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APPLICATION OF SOME NATURAL ADSORBENTS TO SINGLE- AND DOUBLE-MEDIUM FILTRATION OF A MODEL SYSTEM AND SURFACE RIVER WATER

Some physico-chemical properties of anthracite, ceramsite, and quartz sand have been investigated within a wider study of possible applications of some natural materials as filtration media. The applicability of these materials was tested in the process of separation of suspended particles from kaoline suspensions (model system) and surface river water. They were examined under conditions of the single- and double-medium open, fast, gravitational filtration. It has been found that separation of suspended particles by filtration was almost complete. Besides, a significant increase in the active filtration period as compared to classical sand filters has been stated.

1. INTRODUCTION

Description of filtration as a complex method of separation of a solid from liquid phase requires simultaneous consideration of a number of physico-chemical and hydrodynamic parameters [1]–[9]. As the adhesion forces between solid particles of the dispersed phase and the surface of filtration medium depend on the textural characteristics of the latter, it is of great importance to study the morphology of both grains and pores, pore size distribution, properties of the interphase region, etc.

In the light of the above facts we have undertaken a study of adsorption characteristics of some natural adsorbents such as anthracite, ceramsite, and quartz sand. These materials were characterized by determining their textural properties and tested under conditions of the single- and double-medium filters in clarification processes of a model system and surface river water.

2. EXPERIMENTAL

All filtration experiments were carried out on a set-up schematically presented in fig. 1. Its main part was a glass tube, 250 cm high and 2.5 cm in diameter. The ambient temperature was 20 ± 0.5°C.

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The model suspension of kaoline (Salzmünde, GDR) was prepared by dispersion of 0.25 g of the fine powder sample in 1 dm^3 of distilled water. Prior to filtration, surface river water was treated by the $Al_2(SO_4)_3 \times 18H_2O$ coagulant and an anionic polyacrylamide-based flocculant, A_3. The floccules formed were separated by sedimentation, and the water, partly clarified, was supplied at the top of the filtration column.

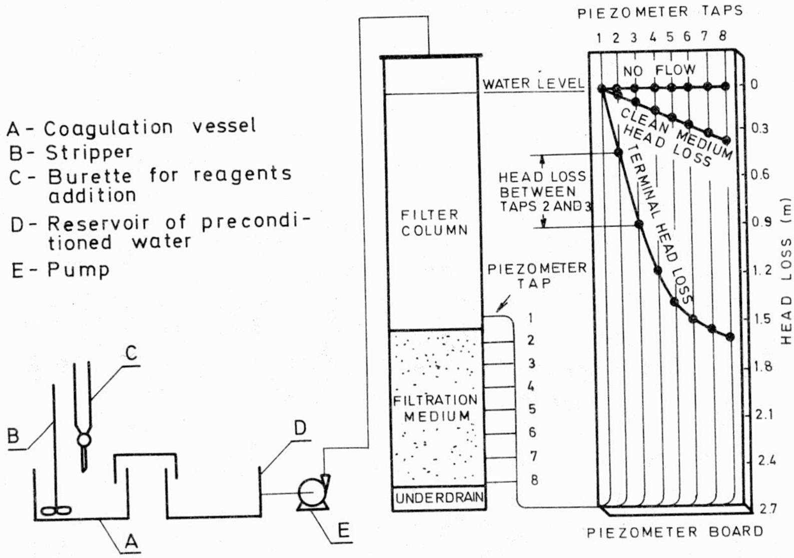

Fig. 1. Schematic diagram of the set-up for conditioning and filtration of water

Changes of zeta potential of particles in the influent were measured by the electrophoretic method with the use of a zeta-meter ZM 77 (Zeta-meter Inc. New York). The filtration kinetics was followed by determining the permanganate consumption, turbidity, and suspended matter content by standard methods. The X-ray analyses were carried out on a Philips PW 1050/25 difractometer with the use of the CuK_α radiation. Changes of aluminium concentration at different depths of the filtration medium were monitored by X-ray fluorescence spectromery on a VRA-20 analyser, VEB Carl Zeiss, Jena.

The pore volume distribution was investigated in the region of transient pores and macropores by the mercury method with the use of a Carlo Erba 2000 porosimeter. Specific surface of samples was determined by the BET method on the basis of the low-temperature adsorption isotherms of nitrogen with the application of a standard volumetric apparatus. A JEOL ISM-35 scanning electron microscope was used to study textural properties of the samples.

