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PLASTIC SCREEN AS THE BIOFILTER MEDIUM

The results of pilot-scale investigations of industrial-municipal wastewater treatment on a plastic medium bioffiter are discussed. The filter was packed with strips of flabby polyethylene screen. Wastewater treatment effciency, wastes being not recycled, as well as characteristics of the biofilm were determined. The dependence of wastewater treatment efficiency on the parameters of filter operation was interpreted based on selected mathematical models.

NOMENCLATURE

A_v — specific surface area of the medium, m^2/m^3,
H — height of the biofilter medium, m,
Q — hydraulic loading, m^3/m^2h,
L — load of pollutants, kg/m^3d,
S_0 — influent concentration, mg/dm^3,
S_e — effluent concentration, mg/dm^3,
T — temperature, °C,
t — time of flow through the biofilter, s,
V — biofilter volume, m^3,
$\eta = -S_0 - S_e/S_0$ — effect of the removal of pollutants, %,
C, K_{20}, n, O — empirical coefficients,
k_{20} — constant of BOD removal rate for $T = 20°C$,
c_w — coefficient of the medium surface area utilization,
— coefficient of the specific surface area reduction due to covering with the biofilm.

1. AIM OF INVESTIGATIONS

In the field of wastewater treatment the biofilter is one of the oldest engineering devices applied in biological treatment processes. New plastic media introduced during the last twenty years allowed to intensity the biological treatment processes and to revive the popularity of this method for wastewater treatment. Various plastic media are well known and still newer types are being introduced into the filter practice.

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The results of investigations on the municipal-industrial wastewater treatment on a new medium characterized by favourable technological and economical parameters are given in the present paper.

The experiments conducted on a model-pilot scale were carried out first in the laboratory on synthetic wastes [1] and then in the municipal department of sanitation on municipal wastes containing great amounts of industrial wastes [2].

The experiments aimed at determining the rate of flow through the filter, at evaluating the wastewater treatment efficiency, and at determining the composition of the biofilm.

The applicability of the selected mathematical models to the description of parameters for the municipal-industrial wastewater treatment on a filter packed with the screen medium was analyzed.

2. EXPERIMENTAL INSTALLATION

The experimental installation was situated in the wastewater pumping station being a part of the town sewage system. Wastes were supplied to the filter from the pressure conduit to the primary settling tanks, then gravitationally through the feeder to the filter and finally to the scoop chamber of the pumping station. The installation operated without the secondary settling tank and wastes were not recycled.

The task of primary settling tanks was to arrest larger suspended solids that could plug the conduits and system of wastes distribution onto the filter, as well as to keep the liquid level constant which allowed the unvarying rate of inflow to the filter.

The filter medium was a flabby plastic screen (fig. 1) [3]. The heigh of the filter medium was $H = 4$ m, and the cross-section of the filter was 0.23×0.23 m. The characteristic parameters of the biofilter are given in table 1.

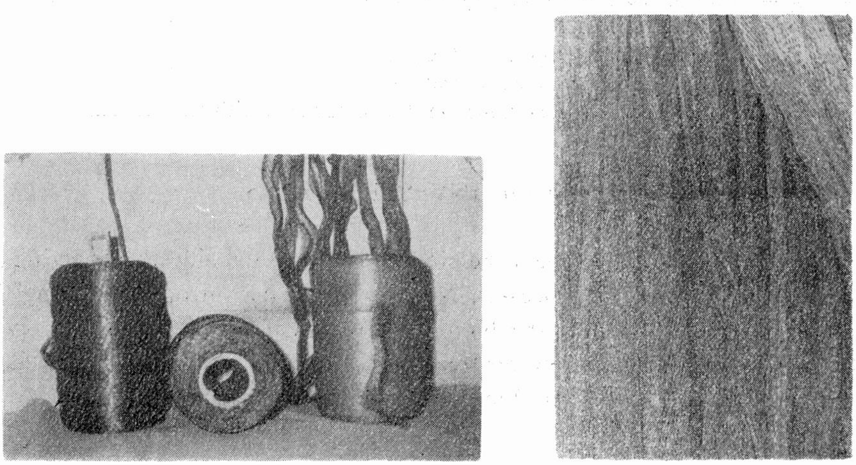

Fig. 1. Plastic screen as the biofilter medium

Rys. 1. Siatka z tworzywa jako wypełnienie złoża biologicznego

Table 1

Characteristics of model biofilter screen medium

Wielkości charakteryzujące wypełnienie siatkowe modelu złoża biologicznego

Parameter	Unit	Amount
Biofilter dimensions $a \times b \times H$	m	$0.23 \times 0.23 \times 4.0$
Cross-section $F = a \times b$	m^2	0.053
Medium volume V	m^3	0.212
Necessary amount of screen	m	320
Medium weight	kg	2.56
Volume of air spaces	%	98.5
Amount of screen per 1 m^3 of medium*	m/m^3	800–1500
Weight of 1 m^3 of medium (without biofilm)	kg/m^3	6.4–12.0

