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## TECHNICAL AND ECONOMIC CONSIDERATIONS IN INDUSTRIAL WASTEWATER TREATMENT

Increasingly stringent wastewater effluent requirements in the United States and other parts of the world are placing emphasis on optimizing existing processes, developing performance and economics of advanced water treatment processes and evaluating in-plant alternatives for wastewater reduction and by-product recovery. It has become apparent in most industries that a cost effective solution to future water quality problems will involve a combination of the above three considerations.

Major emphasis to this point in time has been directed toward removal of BOD and suspended solids. In the future, however, removal of nitrogen, phosphorus, and non-degradable organics will require consideration. Trace quantities of heavy metals and toxic organics will also require removal either at the source or by end-of-pipe treatment.

### 1. WASTEWATER TREATMENT PROCESSES

There is little doubt that biological processes will continue to be employed as a baseline treatment process for most organic municipal and industrial wastewaters in the future as effluent limitations become more stringent. This is a result of the construction of biological wastewater treatment plants to meet present requirements and the favorable economics and effluent quality attainable from biological wastewater treatment over physical-chemical treatments for most organic wastewaters for the removal of biodegradable organics.

Future effluent requirements can be met by improved pretreatment, by modifications to the biological treatment process, by add-on post treatments or by in-plant change to reduce volume and loading to the wastewater treatment system. The various alternatives are shown in fig. 1. Pretreatment should minimize variation in wastewater loading and remove pollutants which interfere with the biological process operation or pass through the system such as oil and grease and heavy metals. Pretreatment should, therefore, consider improved equalization, and more effective removal of non-compatible pollutants such as oil, sulfides, heavy metals, and inhibitory organics from the wastewater entering the biological process. For example, mixed media filtration of a petroleum refining wastewater prior to activated sludge resulted in effluent levels of  $5 \text{ mg/dm}^3$  oil and  $10 \text{ mg/dm}^3$  suspended solids.

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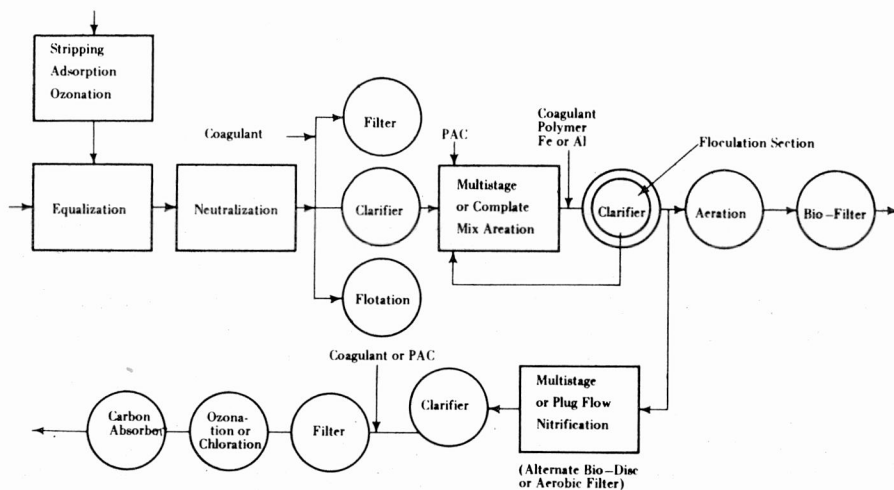


Fig. 1. Substitution diagram of wastewater treatment alternatives  
Rys. 1. Schemat zastępczy wariantów oczyszczania wody

Activated sludge studies were conducted on an organic chemicals wastewater containing a pesticide with and without pre-carbon treatment of the pesticide stream. The resulting reaction rate coefficients according to eq. (1) are shown in table 1.

Table 1

Reaction rate coefficients with and without carbon pretreatment of a pesticide wastewater  
Współczynniki szybkości reakcji przy i bez wstępnego oczyszczania ścieków pestycydowych

	Non-carbon treated K	Carbon treated K
28 °C	2.25	23.1
8 °C	0.81	6.5

It is obvious that screening of suspect wastewater components is essential for optimization of the biological process.

Wastewaters from the organic chemicals industry will frequently contain high concentrations of volatile organics. These will frequently have to be removed prior to biological treatment to avoid air pollution problems.

Modifications to the biological treatment plant include the addition of powdered activated carbon (PAC) to the aeration basin and addition of a flocculating chamber with or without polymers immediately prior to or incorporated in the final clarifier. The addition of PAC offers several process advantages; surfactants which cause foaming, non-degradable

organics and color are adsorbed on the carbon. The carbon further aids in sludge settling and dewatering. In some cases dispersed solids can be effectively removed by the addition of a cationic polymer alum or ferric salts added to the flocculation section.

