table 9

Tertiary granularly carbon adsorption design parameters and operating results

Parametry projektowe oraz efekt oczyszczania ścieków poprzez adsorpcję na granulowanym węglu aktywnym

Operating Data	Pomona	Lake Tahoe	Nassau County
Source of waste	Domestic	Domestic	Domestic
Secondary treatment	Standard acti- vated sludge	Standard acti- vated sludge	High-rate acti- vated sludge
Pre-treatment	Chlorination	Coagulation & Filtration	Coagulation & Filtration
Carbon type, mesh	16 × 40	8 × 30	8 × 30
Nominal contact time, min	36	13	24
Loading rate, m ³ /m ² ·h	17.1	19.5	18.3
Carbon column performance	Inf Eff	Inf Eff	Inf Eff
COD, g/m ³	47 10	20-30 2-10	— 5
BOD, g/m ³	— —	5-20 2-5	— —
Color, Pt-Co units	30 3	20-50 5	— —
Carbon dosage, kg/1000 m ³	42	30	60

wastewaters requires the use of several columns in series or a pulsed bed in order to achieve optimal use of the carbon as shown in Figure 8. For three columns in series, when breakthrough occurs in the third column, the carbon in Column 1 is in equilibrium with the influent and has attained its maximum capacity. This is then replaced with new or regenerated carbon. Performance characteristics for carbon polishing of secondary effluents is summarized in Table 9.

Thermal regeneration of the carbon will result in a 5-10 per cent weight loss through attrition and oxidation and some loss in capacity due to changes in pore size and surface area during regeneration as shown in Table 10. It is for this reason that accurate estimates of carbon usage and cost should be made with regenerated carbon. Recently macroreticular resins [18] (polymeric adsorbents) have been applied to the adsorption of organics and color from industrial wastewaters. The resins are usually regenerated with a solvent such as methanol which is in turn recovered. The most promising application of these resins has been for

Table 10

Effect of regeneration on bituminous coal carbon's physical properties and performance [17]

Wpływ regeneracji na własności fizyczne i pracę bitumicznego węgla aktywnego

Location	Regeneration number	Iodine number	Molasses number	Ash, %	Loading, g coluble COD/g carbon
Pittsburgh Activated Carbon Company	0	942	—	5.3	0.17*
	10	588	—	11.9	0.13*
MSA Research Corporation	0	1090	250	5.7	0.17**
	3	940	355	9.5	0.15**
Pomona	0	1100	—	—	0.46
	7	700	—	—	0.29
Pomona	0	1028	—	—	0.22
	10	686	—	—	0.17
Tahoe	0	935	—	5.0	0.36
	4	820	—	7.1	0.38
Pomona	0	1100	—	—	0.59
	4	690	—	—	0.49

* ABS

** Actual weight increase during use.

Aktualne zwiększenie ciężaru podczas użytkowania.

the removal of color from bleach plant and textile dye wastewaters. Application to bleach plant effluents is shown in Figure 9. The first two stages of the bleach operation contain most of the color and are treated through the resins. The waste is pretreated by filtration. The resins are regenerated with 3 percent caustic (weak wash) which is returned to the recovery furnace. Removal of 85 % color, 40 % BOD and 60 % COD has been reported. The resin is regenerated with caustic from the recovery system and the spent regenerant recycled to the recovery furnace. Projected costs would indicate this process to be \$ 0.55/ton as compared to \$ 1.80/ton for lime coagulation.

Recently, secondary effluent polishing using a strong base anion exchange resin in the chloride form has been reported [16]. This yields a reduction in NO_3^- , PO_4^- , dissolved organics and suspended solids. (If the effluent suspended solids concentration is high, the ion exchange