3. RESULTS AND DISCUSSION

Two types of filtration have been investigated, namely the single-medium filtration through quartz sand and ceramsite (cases A and B) and two versions of double-medium filtration, i.e., through ceramsite/quartz sand (case C) and anthracite/quartz sand (case D). The medium grain characteristics are given in tab. 1.

Table 1

Types of filtration media, grain parameters, and the bed depth

Medium	d_{min} mm	d_{max} mm	$d_{eq} = \frac{100}{\Sigma pi/di}$	$\frac{1}{d_{eq}} = \frac{0.5}{d_{eq1}} + \frac{0.5}{d_{eq1}}$	Bed depth mm a	Bed depth mm b
A) Single-medium quartz sand	0.40	1.00	0.533	–	700	700
B) Single-medium ceramsite	0.80	1.60	0.955	–	700	700
C) Double-medium	0.80	1.60	–	0.684	350	400
ceramsite – quartz sand	0.40	1.00			350	600
D) Double-medium	0.63	1.60	–	0.675	350	400
anthracite – quartz sand	0.40	1.00			350	600

a – in filtration of the model suspension of kaoline,
b – in filtration of surface river water.

Single-medium filtration through quartz sand. In order to determine the basic structural characteristics of the quartz sand used, it was studied via the X-ray and porosimetric analyses (figs. 2 and 3). As seen from fig. 3 the porosity of quartz sand is 0.017 cm^3/g.

The filtration cycle is short, and for the model influent it lasted 10–12 h, as seen from fig. 4. Turbidity of the influent was 16.5–19.4 NTU, which corresponds to

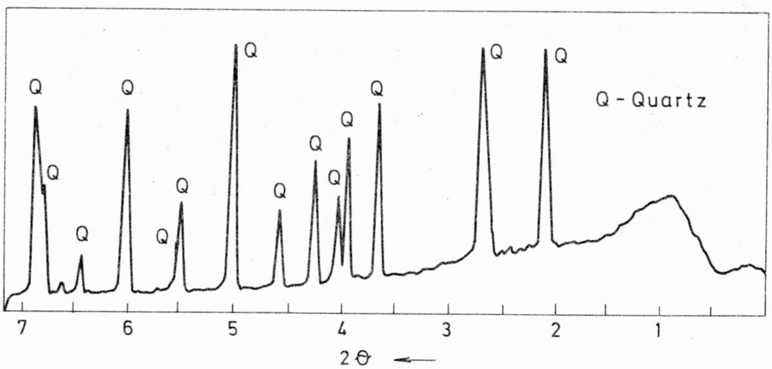

Fig. 2. X-ray difractogram of quartz sand

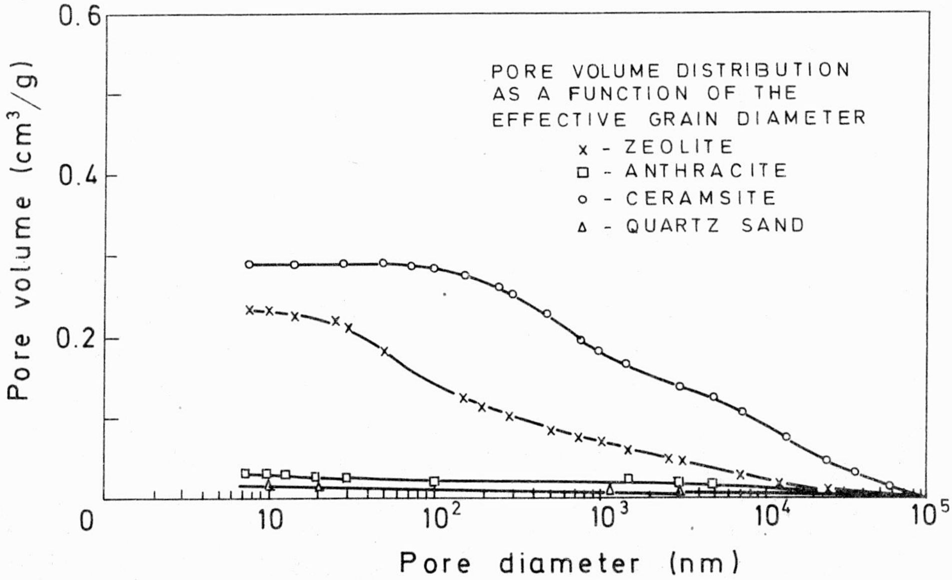

Fig. 3. Pore volume distribution as a function of the effective grain diameter of zeolite, quartz sand, ceramsite, and anthracite