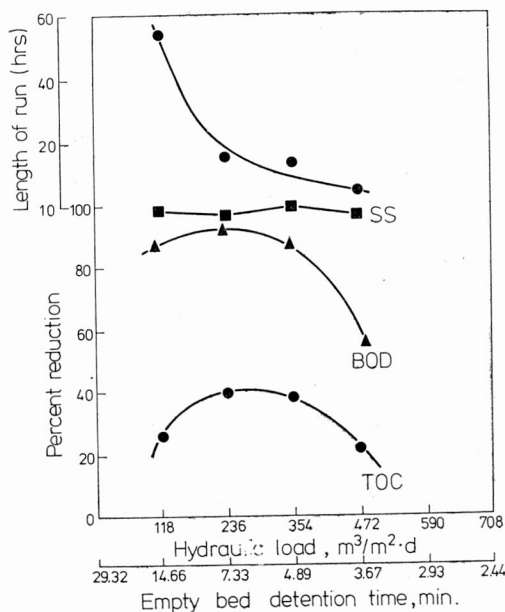


Fig. 2. Percent SOC and VSS removal vs. hydraulic load  
 Rys. 2. Zależność usuwania SOC i VSS od ładunku hydraulicznego

Post treatments are employed to remove residual suspended solids, nitrogen, phosphorus and refractory COD. Nitrogen removal from organic industrial wastewaters will in most cases employ biological nitrification with denitrification if required. The presence of inhibitory substances in the influent wastewater usually requires a two stage design.

Suspended solids from biological systems pose particular problems in many industrial wastewaters. Dispersed solids result from high total dissolved solids and the presence of surfactants which decrease the surface tension. A reduction in aeration tank temperature will cause an increase in effluent suspended solids. Effluent suspended solids may be reduced by addition of a polyelectrolyte prior to the final clarifier or by post treatment employing filtration or coagulation. In the case of dispersed suspended solids, filtration will require the addition of a coagulant for high removal efficiencies. When the suspended solids loading to the filter exceeds about  $100 \text{ mg/dm}^3$ , coagulation is to be preferred in order to avoid excessive back washing of the filter.

Carbon adsorption can be employed in a physical-chemical treatment sequence or as a post treatment following biological oxidation. Ozonation or chlorination will remove colour and some refractory organics. In the case of ozonation molecular modification may render the organics more biodegradable or more adsorbable on carbon.

## 2. BIOLOGICAL TREATMENT

This paper will consider the activated sludge process as the biological treatment method although other processes such as the aerated lagoon or the rotating biological contactor could also be employed and would be subject to the same constraints as the activated sludge process. The three primary factors which will affect the performance of the activated sludge process are variation in organic loading (F/M), variation in temperature and variation in product mix which changes the wastewater composition and hence the reaction rate coefficient  $k$ .

The reaction rate coefficient  $k$  is defined by the kinetic model [1], [2]

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

in which  $S_0$ ,  $S_e$  are influent and effluent BOD [mg/dm<sup>3</sup>],  $X_v$  — mixed liquor volatile suspended solids [mg/dm<sup>3</sup>],  $t$  — aeration detention time [d],  $k$  — reaction coefficient [d<sup>-1</sup>].

The coefficient  $k$  for several industrial wastewater is shown in table 2.

Table 2

Reaction rate coefficients for organic wastewater  
Współczynniki szybkości reakcji dla ścieków organicznych

Wastewater	$k$ days <sup>-1</sup>	Temp. °C
Potato Processing	36.0	20
Peptone	4.03	22
Sulfite Paper Mill	5.0	18
Vinyl Acetate Monomer	5.3	20
Polyester Fibre	14.0	21
Formaldehyde, Propanol, Methanol	19.0	20
Cellulose Acetate	2.6	20
AZO dyes, Epoxy, Optical Brighteners	2.2	18
Petroleum Refinery	9.1	20
Vegetable Tannery	1.2	20
Organic Phosphates	5.0	21
High Nitrogen Organics	22.2	22
Organic Intermediates	20.6	26
	5.8	8
Viscose Rayon and Nylon	8.2	19
	6.7	11
Soluble fraction of domestic wastewater	8.0	20

Variation in wastewater composition will affect the magnitude of  $k$ . Plants with a highly variable wastewater composition such as a multiproduct chemicals plant will experience a variable effluent quality due to changes in  $k$ . This effect can be dampened to some degree by increased equalization. In the same manner variation in organic loading can be dampened by increased equalization.

Seasonal changes in aeration basin temperature will effect  $k$  and hence effluent quality. Changes in basin temperature can be minimized by appropriate selection of aeration equipment. Where low winter temperatures are critical diffused aeration will result in a lower drop in temperature than surface aeration units.

In some cases high wastewater temperatures will affect plant performance, particularly during the summer. Surface aeration units which exhibit a maximum cooling effect would be advantageous in this case. The use of high purity oxygen systems for low temperature conditions has the advantage of maintaining higher aeration temperatures through covered tanks and lower heat losses.

### 3. FILTRATION

The effluent suspended solids from secondary clarification of a domestic wastewater may be expected to average  $30 \text{ mg/dm}^3$  of settleable solids which are readily removable by post filtration. In the treatment of industrial wastewaters, however, the effluent suspended solids may increase with an increase in total dissolved solids and a decrease in temperature. Two years of operating data from the activated sludge plant of Union Carbide in Charleston, West Virginia, showed an average effluent suspended solids of  $42 \text{ mg/dm}^3$  during the summer and  $104 \text{ mg/dm}^3$  during the winter. Reducing surface tension will also affect the concentration of effluent suspended solids. Analysis of operating data from a deinking board mill showed a correlation between effluent suspended solids and surfactant usage in the mill. These additional solids are usually dispersed and can only be removed by coagulation or filtration with the addition of coagulants.