* Depending on the way of screen preparation

3. SCOPE AND METHODS OF INVESTIGATIONS

The investigations were performed in two stages. At the first preliminary stage lasting for two months only the wastes inflowing and outflowing from the filter were examined for hydraulic loadings of 0.6, 1.2 and 6.0 m^3/m^2h. The wastes were fed onto the filter continually.

At the second main stage lasting from January to June the investigations were conducted for six values of hydraulic loading. At low hydraulic loadings, the wastes were supplied to the filter periodically, and at higher loadings—continually. For analytical determinations the wastes were sampled before entering the filter, at 1/3 of its height, at 2/3 of its height, and after the outflow from the filter. Prior to physicochemical determination the 30-minute sedimentation of samples was performed in order to separate easily falling suspensions. The samples used for determinations were either single or, less frequently, averaged from the samples taken every two hours during 24 hours.

The following parameters were determined: air temperature, temperature of wastes, reaction, permanganate value, COD and BOD_5. Periodically, the physicochemical determinations were performed for the wastes investigated over a full range. The film was sampled for biological examination once a month at four filter levels, at the surface and at the layers lying at the depths of 1.3, 2.6 and 4.0 m from the top. The volume of a single sample varied from 1.0 to 6.0 cm^3. The whole sample of the film was carried to measuring vessels with a ground-in stopper and shaked to make the suspension more uniform. Then 0.05 cm^3 of the sample was taken for quantitative and taxonomic analysis performed by means of a biological microscope. The number of organisms was calculated per 1 cm^3 of the sample. The time of flow was determined in the laboratory on a medium with no biofilm.

The model filter was a plexi pipe of the diameter $d = 0.1$ m and height $H = 2.0$ m. The method employed was that making use of the coloured mark. In this case it was Rodamine. The colorimetric studies were performed by means of Zeiss Spektrocolorimeter named Spekol, equipped with the attachment for fluorescence measurements.

4. CHARACTERISTICS OF THE INVESTIGATED WASTES

In order to determine the quantitative and qualitative characteristics which are indispensable to design a treatment plant, the changes in concentration of wastes were examined over one week [4] (for all the week days). BOD_5 averaged for 24 hours varied from 217 mg O_2/dm^3 (Sunday, Monday) to 490 mg O_2/dm^3 (Wednesday, Thursday). Mean COD values ranged from 330 mg O_2/dm^3 (Sunday, Monday) to 1150 mg O_2/dm^3 (Wednesday, Thursday); mean concentration of total suspension—from 193 mg/dm^3 to 570 mg/dm^3; dry residue—from 716 mg/dm^3 to 3360 mg/dm^3; the content of fats—from 82 mg/dm^3 to 250 mg/dm^3; and the content of total nitrogen—from 28 mg/dm^3 to 70 mg/dm^3. Over the whole period of investigations the wastes were slightly basic with pH varying within the range 7.1–8.5. Such toxic substances as phenols, copper, zinc and chromium were detected. The composition of pollutants in wastes was found to vary considerably. The correlation coefficient of COD and BOD was low. Somewhat higher was the correlation coefficient of BOD and permanganate value.