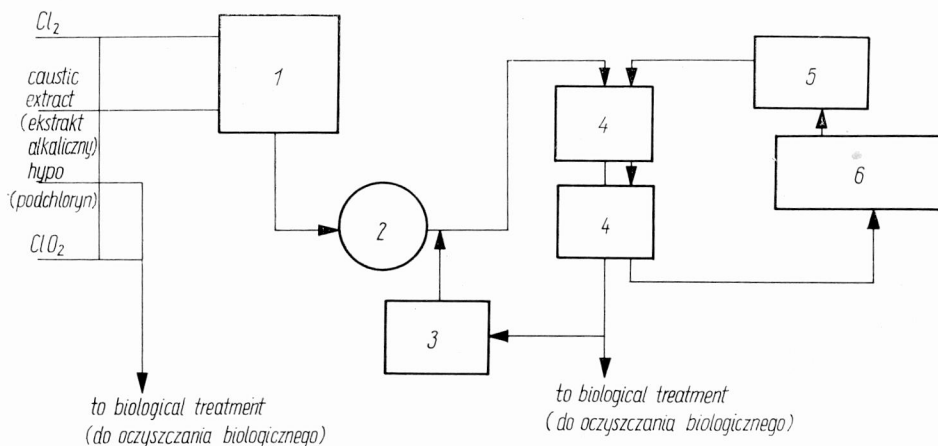


Fig. 9. Color removal from bleach plant effluent by resin adsorption;
 1 - holding tank, 2 - filter, 3 - effluent holding, 4 - resin, 5 - weak wash, 6 - recovery

Rys. 9. Usuwanie barwy ze ścieków bielarskich przy użyciu adsorbentów organicznych;
 1 - zbiornik magazynujący, 2 - filtr, 3 - odpływowy zbiornik magazynujący,
 4 - sorbent, 5 - płukanie, 6 - odzysk

should be preceded by filtration.) SO_4^{2-} is replaced by Cl^- so that application of this resin is usually limited to low sulfate waters. Results obtained are summarized in Table 1.

Total tertiary treatment has only been applied in a limited number of cases, the most publicized being Lake Tahoe, USA and Windhoek, South West Africa.

6. ECONOMICS OF ADVANCED WASTEWATER TREATMENT

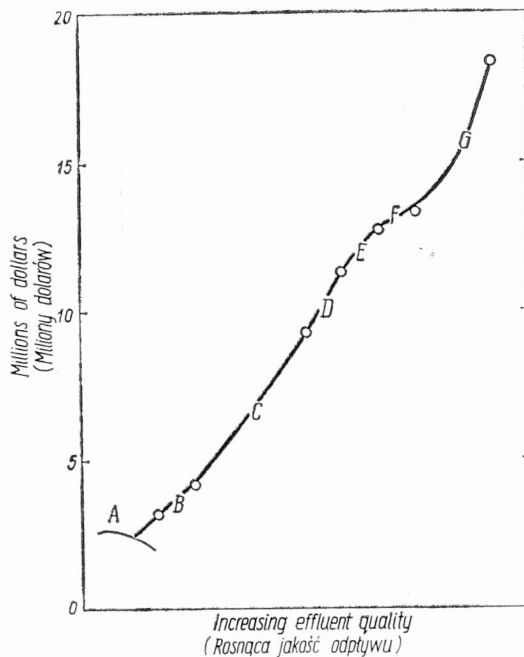
A discussion of economics in this paper can have only a relative value since costs differ materially in various parts of the world. Physical-chemical treatment of domestic sewage has reported costs of 4-5.3 ϵ/m^3 (USA). Treatment of primary effluent to produce a potable water by physical-chemical processes has been reported as 8.3 ϵ/m^3 in South Africa [16]. When considering industrial wastewaters, the costs of carbon adsorption can be expected to vary from 2.6-13.2 ϵ/m^3 for influent COD concentrations of 150-1000 g/m^3 and flows of 3,785-113,550 m^3/d [14]. The cost of tertiary treatment (following secondary biological treatment) has been

reported as $7.1 \text{ €}/\text{m}^3$ at Lake Tahoe [7]. Tertiary treatment in South Africa has been reported to cost $6.6 \text{ €}/\text{m}^3$. Columnar denitrification to reduce $20 \text{ g}/\text{m}^3$ been reported to cost $0.3\text{--}2.4 \text{ €}/\text{m}^3$. Ammonia removal by ion exchange is reported as $3.5 \text{ €}/\text{m}^3$ and $2.3 \text{ €}/\text{m}^3$ without and with regenerant reuse for a $37,850 \text{ m}^3/\text{d}$ plant.

Fig. 10. Cost of secondary and tertiary treatment for a chemical plant effluent;

A – neutralization, equalization,
B – primary clarification,
C – activated sludge, *D* – second stage biological, *E* – sludge disposal, *F* – filtration, *G* – carbon adsorption

Rys. 10. Koszt biologicznego i fizykochemicznego oczyszczania ścieków z przemysłu chemicznego; *A* – neutralizacja, wyrównanie składu, *B* – sedimentacja wstępna, *C* – osad czynny, *D* – drugi stopień oczyszczania biologicznego, *E* – przeróbka osadu, *F* – filtracja, *G* – adsorpcja na węglu aktywnym



Anion exchange effluent polishing is reported to cost $7.1 \text{ €}/\text{m}^3$, not including regenerant disposal [25].