While effective filtration of municipal secondary effluents can usually be achieved without the addition of coagulants, many industrial effluents contain high concentrations of dispersed solids and require the addition of coagulants. Secondary effluent from the treatment of acrylate monomer wastewater required  $60 \text{ mg/dm}^3$  of  $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$  to reduce the effluent suspended solid from  $20 \text{ mg/dm}^3$  to  $3 \text{ mg/dm}^3$  at a loading of  $236 \text{ m}^3/\text{m}^2 \cdot \text{d}$  in a mixed media filter. The type of coagulant employed can also have a marked effect on head loss and the resulting filtration cycle.

Recently Goup et al. [11] reported on an expanded clay filter media which serves the dual purpose of suspended solids removal and biological action for further removal of BOD from secondary effluents. The porous structure of the media retains the biological film during backwashing. Aeration of the effluent prior to filtration provides enough oxygen to maintain aerobic conditions in the filter for soluble BOD levels in the order of  $20 \text{ mg/dm}^3$ . Reported data indicates that soluble COD and suspended solids are reduced from  $34$  to  $18 \text{ mg/dm}^3$  and  $28$  to  $8 \text{ mg/dm}^3$ , respectively, at a hydraulic loading of  $10 \text{ m/h}$ . The media depth was  $1.5$  meters. Since effluent BOD levels in the order of  $10 \text{ mg/dm}^3$  will be common in the United States effluent filtration to combine aerobic biological oxidation and residual suspended solids removal offers considerable appeal. A study has recently been completed by ROQUE RAMON SEDA [1] using an upflow sand filter with preaeration of the secondary effluent. High removals of suspended solids and soluble BOD were achieved over a wide range of flow rates as shown in fig. 2.

#### 4. NITRIFICATION-DENITRIFICATION

There are two design considerations if effective nitrification is to occur. A minimum sludge age to insure the growth of *Nitrosomonas* is essential. For domestic sewage and synthetic substrates [9], [18] a sludge age in the order of six days at 20°C is adequate to achieve complete nitrification. In addition to sludge age, the rate of nitrification must be considered. WONG-CHONG and LOEHR [20] showed a nitrification rate of 1.04 mg/dm<sup>3</sup>/h/mgVSS. Some industrial wastewaters have yielded a lower rate. For example, second stage nitrification from an organic chemicals wastewater showed a nitrification rate of 0.42 mg NH<sub>3</sub>-N/mg active nitrifiers/day. When carbonaceous BOD is present the fraction of nitrifying biomass in the sludge is substantially reduced since the cell yield from organic carbon is significantly higher than that from ammonia. For example, the percent nitrifiers (as VSS) in a sludge from a single stage treatment removing 150 mg/dm<sup>3</sup> BOD and 25 mg/dm<sup>3</sup> NH<sub>3</sub>-N was calculated to be 4.9% while in a second stage unit removing 10 mg/dm<sup>3</sup> BOD and 25 mg/dm<sup>3</sup> NH<sub>3</sub>-N the percent nitrifiers was calculated as 43%. The fraction of the nitrifiers in the activated sludge can be estimated from eq. (2) assuming a yield coefficient of 0.15 mg VSS/mg NH<sub>3</sub>-N oxidized.

$$= \frac{0.15 N_{\text{ox}}}{a S_r + 0.15 N_{\text{ox}}} \quad (2)$$

This would imply that a two stage system, the first optimized for BOD removal and the second for nitrification, would provide the best overall performance and minimize effluent variability. For any given case, the economics of two stage vs. one stage vs. the effluent quality requirement would have to be evaluated. Since many industrial wastewater constituents include some organics and heavy metals, inhibit nitrification, the achievable rates of industrial wastes may vary markedly from domestic wastewater and should be confirmed in a laboratory or pilot plant study. For example Cr<sup>+6</sup> in concentrations in excess of 0.5 mg/dm<sup>3</sup> was found to inhibit nitrification in a chemical plant effluent. As shown later the addition of powdered activated carbon may be beneficial in these cases.

Nitrification is a zero order reaction to low effluent levels. Considering mixing and short circuiting, a multistage or plug flow reactor will show the highest efficiency.

##### 4.1. DENITRIFICATION

Denitrifying bacteria replace oxygen with nitrate as the terminal electron acceptor for the oxidation of a substrate. The nitrate nitrogen is reduced to N<sub>2</sub>, NO and N<sub>2</sub>O.

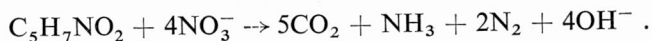
Many bacteria possess the ability to denitrify. Among these are the general *Pseudomonas*, *Bacillus* and *Micrococcus*.

The reduction of nitrate can be assimilatory or dissimilatory. Assimilatory reduction is only important for synthesis in the absence of ammonia in which the nitrate nitrogen is used for cell synthesis. This will not be further considered here.

It has been shown that organisms obtain less energy from the oxidation of a certain

amount of substrate under nitrate respiration than when oxygen is used as a terminal electron acceptor. It has been postulated that only half as much energy is transferred to the cell under denitrifying conditions. While denitrification is considered to occur in the absence of oxygen, it has been observed in aerobic processes. This can be attributed to the fact that filmed reactors will possess an aerobic layer and an anaerobic sublayer. Nitrogen oxidized in the aerobic layer may be denitrified in the anaerobic sublayer.