5. RESULTS

5.1. MICROBIOLOGICAL CHARACTERISTICS OF THE FILM

The colour of the investigated biofilm changed from grey-beige to grey-brown, and then to brown-black. From January to the end of the first decade of May (at the hydraulic loading Q varying from 1.0 to 2.5 m^3/m^2 h) no significant changes in the filter biocoenosis were observed. In that period great amounts of filamentous bacteria of the genus *Sphaerotilus* sp. were observed. Generally, they were most numerous at the top layer of the filter and their content decreased with the filter depth. Great amounts of floating bacteria were observed over the whole period of investigations. In the top layer, cylindrical forms of great size were dominant, whereas in the deeper layers the bacteria of smaller size mainly occurred. The bacteria of the genus *Zooglea* sp., which were most numerous in the first examination, occurred only in top layers of the filter. The number of bacteria of the genus *Spirillum* sp. and *Beggiatoa alba* increased in the succesive examinations, being the highest in the last examination. Fungi whose amount varied to some extent were also most numerous in the last two examinations (at the hydraulic loadings of 4.0 and 5.0 m^3/m^2 h). Animal organisms were represented by protozoans (of the class *Mastigophora*, *Rhizopoda* and *Ciliata*) and nematodes. The initially great number of mastigophores decreased with time. They were found to be most numerous in the surface layer of the filter and less numerous in the deeper layers. The observed rhizopods were mainly those of the class *Testacea*, occurring over the whole period of investigations in various quantities and at various levels of the filter and those of the class *Amoeba* sp. which were quite numerous in the first two examinations; in further examinations they occurred sporadically. Both the number of ciliates and variety of their species were the greatest in the bottom layers. The resident (sedentary) forms of infusorians were observed only in the bottom layers. Both the composition of biocoenosis and number of organism in samples taken in the last two examinations were different from those in samples taken in the previous period. The organisms that dominated at all the levels were bacteria of the genus *Spirillum* sp. and *Beggiatoa* sp. Moreover, in the bottom layers there occurred great quantities of bacteria of the genus *Zooglea* sp. and threadlike bacteria of the genus *Sphaerotilus* sp. Fungi were most numerous in the surface layer. Of the protozoans, that occurred in the filter in very small quantities, most numerous in all the layers were mastigophorans.

It may be stated generally that in the last period of investigations the filter biocoenosis was poor (great number of bacteria of the genus *Beggiatoa* sp. and *Spirillum* sp., at the small number of protozoans which were completely lacking in the deepest layers), especially in the surface layer.

5.2. EVALUATION OF THE EFFECT OF POLLUTANTS REMOVAL ON THE FILTER

The evaluation of filter efficiency was based on the decrease in values of such indices as BOD_5, permanganate value, and COD. Because of great variability of index values (great scattering of measuring points) the values η and L were evaluated using arithmetic means and, for comparison, medians (for a series of greater number of measuring points — figs. 2 and 3).

For low hydraulic loadings ($Q = 1.0$ m^3/m^2 h) and low loadings of wastes (up to 1 kg BOD_5/m^3d) the removal of pollutants η varied from 70% to 75%. With the increasing Q and L the removal effect decreased and at $Q = 5$ m^3/m^2 h and $L = 7.20$ kg BOD_5/m^3 d it amounted to $\eta = 47\%$ for BOD_5 (fig. 4), $\eta = 43\%$ for COD, and $\eta = 53\%$ for permanganate value. The scattering of measuring points obtained from single samples is presented in fig. 5.

5.3. INFLUENCE OF FILTER HEIGHT ON THE EFFECT

The decrease in the load of pollutants varied depending on filter height. Variations in the removal of pollutants with changing hydraulic loading are given in fig. 6. Characteristically, at lower loads of pollutants ($L = 1.0$–2.4 kg O_2/m^3 d) and lower hydraulic loadings ($Q = 1.0$–1.8 m^3/m^2 h) the largest part of pollutants was removed at the top of the filter, up to the depth of 1.33 m the removal being much lower in the deeper layers. The growth of the biological film was most also intensive at the top of the filter, probably due to a more intensive sorption of fine suspensions and colloids on the biofilm surface. At higher values of Q and L there was a little spread in values of the pollutants removal at various levels of the filter. The quantitative distribution of the film along the height of the medium was also more levelled. The quantitative removal of COD along the height of the filter is similar in nature to that of BOD_5.

6. ADAPTATION OF MATHEMATICAL MODELS

The dependence of wastewater treatment efficiency on such technological parameters as Q, H, L, S is approached by the researchers in this field in various ways by means of a number of mathematical models. To the mathematical description of the operation of the screen filter the well-known ECKENFELDER'S [5] equation as well as the way of its interpretation suggested by OLESZKIEWICZ [6] were applied.