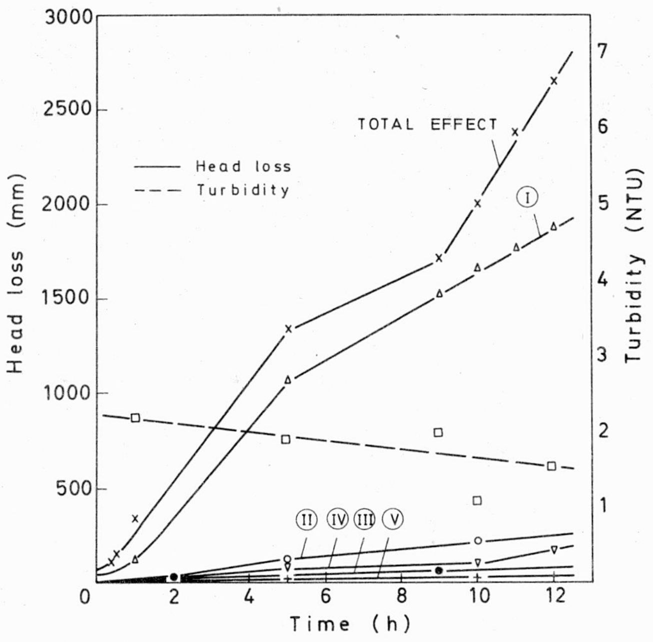

Fig. 4. Changes of the head loss and turbidity with bed depth in single-medium filtration through quartz sand as functions of time

a content of suspended matter of 6.8 mg/dm^3, while that of the filtrate was 1.0–2.5 NTU, the suspended matter content being practically equal to zero.

Penetration and deposition of the precipitate in the single-medium quartz sand filter were defined via determination of the aluminium concentration (expressed as number of counts per second) by the X-ray fluorescent analysis. The results are pesented in fig. 5.

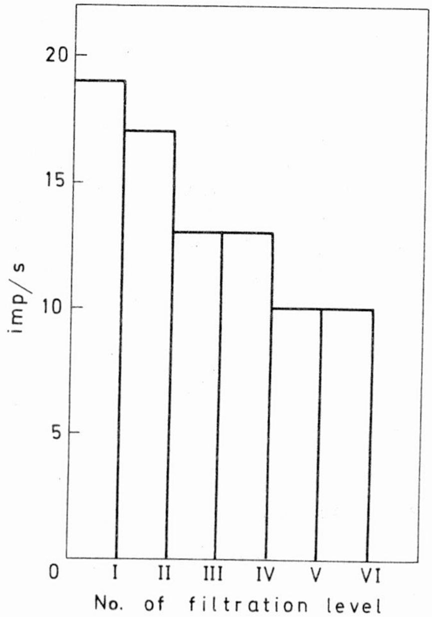

Fig. 5. Changes of aluminium concentration with the depth of filtration medium

It is evident that separation of suspended particles and remaining floccules takes place mainly on the bed surface in the first layer, and shows a kind of exponential decrease with the filter depth.

Single-medium filtration through ceramsite. The results of the X-ray analysis of ceramsite are presented in fig. 6. On the basis of the characteristic signals on the difractogram and their intensities, it can be concluded that ceramsite consists of the mineral quartz and feldspar.

Turbidity of the influent ranged within 13.2–15.8 NTU, whereas for the effluent at the end of the filtration cycle it amounted to 0.4–1.8 NTU. The suspended matter content was 5.4 and 0.0 mg/dm^3, while the permanganate consumption was 5.4 and 2.8 mg/dm^3 for the influent and effluent, respectively.

A filtration cycle of the single-medium filtration through ceramsite is illustrated in fig. 7. The deposition and distribution of the precipitate (consisting of small floccules) in filter B are illustrated in fig. 8. The behaviour of the system is generally similar to that in the previous case.