Denitrification can result from the endogenous metabolism of the biomass. Under these conditions CHRISTENSEN and HARREMOES [6] have proposed the reaction:



The theoretical consumption of sludge based on this equation is 2 mg VSS/mg NO<sub>3</sub>-N. WUHRMANN [21] pioneered work on endogenous denitrification. He indicated that both the nitrate and oxygen respiration rates under endogenous conditions depend on the type and quantity of substrates which can be mobilized by the cells and therefore the two rates should be closely related. These data are shown in fig. 3. Reported results on endogenous denitrification rates are summarized in table 3.

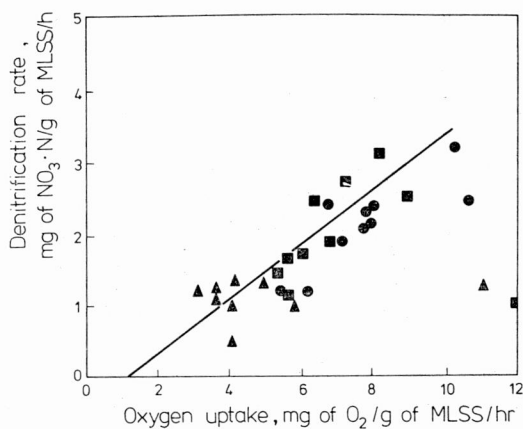
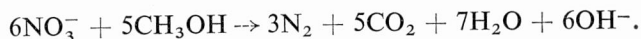


Fig. 3. Correlation between oxygen uptake and denitrification

Rys. 3. Korelacja pomiędzy poborem tlenu i denitryfikacją

For most practical applications denitrification through endogenous metabolism is too slow to be cost effective and a carbon source needs to be added to enhance the reaction. Early work in the United States employed methanol for this purpose. The dissimilatory nitrate reduction reaction is:



A theoretical methanol requirement is 2.47 mg methanol/mg NO<sub>3</sub>-N denitrified. The equation predicts that 3.57 mg alkalinity as CaCO<sub>3</sub> will be formed for each mg of nitrate nitrogen reduced. Field studies have shown 2.89 mg alkalinity/mg NO<sub>3</sub>-N reduced.

Present economics mitigate against the use of methanol as a carbon source for denitrification. Rather, when treating domestic wastewater process variants using an aerobic-anoxic system in which the BOD of the wastewater serves as a carbon source is the most cost effective approach in majority of cases.

Table 3

Endogenous denitrification rates  
Szybkość denitryfikacji endogennej

Denitrification rate mg NO <sub>3</sub> -N/g VSS/h	Temperature °C	Reference
1.7	17.1	[21]
0.7	73.6	[21]
0.9-1.1	16	[15]
1.6	12-16	[13]
2.0	20	[17]
1.1	20	[5]
1.3	20	[3]
0.5	10	[4]
0.8	15.5	[4]
1.25	25	[4]

In the treatment of industrial wastewaters depending on the situation, the BOD of the wastewater serves as the carbon source. Available data would indicate that denitrification from specific organics is a zero order reaction. Rates reported by a variety of investigators are summarized in table 4. Studies by the writer on an organic chemicals wastewater containing nitrate showed that the nitrate reduction rate was related to the BOD removal rate and hence the oxygen uptake rate. This follows the conclusions drawn by WUHRMANN [21].

Table 4

Denitrification rates with external substrate  
Szybkość denitryfikacji z substratem zewnętrznym

Substrate	Denitrification rate mg NO <sub>3</sub> -N/g VSS/h	Temperature °C	Reference
Methanol	15-25	20	[7]
Methanol	1-16	variable	[6]
Methanol	6.2-16.7	20	[9]
Glucose	2.5-3.0	20	[2]
Volatile acids	15	20	[8]
	4.2	10	[8]
Brewery	9.2-10.4	19-24	[19]
Sewage	1.4-2.5	20	[2]
	2-3	20	[6]
	1.1	10	[14]
	2.9	20	[9]



BOD removal kinetics can be defined by the relationship:

$$\frac{S_0 - S_e}{X_v t} = K \frac{S_e}{S_0} \quad (3)$$

Oxygen utilization in the activated sludge process is defined:

$$O_2/\text{day} = a' S_r + b' X_v t \quad (4)$$

Equation (4) can be re-expressed:

$$\frac{O_2}{X_v t} = a' \frac{S_r}{X_v t} + b \quad (4a)$$

and since

$$\frac{O_2}{X_v t} \cong \frac{NO_3 - N_R}{X_v t},$$

where  $N_R$  — removed N, then:

$$\frac{NO_3 - N_R}{X_v t} = C \frac{S_r}{X_v t} + b \quad (5)$$

Equation (5) for an organic chemicals wastewater is shown in fig. 4. The relationship between denitrification rate and nitrogen remaining for a synthetic fiber wastewater is shown in fig. 5. The kinetic relationship between BOD removal rate as defined by eq. (3) and denitrification rate for a chemicals wastewater is shown in fig. 6.