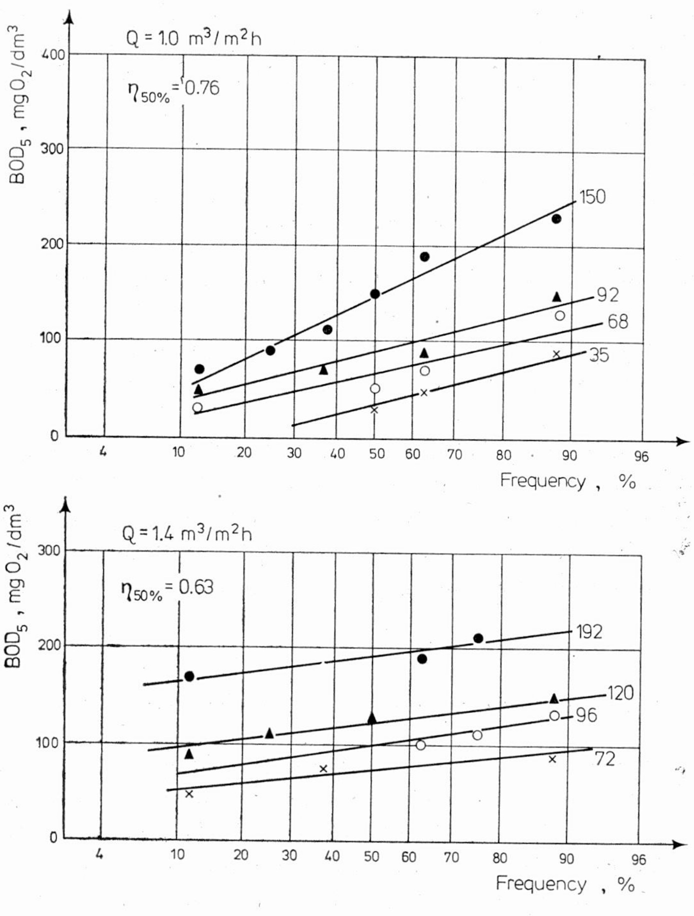

Fig. 2. BOD_5 values vs. particular filter heights for hydraulic loading $Q = 1.0\ m^3/m^2\ h$ and $Q = 1.4\ m^3/m^2\ h$

Rys. 2. Zmienność wartości BZT_5 na poszczególnych wysokościach złoża dla obciążenia hydraulicznego $Q = 1{,}0\ m^3/m^2\ h$ oraz $Q = 1{,}4\ m^3/m^2\ h$

For the filter with no recycle the Eckenfelder's equation is in the form:

$$\frac{S_e}{S_0} = \exp\left(-K_{20}\,\Theta^{T-20} H Q^{-n}\right), \tag{1}$$

where the coefficient K_{20} may be characterized by

$$K_{20} = k_{20} A_v \cdot f_t \cdot c_w. \tag{2}$$

The coefficient Θ describing the temperature effect on the removal rate varies in the

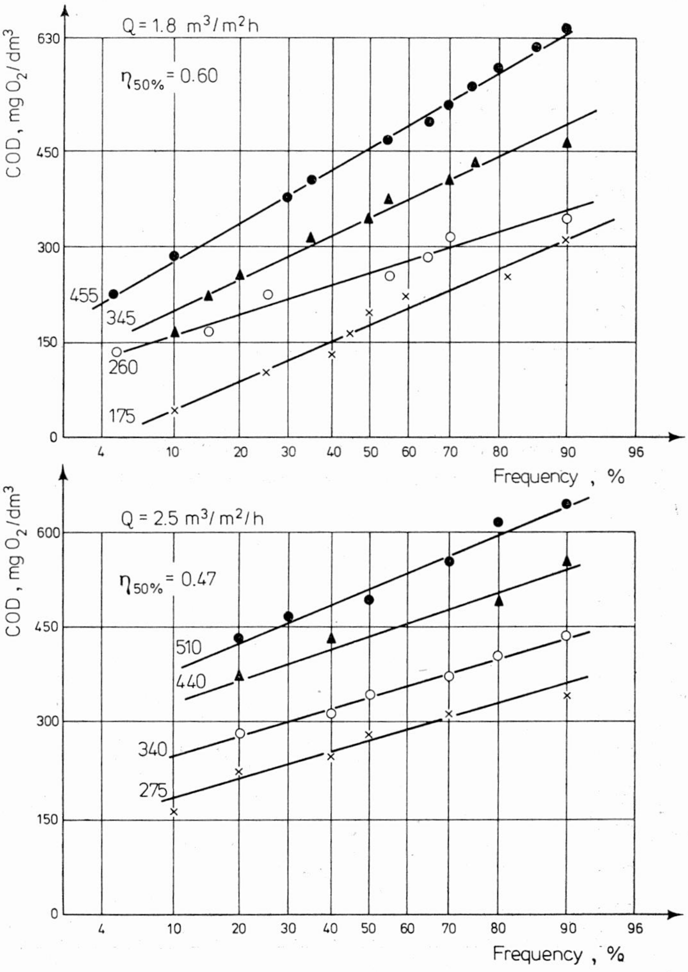

Fig. 3. COD values vs. particular filter heights for hydraulic loading $Q = 1.8$ m³/m² h and $Q = 2.5$ m³/m² h

Rys. 3. Zmienność wartości ChZT na poszczególnych wysokościach złoża dla obciążenia hydraulicznego $Q = 1{,}8$ m³/m² h oraz $Q = 2{,}5$ m³/m² h range 1.016–1.08, but it is usually assumed to be equal to 1.035 [7], [8]. The values of the coefficient K and n from equation (2) were determined graphically.