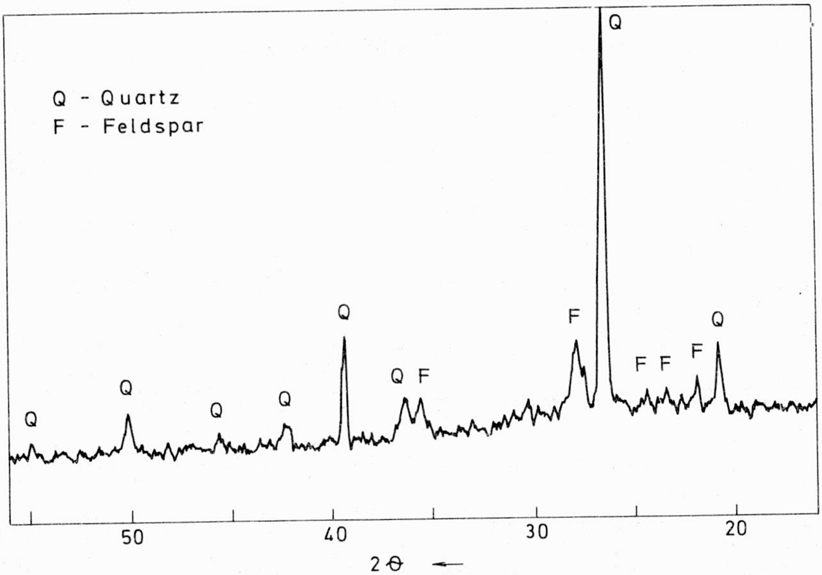

Fig. 6. X-ray difractogram of ceramsite

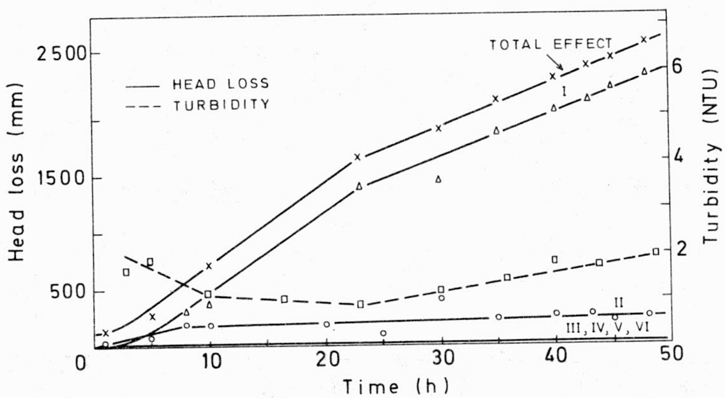

Fig. 7. Changes of head loss and turbidity with depth of ceramsite filtration bed as functions of time

Double-medium filtration. In order to find a suitable combination of filtration media, two versions of double-medium filtration have been studied (cases C and D).

The filtration cycle data for the combination ceramsite–quartz sand are given in tab. 2. The influent turbidity of 16.4–23.2 NTU has dropped after filtration down to 0.0–2.1 NTU. The suspended matter content, which at the beginning amounted to 18.8 mg/dm^3, reduced partially to zero in the course of 50 h of filter operation.

The main feature of this filter was the activity exhibited by the first and second

Table 2

Changes of head loss with the bed depth of filter C as a function of time

		Head loss (cm)								
		1	2	3	4	5	6	7	$\Sigma \Delta P$	
1	13.7	1.6	2.5	4.8	8.3	8.0	2.7	0.0	27.9	1.8
5	13.4	6.0	7.0	4.0	13.3	8.0	2.7	0.0	41.0	–
9	10.4	11	14	7.3	13.3	7.0	2.0	0.0	54.6	–
12	9.2	15.7	19.3	5.5	19.5	6.7	2.5	0.3	69.5	2.1
24	8.2	28.2	31	8.7	26	6.7	4.0	0.5	105.1	–
33	7.1	40.5	44.5	14.0	32.6	7.5	4.0	0.0	143.1	1.5
36	7.2	46.5	50	11.5	39	7.0	5.5	0.0	159.5	–
48	5.5	60	66	21	36	8.0	4.0	0.0	195	–
50	5.2	61	76	13	43	0.5	7.5	4.0	205	–
54	4.9	68	82	18	45	7.5	6.7	0.0	227.5	2.0

layers and, to a certain extent, by the fourth layer, which was not the case with the former two filters. The corresponding results for the anthracite–quartz sand filter combination are given in tab. 3.