A detailed analysis of costs was made for secondary and tertiary treatment of a wastewater from a chemical complex with a flow of $25,000 \text{ m}^3/\text{d}$ and a BOD of $650 \text{ g}/\text{m}^3$. Costs of secondary and tertiary treatment are shown in Figure 10.

CONCLUSIONS

There are a number of process combinations including biological, physical and chemical processes which are technically feasible to produce an effluent of any desired quality. The selection of the optimum process

combination to yield the least cost will depend upon the volume and characteristics of the wastewaters being treated and upon the availability and cost of chemicals and equipment. This paper has attempted to summarize present technological development in the United States to produce treated wastewater effluents of varying degrees of quality.

WSPÓŁCZESNE KIERUNKI ROZWOJU TECHNOLOGII ŚCIEKÓW

Z uwagi na zaostrzające się ciągle kryteria ochrony wód przed zanieczyszczeniem, coraz częściej zachodzi konieczność stosowania nie tylko wysoko sprawnego biologicznego oczyszczania ścieków w celu maksymalnego ograniczenia zawartości BZT₅ i zawiesin w odpływie lecz również innych metod, umożliwiających usuwanie substancji organicznych odpornych na rozkład biochemiczny (ChZT, C_{org}), związków biogenych (N i P) oraz nadmiernego zasolenia. Metody te, wchodzące w skład trzeciego i czwartego stopnia oczyszczania, polegają na stosowaniu procesów fizykochemicznych po oczyszczeniu biologicznym lub z pominięciem biologicznych metod oczyszczania.

W artykule podano najnowsze światowe osiągnięcia w technologii oczyszczania ścieków, które umożliwiają wybór optymalnej kombinacji procesów biologicznych i fizykochemicznych, dzięki czemu uzyskuje się odpływ o pożądanej jakości przy najniższych sumarycznych kosztach.

Parametrami decydującymi o jakości odpływu z biologicznej części oczyszczalni z osadem czynnym są: obciążenie biomasy (F/M) oraz wiek osadu.

Od wartości obciążenia osadu zależy udział rozpuszczalnej i nierozpuszczalnej frakcji BZT₅ w odpływie oraz udział rozpuszczonej frakcji ładunku ChZT. Nazbyt wysokie obciążenia biomasy (niski wiek) powodują pęcznienie osadu i jego ucieczkę z osadnika wtórnego, a to jest przyczyną wzrostu zawartości zawiesin i ładunku BZT₅ w odpływie. Przy bardzo niskich obciążeniach biomasy (wysoki wiek) następuje dyspersja i utlenianie kłaczków osadu czynnego oraz uwolnienie znacznego ładunku fosforu i związków refrakcyjnych. Powoduje to wzrost zawartości rozpuszczonego ChZT i fosforu w odpływie.

Jakość oczyszczonych ścieków zależy także od zasolenia i zawartości BZT₅ w ściekach surowych. Wysokie wartości tych wskaźników powodują, odpowiednio, wzrost stężenia nierozpuszczonej i rozpuszczonej frakcji BZT₅ w odpływie.

Sprawność oczyszczania ścieków w trzecim i czwartym stopniu zależy nie tylko od średnich zawartości poszczególnych składników lecz także od zakresu ich fluktuacji w ściekach surowych i biologicznie oczyszczonych.

Zróźnicowanie jakościowe składu, nadmierne wahania BZT₅ i temperatury ścieków surowych powodują zmienność stałej k szybkości procesów biochemicznych, a tym samym — zmiany zawartości rozpuszczonego BZT₅ w ściekach oczyszczonych biologicznie. Związane z tym wahania obciążenia biomasy mogą także wywołać okresowe zmiany zawartości zawiesin i nierozpuszczonego BZT₅. Tak więc staranne wyrównanie składu ścieków surowych oraz stała kontrola jakości odpływu z biologicznej części oczyszczalni jest nieodzownym warunkiem poprawnej eksploatacji urządzeń w trzecim i czwartym stopniu oczyszczania.

Odplyw o bardzo stabilnej charakterystyce można uzyskać stosując osad czynny natleniany tlenem technicznym zamiast konwencjonalnego osadu napowietrzanego. Natleniany osad czynny (10 g/m^3 rozpuszczonego O_2) odznacza się także lepszymi własnościami sedymentacyjnymi, niższym przyrostem biomasy oraz wyższą sprawnością oczyszczania, którą można dodatkowo podnieść wprowadzając do komory natleniania pylisty węgiel aktywny.