The values of the coefficients (figs. 7–9) determined for the screen medium and industrial-municipal wastewater under investigation were $n = 1$ and $K_{20} = 0.478$.

The formula proposed by OLESZKIEWICZ [6]

$$S_e = S_x \exp(-K/L) \tag{3}$$

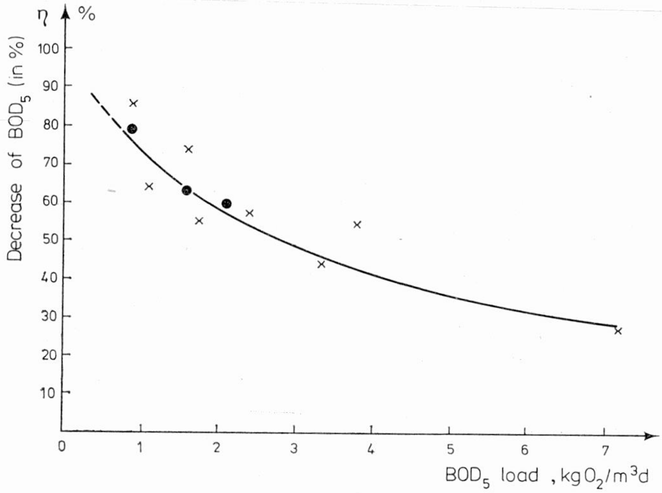

Fig. 4. BOD_5 removal (in %) vs. BOD_5 loading

Rys. 4. Zależność procentu obniżenia BZT_5 od obciążenia ładunkiem BZT_5

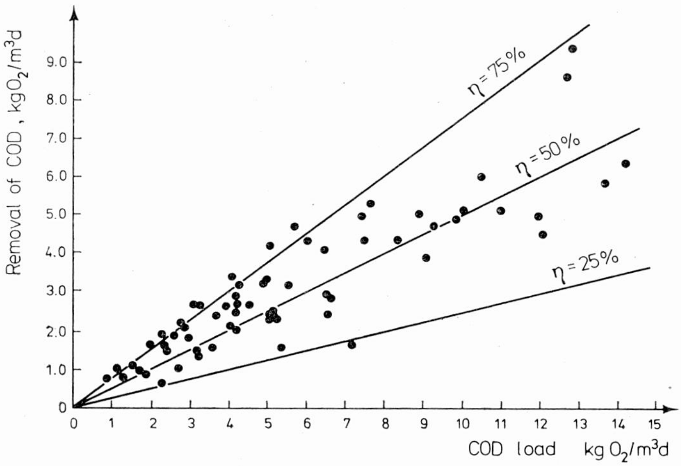

Fig. 5. Characteristics of pollutants load removal expressed by COD on the filter

Rys. 5. Charakterystyka usuwania na złożu ładunku zanieczyszczeń określonego przez ChZT describes well the filter operation for a number of cases of concentrated industrial wastewater treatment.

After transforming equation (3) to the form

$$\lg S_e = -\frac{K}{2.3}\frac{1}{L} + \lg S_X \tag{4}$$

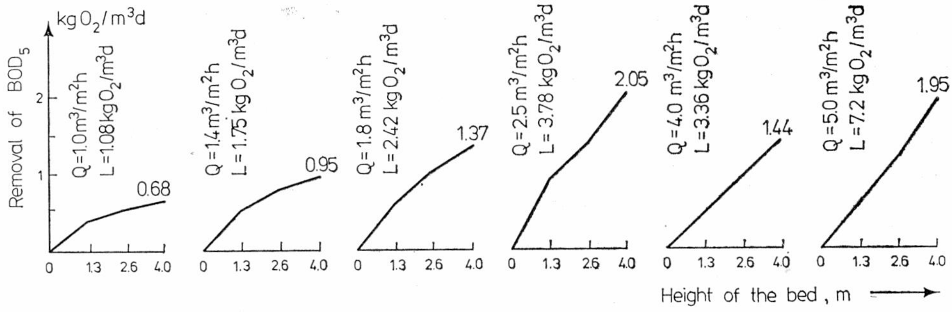

Fig. 6. Values of pollutants removal expressed by BOD_5 vs. particular filter heights for various Q and L