Turbidity of the influent ranged within 11.8–17.0 NTU, while that of the filtrate was 0.0–1.8 NTU. The suspended matter contents amounted to 4.1 and 3.2 mg/dm^3 for the influent and effluent, respectively. At the same time, the permanganate consumption dropped from 4.1 to 3.2 mg/dm^3.

Considering the work of the two double-medium filters (C and D), it can be concluded that filtration process takes place in depth of the filtration medium. The

Table 3

Changes of head loss with the bed depth of filter D as a function of time

		Head loss (cm)								
		1	2	3	4	5	6	7	$\Sigma \Delta P$	
1	12.2	2.5	2.0	2.5	8.0	3.0	0.5	0.0	18.5	1.8
5	11.8	8.3	3.5	5.2	6.1	2.8	0.6	0.0	26.5	–
10	10.9	30.0	8.1	13.1	7.5	3.2	1.0	0.0	62.9	0.5
22	10.3	50.8	13.2	21.0	6.8	1.9	1.3	0.0	95.0	–
25	9.9	57.2	15.6	26.2	7.8	3.5	0.9	0.0	111.2	–
30	9.5	69.0	20.1	31.0	8.1	3.6	0.8	0.0	132.6	0.1
32	9.3	74.0	23.1	33.8	9.2	2.0	1.0	0.0	143.1	–
45	8.5	85.0	25.2	35.6	13.0	3.4	0.5	0.0	162.7	0.3
50	8.2	106.3	31.3	37.2	13.5	4.0	1.3	0.0	193.6	–
57	7.6	112	38.0	38.0	14.0	3.8	0.9	0.0	206.7	0.0
68	5.2	118	48.1	41.8	14.5	3.1	1.2	0.0	225.9	–

values of head-loss measured at different heights of the column indicate that other layers, not only the first one and bed surface, are also active.

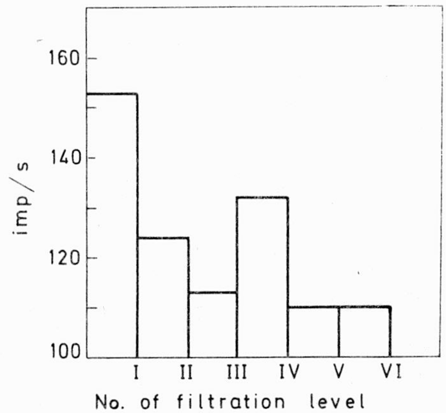

Fig. 8. Changes of aluminium concentration with bed depth of the filter B

4. INFLUENT CONDITIONING

The optimal contents of the basic coagulant $Al_2(SO_4)_3 \times 18\,H_2O$ for both influents (the model suspension and surface river water) were determined by *jar-test.*

Basic physico-chemical characteristics of the influent prior to its chemical treatment are given in tab. 4. The optimal amounts of the coagulant and flocculant for the model suspension can be obtained from the data of the jar-test (tabs. 5 and 6).

Table 4

Some physico-chemical characteristics of the influent prior to its chemical treatment

Parameter	Turbidity NTU	Zeta potential mV	$KMnO_4$ consumption mg/dm^3	pH
Model suspension	87	−36.38	7.0	7.60
River water	14	−26.95	22.0	7.80

On the basis of these results it can be concluded that the optimal conditions for coagulation and flocculation in the model system are achieved at 51.1 mg/dm^3 $Al_2(SO_4)_3$ and 1.50 mg/dm^3 of polyelectrolyte A_3.

The analogous experiments were also carried out for the other influent, surface river water. The results showed that particles were negatively charged, as the zeta

Table 5

Results of the jar-test for determination of the optimal coagulant content in the model suspension

$Al_2(SO_4)_3$ mg/dm^3	Zeta potential mV	Sedimentation rate cm/min	$KMnO_4$ consumption mg/dm^3	Turbidity NTU	pH
0	−44.6	—	7.0	35.0	7.00
17.0	−46.5	1.5	4.7	10.1	7.30
34.1	−29.1	1.4	4.5	4.6	7.30
51.1	−26.6	2.6	4.4	4.3	7.20
68.2	−36.3	2.2	4.9	6.3	7.20
102.3	−38.8	1.5	5.1	10.2	7.20
136.0	−42.0	—	4.8	20.0	7.15