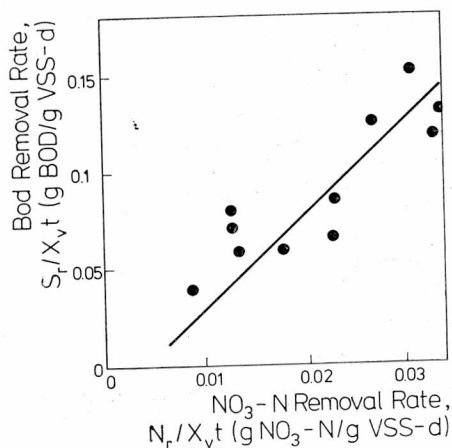


Fig. 4.  $NO_3-N$ /BOD removal ratio in denitrification

Rys. 4. Stosunek usuwania  $NO_3-N$ /BZT w procesie denitryfikacji

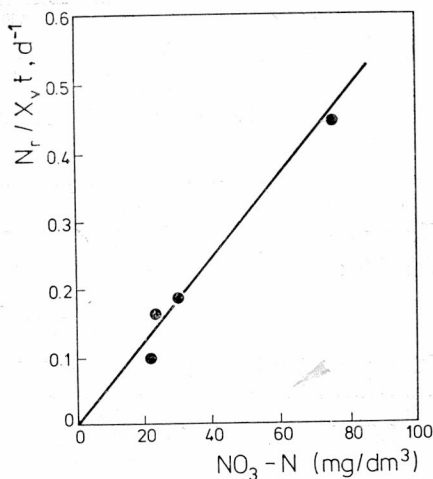


Fig. 5. Relationship between denitrification rate and nitrate remaining — synthetic fibre wastewater

Rys. 5. Związek pomiędzy szybkością denitryfikacji i pozostającymi azotanami (ścieki włókien syntetycznych)

Combining eqs. (3) and (5) would lead to the kinetic relationship shown in eq. (6) for complex wastewaters:

$$\frac{\text{NO}_3 - \text{N}_R}{X_v t} = CK \frac{S_e}{S_0} + b. \quad (6)$$

Insufficient data is available at present to test the general validity of eq. (6).

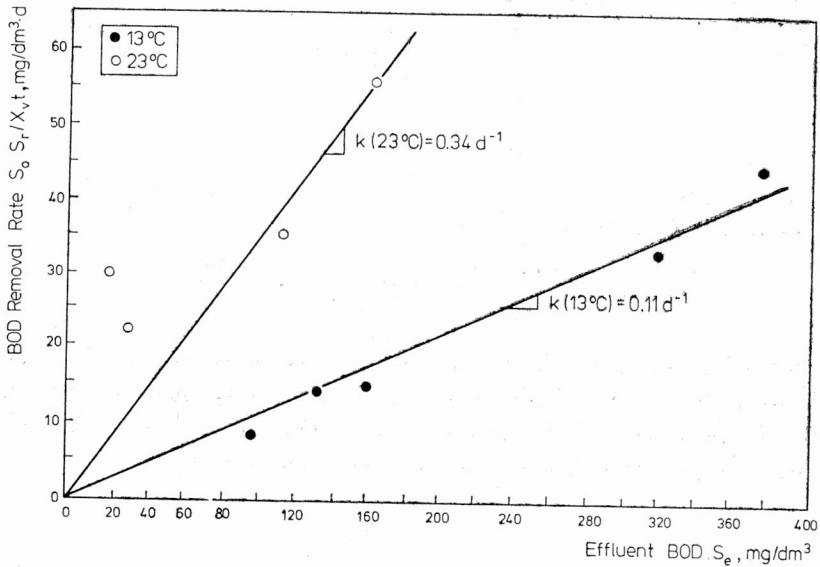


Fig. 6. BOD removal rate in denitrification

Rys. 6. Szybkość usuwania BZT w procesie denitryfikacji

#### 4.2. TEMPERATURE EFFECTS IN DENITRIFICATION

The temperature effect on the denitrification rate can be defined by the conventional relationship:

$$K_{D_t} = K_{D_{20^\circ\text{C}}} \Theta^{(T-20)}. \quad (7)$$

The reported values of  $\Theta$  have varied from 1.05 to 1.20. For attached growth denitrifying systems  $\Theta$  varied from 1.05 to 1.07. For suspended growth systems  $\Theta$  varied from 1.07 to 1.20. Data for denitrification of an industrial wastewater is shown in fig. 7.

#### 5. OZONATION AND CHLORINATION

The removal of colour and residual refractory organics from secondary effluents can be achieved in many cases by ozonation or chlorination. Ozonation of a secondary dye waste effluent for colour removal is shown in fig. 8. While there was a decrease in TOC

in the final filtered effluent the soluble BOD increased from 10 mg/dm<sup>3</sup> to 40 mg/dm<sup>3</sup> due to conversion of refractory to biodegradable compounds. Similar results were obtained from the ozonation of secondary effluent from low and high rate activated sludge units treating a tobacco processing wastewater as shown in table 5.