Rys. 6. Wielkości zmniejszenia zanieczyszczeń wyrażone w BZT_5 na poszczególnych wysokościach złoża dla różnych Q i L

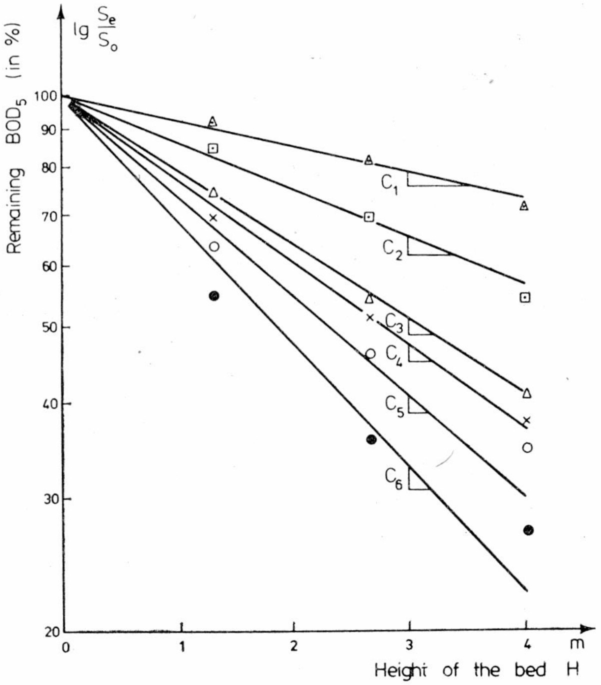

Fig. 7. Graphical determination of the coefficients C for various hydraulic loadings

Rys. 7. Graficzne wyznaczenie wartości współczynników C dla różnych obciążeń hydraulicznych

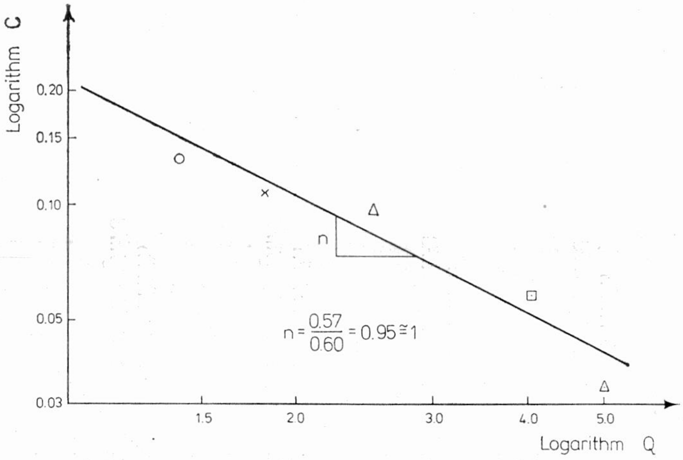

Fig. 8. Graphical determination of the coefficient n

Rys. 8. Graficzne wyznaczenie wartości współczynnika n

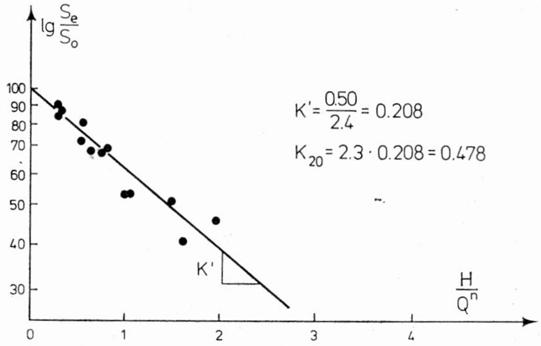

Fig. 9. Graphical determination of the value K_{20}

Rys. 9. Graficzne wyznaczenie wartości K_{20}

the values of K and S_x (fig. 10) may be determined graphically. S_x often reffers to mean influent concentration. Mean (for the whole period of investigations) influent BOD_5 concentration was equal to 260 mg O_2/dm^3. Mean value of S_x^1 and S_x^2 is 252 mg O_2/dm^3 which is approximate to mean BOD_5 of raw wastes.

7. HYDRAULIC INVESTIGATIONS

The coefficient n in equation (1) may also be determined based on examining the time of flow through the filter.