Table 6

Results of the jar-test for determination of the optimal flocculant content

Polyelectrolyte A_3 mg/dm^3	Zeta potential mV	Sedimentation rate mm/min	Turbidity NTU	$KMnO_4$ consumption mg/dm^3	pH
0.25	−29.7	—	28.29	2.9	7.15
0.50	−29.2	0.50	27.61	2.8	7.15
1.00	−31.9	2.00	19.45	2.9	7.15
1.50	−29.7	3.80	14.13	2.5	7.15
2.00	−33.0	3.40	15.77	2.9	7.15
3.00	−33.5	2.20	15.88	2.9	7.15

potential at pH 7.10 was −27 mV. On reaching the optimal level of the coagulant (51.1 mg/dm^3) and flocculant (2.0 mg/dm^3), the zeta potential was −14.7 mV. When comparing the filtration cycles of surface river water and of model suspension, it comes out that in the former case the cycle was 20–50% shorter. This is a consequence of the increased bed thickness of the lower medium in double-filtration of surface river water.

Other characteristics of filtration media. The SEM experiments revealed certain layered nature of quartz sand. It is possible that efficiency of the filtration bed is mainly influenced by the grain position in the column. This should be borne in mind when constructing an efficient column. An additional characteristic of this material is a low roughness factor of the surface which reduces its retention ability for precipitate. When quartz sand is used as a filtration medium, the retention degree of precipitate in layer I is above the expected one, whereas the amount of the precipitate in layer VI is minimal.

Textural studies of ceramsite indicate its spongy nature, as it is rich in pores of various size. The pore volume and specific surface of ceramsite as well as other materials used are given in tab. 7.

Table 7

The porosity parameters of the studied materials

Sample	Surface area m^2/g	Pore volume cm^3/g
Anthracite	0.16	0.031
Ceramsite	9.0	0.290
Quartz sand	1.3	0.017

In addition, the ceramsite grain surface is characterized by the presence of certain flakes yielding the enhancement of the surface area, and thus the improved adsorption characteristics. This is the reason why the precipitate retention on layer I of the single-medium filtration with ceramsite is significantly enhanced as compared to the layer I of the filter A.

As for the double-medium filters C and D, it can be pointed out that thick precipitate strata are formed in layer I, while in layer VI they are present to a much lower extent but significantly more if compared to the same layer of the filter A.

5. CONCLUSIONS

1. Filtration process in the case of single-medium filters takes place on the surface medium and in the layer I, whereas in double-medium filtration the active layers are I–IV.

2. Both types of filtration beds are characterized by the presence of large precipitate strata on the surface and in the layer I. Accumulation of the precipitate in the layer VI in double-medium filtration is significantly greater than in the case of single-medium filtration.

3. Filtration properties of the studied materials can be explained in terms of their textural characteristics. They are certainly the reason why an increased effectiveness of filtration cycle is observed if compared to classical sand filters.

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ZASTOSOWANIE WYBRANYCH NATURALNYCH ADSORBENTÓW W JEDNO- I DWUWARSTWOWEJ FILTRACJI UKŁADU MODELOWEGO I WODY RZECZNEJ

Zbadano możliwość zastosowania wybranych substancji naturalnych jako materiału filtracyjnego. Określono pewne własności fizykochemiczne antracytu, keramzytu i piasku kwarcowego. Przydatność tych materiałów zbadano w procesie jedno- i dwuwarstwowej filtracji zawiesiny kaolinu (układ modelowy) oraz wody rzecznej. Stwierdzono prawie całkowite usunięcie zawiesin oraz znaczne wydłużenie czasu filtracji w porównaniu z konwencjonalnymi złożami piaskowymi.

ПРИМЕНЕНИЕ ИЗБРАННЫХ НАТУРАЛЬНЫХ АДСОРБЕНТОВ В ОДНО- И ДВУХСЛОЙНОЙ ФИЛЬТРАЦИИ МОДЕЛЬНОЙ СИСТЕМЫ И РЕЧНОЙ ВОДЫ

Исследована возможность применения избранных натуральных веществ в качестве фильтрационного материала. Определены некоторые физикохимические свойства антрацита, керамзита и кварцевого песка. Пригодность этих материалов исследована в процессе одно- и двухслойной фильтрации суспензии каолина (модельная система) и речной воды. Было установлено почти полное удаление суспензий и значительное удлинение времени фильтрации по сравнению с конвенциональными песчаными залежами.