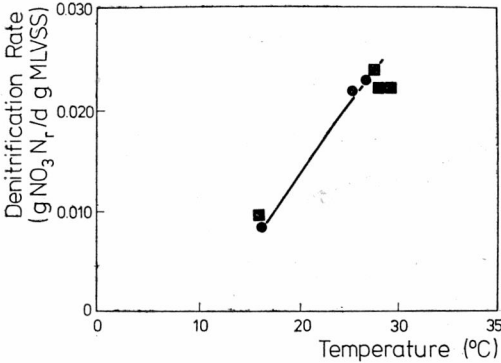


Fig. 7. Denitrification rate, temperature effect (not nitrate limited)

■ — continuous flow rate; ● — batch results

Rys. 7. Szybkość denitryfikacji i efekt temperatury

■ — wyniki przepływu ciągłego; ● — wyniki dozowania

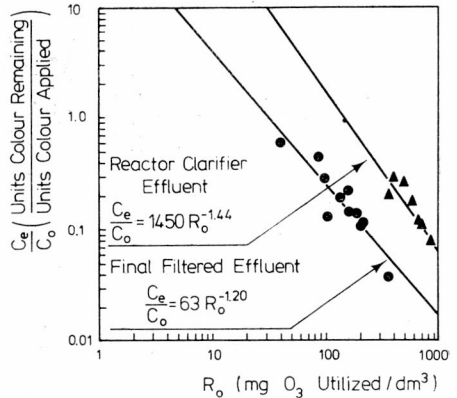


Fig. 8. Correlation of colour removal with ozone utilized dye-wastewater

Rys. 8. Korelacja pomiędzy usuwaniem barwy i zużyciem tlenu

Table 5

Ozonation test results on secondary clarifier effluent  
Wyniki testu ozonacji w ściekach wtórnie oczyszczonych na osadniku

Parameter	Low F/M (0.15)		High F/M (0.60)	
	time (min) <sup>a</sup>		time (min) <sup>a</sup>	
	0	60	0	60
BOD (mg/dm <sup>3</sup> )	27	22	97	212
COD (mg/dm <sup>3</sup> )	600	154	1100	802
pH	7.1	8.3	7.1	7.6
Org-N (mg/dm <sup>3</sup> )	25.2	18.9	40	33
NH <sub>3</sub> -N (mg/dm <sup>3</sup> )	3.0	5.8	23	25
Colour (Pt-Co)	3790	30.0	5000	330

<sup>a</sup> Loading of 155 mg O<sub>3</sub>/min

COD reduction by ozonation of an aerated lagoon effluent treating an organic chemicals wastewater is shown in fig. 9. FORD [10] showed that pre-ozonation of wastewater prior to carbon adsorption resulted in considerably higher removals of COD and BOD through

the carbon beds. This has been attributed to molecular changes resulting in increased aerobic biological action in the carbon columns. Ford's results are summarized in fig. 10. Chlorination has also been used for colour removal from secondary effluents. The disad-

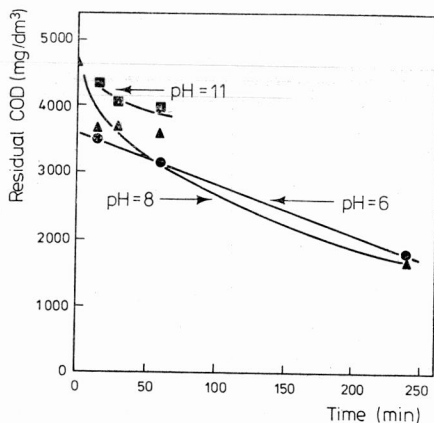


Fig. 9. Effect of pH on COD removal by ozonation-aerated lagoon outflow  
Rys. 9. Wpływ pH na usuwanie ChZT przez ozonowanie (odpływ z napowietrzanej laguny)

vantages to this process are the need for dechlorination and the increase in TDS of the effluent. Results obtained on chlorination of a tobacco processing secondary effluent are shown in fig. 11.

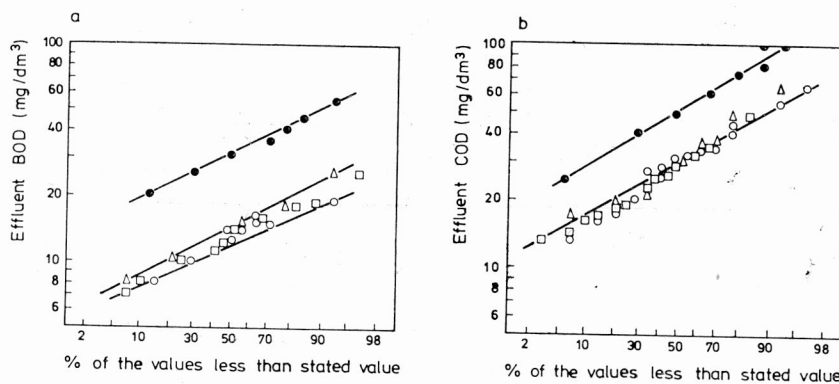


Fig. 10. Effect of ozonation on BOD and COD removal through activated carbon columns

- a) ● — no precarbon ozonation,  $\Delta$  — ozone = 6.2 mg/dm<sup>3</sup>, ○ — ozone = 6.2 mg/dm<sup>3</sup>, □ — ozone = 3.2–6.2 mg/dm<sup>3</sup>  
b) ● — no precarbon ozonation,  $\Delta$  — ozone = 6.2 mg/dm<sup>3</sup>, ○ — ozone = 6.2 mg/dm<sup>3</sup>, □ — ozone = 3.2–6.2 mg/dm<sup>3</sup>