Mathematical grounds for the calculation of mean time of flow through the filter with spherical packing were formulated by HOWLAND [9]. A general form of the equation to calculate the mean time is as follows:

$$t = \frac{CH}{Q^n}, \tag{5}$$

where C and n are the coefficients dependent on the kind of liquid and medium.

The flow time was measured on a laboratory model filter of the height $H = 2$ m for hydraulic loading Q varying from 0.65 m³/m² h to 3.25 m³/m² h. The solution of the coloured dye (Rodamine) was fed continually and the mean time of flow through the

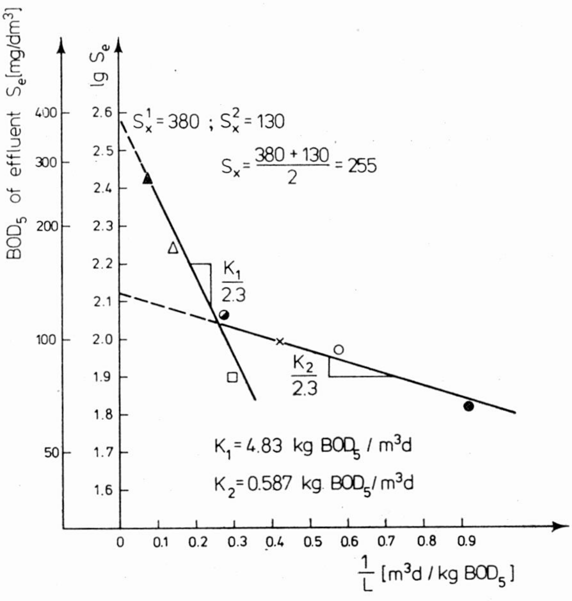

Fig. 10. BOD_5 in the effluent vs. BOD_5 loading

Rys. 10. Zależność BZT_5 w odpływie od obciążenia ładunkiem BZT_5

filter was assumed to be the time of observing in the effluent such a concentration of the index that would correspond to 50% concentration of the index in the influent (fig. 11). Hydraulic loading and corresponding mean times of flow are presented in table 2.

Graphically determined coefficients (fig. 12) assume the values $n = 1$ and $C = 0.063$. A final form of the equation for mean time of flow for a screen medium with no biofilm is as follows:

$$t = \frac{0.063\,H}{Q}. \tag{6}$$

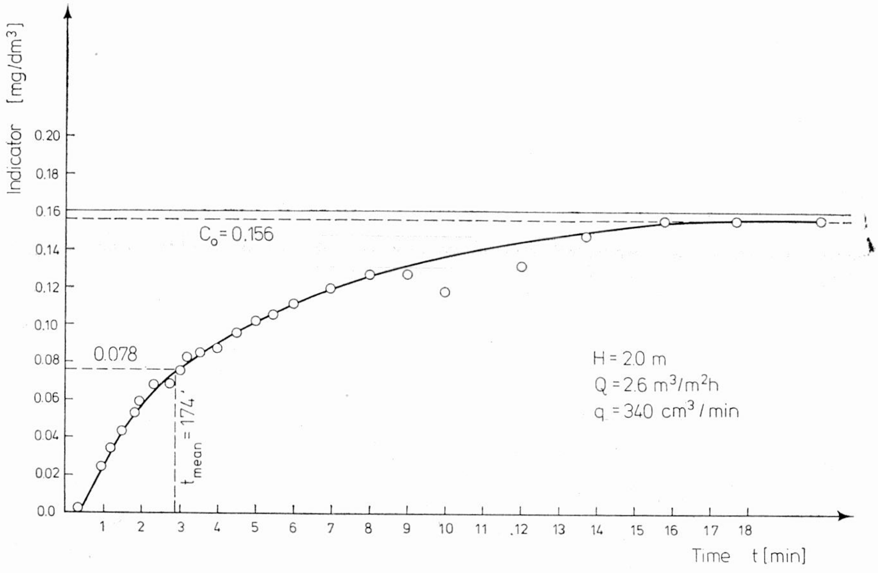

Fig. 11. Determination of the mean time of flow through a screen filter for $Q = 2.6$ m^3/m^2 h

Rys. 11. Wyznaczenie średniego czasu przepływu dla złoża siatkowego dla $Q = 2{,}6$ m^3/m^2 h