Fosfor jest usuwany ze ścieków częściowo w osadniku wstępnym (pierwszy stopień oczyszczania), w procesie osadu czynnego (drugi stopień oczyszczania), a ostatecznie — strącany wapnem, siarczanem glinu lub chlorkiem żelazowym w trzecim stopniu oczyszczania. Obecnie najczęściej stosuje się chemiczne strącanie fosforu dawką glinu przy zachowaniu stosunku molowego $\text{Al}:\text{P} = (1,75 - 2,25):1$ równocześnie z oczyszczaniem biologicznym. Czynniki strącające jest dodawany do końcowej części komory napowietrzania lub przed osadnik wtórny. W ten sposób można usunąć około 90% fosforu.

Azot usuwa się ze ścieków, stosując metody biologiczne, fizyczne i chemiczne. Metoda biologiczna polega na kolejnym stosowaniu nityfikacji azotu organicznego do azotanów (przy niskim obciążeniu biomasy, odpowiednim wieku osadu i dużej zawartości rozpuszczonego tlenu) oraz denityfikacji w warunkach beztlenowych z wydzielaniem gazowego N_2 . Nityfikację prowadzi się zwykle w tej samej komorze, w której są rozkładane substancje węglowe, a denityfikację — najczęściej w wydzielonej komorze anaerobowej lub w złożu zatopionym, gdzie dla intensyfikacji procesu wprowadzany jest dodatkowo substrat nie zawierający azotu, najczęściej metanol.

Opracowane ostatnio w Austrii i RPA modyfikacje tej metody umożliwiają przeprowadzenie zarówno nityfikacji jak i denityfikacji w tej samej komorze dzięki zastosowaniu sekwencji tlenowych i beztlenowych sekcji w komorze napowietrzania osadu.

Aby uzyskać odplyw o wyższej jakości niż zapewniają to metody biologiczne, stosuje się chemiczne oczyszczanie ścieków przez koagulację wapnem, siarczanem glinu lub chlorkiem żelazowym oraz sedymentację, filtrację i adsorpcję na węglu aktywnym. W procesach tych usuwa się także fosfor i azot amoniakalny, który jest utleniany chlorem lub desorbowany w skrubkach po uprzedniej alkalizacji ścieków.

W przypadku odnowy wody z biologicznie lub chemicznie oczyszczonych ścieków stosuje się czwarty stopień oczyszczania, obejmujący koagulację koloidów barwy i mętności, filtrację, sorpcję na węglu aktywnym oraz usuwanie nadmiernego zasolenia w procesie wymiany jonowej. Adsorpcję refrakcyjnych związków organicznych można przeprowadzić, stosując kolumny sorpcyjne z ziarnistym węglem aktywnym lub węglem pylistym, dawkowanym do dopływu na filtr pospieszny (często ze złożem wielowarstwowym).

W artykule porównano koszty oczyszczania ścieków i odnowy wód różnymi metodami.

GEGENWÄRTIGE ENTWICKLUNGSRICHTUNGEN DER ABWÄSSERTeCHNOLOGIE

In diesem Artikel wurden die gegenwärtigen Entwicklungsrichtungen der Abwassertechnologie in den Vereinigten Staaten und in anderen Ländern der Erde dargestellt.

Es wurden auch die komplizierten Reinigungssysteme besprochen, in denen biologische, physikalische und chemische Vorgänge angewandt wurden, welche es ermöglichten gereinigte Abwässer von erforderlicher Beschaffenheit zu erhalten.

In der Arbeit wurden die Auswahlkriterien des wirtschaftliche günstigsten Reinigungssystems für verschiedene Mengen und Arten der Abwässer angegeben.

Bei Festlegung der Kriterien wurden Kosten und Art der zugänglichen chemischen Mittel sowie der mechanischen Einrichtungen in Betracht gezogen.

СОВРЕМЕННЫЕ НАПРАВЛЕНИЯ В РАЗВИТИИ ТЕХНОЛОГИИ СТОЧНЫХ ВОД

В статье представлены современные направления в развитии технологии сточных вод в Соединенных Штатах Америки и в некоторых других странах.

Обсуждены также сложные системы очистки, в которых применяются биологические, химические и физические процессы, позволяющие получать требуемое качество очищенных сточных вод.

В статье приведены критерии экономически оптимального выбора системы очистки для различных количеств и видов сточных вод.

При определении критериев учтены стоимость и вид имеющихся химических средств, а также механического оборудования.

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