Rys. 10. Wpływ ozonowania na usuwanie BZT i ChZT w kolumnach z węglem aktywnym

- a) ● — bez uprzedniego ozonowania,  $\Delta$  — ozon = 6.2 mg/dm<sup>3</sup>, ○ — ozon = 6.2 mg/dm<sup>3</sup>, □ — ozon = 3.2–6.2 mg/dm<sup>3</sup>  
b) ● — bez uprzedniego ozonowania,  $\Delta$  — ozon = 6.2 mg/dm<sup>3</sup>, ○ — ozon = 6.2 mg/dm<sup>3</sup>, □ — ozon = 3.2–6.2 mg/dm<sup>3</sup>

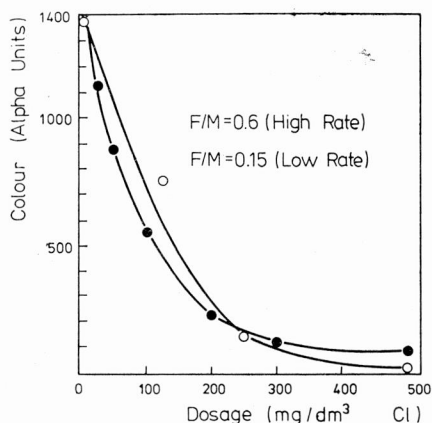


Fig. 11. Colour removal by chlorination  
Rys. 11. Usuwanie barwy przez chlorowanie

### 6. CARBON ADSORPTION

Carbon adsorption is employed for the removal of refractory organics, colour and trace quantities of heavy metals from wastewater. Present practice employs granular carbon columns or powdered carbon added to the activated sludge aeration basins. When carbon is to be employed following biological waste treatment, process optimization

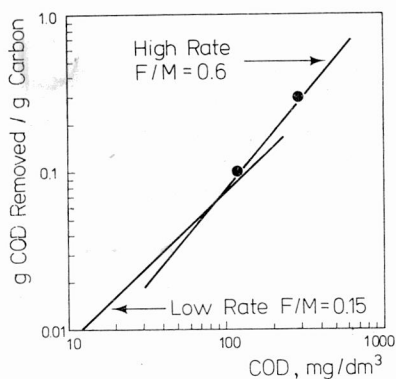


Fig. 12. Secondary effluent adsorption isotherms

Rys. 12. Izotermy adsorpcji odcieku wtórnego

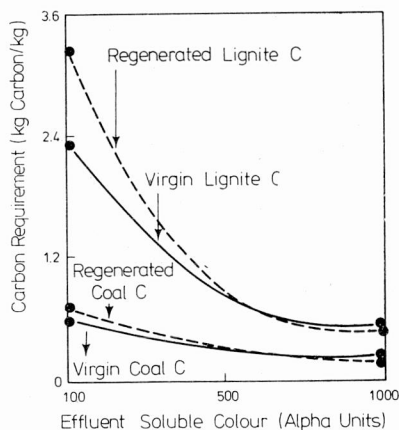


Fig. 13. Comparison of carbon requirements to reach various effluent colour criteria

Rys. 13. Porównanie zapotrzebowania węgla dla uzyskania kryteriów barwy dla różnych odcieków

should consider the level of treatment and cost through the biological process relative to the cost for carbon treatment. Figure 12 shows adsorption isotherms for the high rate and low rate effluents from a tobacco processing wastewater.

There is increasing interest in the use of powdered activated carbon in the activated sludge process. Carbon is added to maintain approximately 10,000 mg/dm<sup>3</sup> of powdered activated carbon and biomass. Economics requires carbon regeneration. In the Zimpro Wet Air Regeneration Unit the spent carbon/organic-slurry is raised to a pressure of approximately 800 psi; mixed with compressed air and passed through a heat exchanger to raise its temperature to approximately 400 °F. In a reactor the air oxidizes the adsorbed organics and the biomass. Only a slight loss in carbon capacity has been reported. Colour removal from a dye house wastewater is shown in table 6. It should be noted that on a bio-

Table 6

PAC-activated sludge for colour removal  
Osad czynny PAC dla usuwania barwy

	Carbon dosage	mg/dm <sup>3</sup>
	254	508
F/M (TOC basis)	0.03	0.036
MLSS (mg/dm <sup>3</sup> )	19,721	14,305
MLVSS (mg/dm <sup>3</sup> )	15,463	11,060
TOC inf. (mg/dm <sup>3</sup> )	462	458
TOC eff. (mg/dm <sup>3</sup> )	77	98
Soluble colour (APHA units)		
Influent	2,490	2,400
Effluent	1,240	550

mass basis the F/M is of the order of 0.2. It has been shown that the use of powdered carbon can enhance nitrification [6] particularly in the case of industrial wastewaters containing inhibitory substances. Further studies are presently being concluded to define the design parameters for the treatment of coke plant and organic chemicals wastewaters.

The type of carbon and the effects of regeneration on carbon capacity need to be considered to develop a cost effective process. Figure 13 shows a comparison of two carbons before and after regeneration on the removal of colour from a dye house secondary effluent.

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#### TECHNICZNE I EKONOMICZNE ASPEKTY OCZYSZCZANIA ŚCIEKÓW PRZEMYSŁOWYCH

Omówiono zasady doboru procesów jednostkowych obniżających zawartość związków biogenych, toksycznych i refrakcyjnych pozostałych po biologicznym oczyszczeniu ścieków uznanym za standard w technologii ścieków przemysłowych. Stosowanie nowoczesnych metod wstępnego oczyszczenia pokazano na przykładzie procesu PAC, gdzie sproszkowany węgiel aktywny adsorbuje detergenty i związki inhibujące bezpośrednio proces biologiczny.