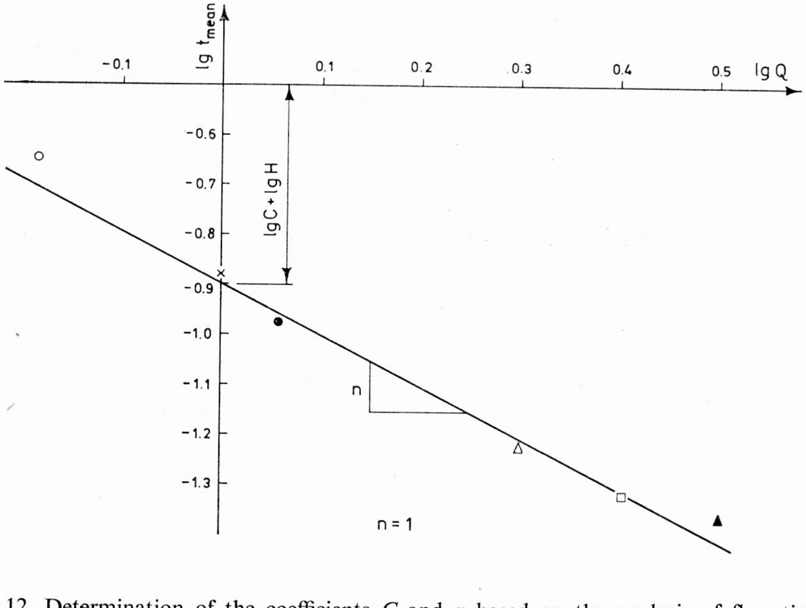

Fig. 12. Determination of the coefficients C and n based on the analysis of flow time

Rys. 12. Wyznaczenie wartości współczynników C i n na podstawie badania czasu przepływu

Table 2

Hydraulic loadings and corresponding mean flow times
Obciążenia hydrauliczne i odpowiadające im średnie czasy przepływu

Q (m^3/m^2 h)	0.65	1.0	1.3	2.0	2.6	3.25
t (mean) (s)	816	480	384	216	174	156

8. CONCLUSIONS

The flabby plastic screens applied as biofilter media satisfied the criterion of adequate mechanical strength and resistance to the action of wastewater compounds as well as to biological activity of microorganisms inhabiting the biofilm.

It was easy to make the medium and it required little material (plastic). Besides, the medium was characterized by a great number of air spaces and it provided a good ground for the development of a biofilm.

The biofilm was found, due to biological tests, to have the organisms composition typical of well operating highly loaded filters. The obtained efficiency of wastewater treatment varied from 75% to 50% for BOD_5 loading in the range 1–3 kg BOD_5/m^3 d, no recycle being applied.

The results obtained may be interpreted based on Eckenfelder's and Oleszkiewicz's equations. The value of coefficient $n = 1$ determined for the medium with a biofilm by interpreting the physicochemical tests of wastewater was the same as in the case of the medium with no biofilm (hydraulic tests).

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SIATKA Z TWORZYWA SZTUCZNEGO JAKO WYPEŁNIENIE ZŁOŻA BIOLOGICZNEGO

W pracy omówiono wyniki półtechnicznych badań nad oczyszczaniem ścieków przemysłowo-miejskich na złożu biologicznym wypełnionym tworzywem sztucznym. Jako wypełnienie złoża zastosowano pasma wiotkiej siatki polietylenowej. Określono efekt oczyszczania ścieków bez stosowania recyrkulacji oraz scharakteryzowano błonę biologiczną. Zależność efektu oczyszczania ścieków od parametrów działania złoża zinterpretowano w oparciu o wybrane modele matematyczne.

EIN KUNSTSTOFFENETZ ALS TROPFKÖRPERFÜLLUNG

Der Beitrag beinhaltet Ergebnisse von Versuchen zur Abwasserreinigung auf einem mit Kunststoff gefüllten Tropfkörper, die im halbtechnischen Maßstab durchgeführt worden sind. Die Schüttung bestand aus einem Netzgebinde aus Polyethylen. Bestimmt wurde die Reinigungsleistung des Tropfkörpers (ohne Rezirkulation) und die Charakteristik des biologischen Rasens. Die Leistung des Körpers ist eine Funktion der Belastung, was mittels entsprechender Modellformeln beschrieben wurde.

ПЛАСТМАССОВАЯ РЕШЕТКА КАК ЗАПОЛНЕНИЕ БИОФИЛЬТРА

Обсуждены результаты полузаводских испытаний по очистке промышленно-городских сточных вод на биофильтре, заполненном пластмассой. В качестве заполнения применялась гибкая этиленовая решетка. Определен эффект очистки сточных вод без применения рециркуляции и дана характеристика биопленки. Зависимость эффекта очистки стоков от параметров действия фильтра истолкована на основе избранных математических моделей.