Przedstawiony proces biologicznej nityfikacji i denityfikacji ilustrowano przykładami klasycznych stałych kinetycznych respiracji denityfikacyjnej i zakończono wyprowadzeniem wzoru na obniżkę zawartości  $N-NO_3$ , wyrażoną jako różnicę stężenia na początku procesu i na końcu  $N_R-NO_3$ :  $(N_R-NO_3)/X_V \cdot t = CK(S_e/S_0) + b$ . Następnie omówiono wpływ temperatury na procesy usuwania azotu, charakteryzując go stałymi  $\theta$  (teta) 1,07-120.

Doczyszczanie ścieków po biologicznym oczyszczeniu omówiono na przykładzie ozonowania, chlorowania i filtracji oraz adsorpcji na węglu aktywnym. Usuwać barwy ozonem i chlorem ze ścieków stwierdzono przewagę technologiczną ozonu, zwłaszcza w przypadku stosowania go przed filtracją, na węglu aktywnym.

Stosowanie procesów z węglem aktywnym, takich jak PAC, gdzie zużywa się duże ilości surowca, wymaga jego regeneracji (dochodzi do 200–500 mg C/dm<sup>3</sup>) in situ na oczyszczalni — najczęściej metodą mokrego utleniania.

### TECHNISCHE UND ÖKONOMISCHE GESICHTSPUNKTE DER REINIGUNG VON INDUSTRIE-ABWÄSSERN

Besprochen werden Grundverfahren die fähig sind, biogene, toxische und refraktäre Stoffe — die nach dem standardmässigem, biologischem Reinigungsprozeß im Abwasser noch verblieben sind — aus diesem zu beseitigen. Die Anwendung neuzeitlicher Methoden in der Primärreinigung, wird am Beispiel des PAC-Prozesses dargestellt; staubförmige Aktivkohle adsorbiert Detergentien und Substanzen die auf den biologischen Prozeß direkt hemmend wirken.

Eine in Details gehende Diskussion der biologischen Nitrifikation und Denitrifikation wird an Beispielen der klassischen Kinetik-Konstanten der Denitrifizierungsatmung veranschaulicht und schließt mit der Aufführung der Formel zum N<sub>NO<sub>3</sub></sub>-Abbau, die als Differenz der Konzentrationen am Anfang und Ende N<sub>R</sub>—NO<sub>3</sub> ab:  $(N_R - NO_3) / X_v \cdot t = CK(S_e/S_0) + b$ .

Nachfolgend wird der Einfluß der Temperatur auf die Stickstoffbeseitigung erörtert und die entsprechende  $\theta$ -Konstante mit 1,07–1,20 festgelegt.

Als weitergehende Reinigungsmaßnahmen nach den biologischen Verfahren, werden Ozonierung, Chlorung und Filtration sowie Adsorption mittels Aktivkohle angeführt. Versuche zur Beseitigung der Färbung mittels Ozon oder Chlor haben erwiesen, daß Ozon bessere Wirkung — vor allem vor der Filtration durch Aktivkohlefilter — hat.

Die Anwendung der Aktivkohle, wie z.B. im PAC-Verfahren, hat einen recht hohen Verbrauch (200–500 mg C/dm<sup>3</sup>) zu Folge; die Regeneration in situ an Ort und Stelle ist unentbehrlich und wird vorwiegend mittels naßer Oxidation durchgeführt.

### ТЕХНИЧЕСКИЕ И ЭКОНОМИЧЕСКИЕ АСПЕКТЫ ОЧИСТКИ ПРОМЫШЛЕННЫХ СТОКОВ

Обсуждены принципы подбора единичных процессов, снижающих содержание биогенных токсических и рефракционных соединений, оставшихся после биологической очистки сточных вод, признанной стандартом в технологии промышленных стоков. Применение новейших методов предварительной очистки показано на примере процесса PAC, где порошкообразный активированный уголь адсорбирует детергенты и соединения непосредственно ингибирующие биологический процесс.

Подробное обсуждение процесса биологической нитрификации и денитрификации иллюстрируется примерами классических кинетических постоянных денитрификационной респирации и окончено выводом формулы для снижения содержания N—NO<sub>3</sub>, выраженного как разность концентрации в начале и в конце процесса N<sub>R</sub>—NO<sub>3</sub>:  $(N_R - NO_3) / X_v \cdot t = CK(S_e/S_0) + b$ . Затем обсуждено влияние температуры на процессы удаления азота, характеризуя его постоянными  $\theta$  1, 07–120.

Дополнительная очистка сточных вод после биологической очистки обсуждена на примере озонирования, хлорирования и фильтрации, а также адсорбции на активированном угле. Удаляя окраску озоном и хлором из сточных вод, выявлено технологическое преобладание озона, в частности, в случае применения его до фильтрации на активированном угле.

Применение процессов с активированным углём — таких как PAC, где расходуются большие количества сырья, требует его регенерации (доходит до 200–500 мг C/дм<sup>3</sup>) в месте нахождения на очистной станции — чаще всего методом мокрого окисления.