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DEFINING THE OPTIMAL RANGE OF A FILTER BED'S d_{10} REPLACEMENT DIAMETER IN VERTICAL FLOW SAND FILTERS

The article presents the values of the optimal range of grain size diameter used in designing vertical flow sand filters. This is the crucial parameter since the filter bed grain size influences the concentration of pollutants in treated wastewater. Analyses were carried out on a column model installation consisting of five PCV columns with a 200 mm diameter. Sand and gravel having a d_{10} diameter from 0.28 to 4.28 mm were used as column filling. The research was carried out from March 2005 to February 2006. Wastewater was initially treated in a septic tank prior to reaching the model installation. Three physicochemical indexes were analyzed in wastewater: BOD_5, COD_{Cr} and total suspended solids. The range in size of the d_{10} diameter for each pollution index tested was defined as well as a single range of diameters for all three indexes. Based on the analysis of vertical flow sand filters, it was determined that the optimal d_{10} diameter of sand is from 0.28 to 1.65 mm.

1. INTRODUCTION

Sand filters are among the most common wastewater treatment technologies. Vertical flow sand filters are used as filter beds or as drain ditches. In the first case, an area of native ground is excavated for the filter and then filled with material having the correct grain size distribution. This kind of filter most often uses sand or small gravel. In the case of drain ditches, the native ground is excavated to a minimum depth of 60 cm and a width of 50 cm. It is then filled using material with the correct parameters. In Saxony, the depth of optimal drain ditches can be up to 120 cm. These filters consist of three filter layers: the top and bottom layers are composed of large grains, while the middle layer is filled with smaller diameter gravel.

The combination of septic tanks with sand filters is the simplest wastewater treatment technology for small flows (50 $m^3 \cdot d^{-1}$). These filters achieve high treat-

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ment efficiency for nitrification, although the efficiency of dephosphatation or denitrification is unsatisfactory [1]. Removing the sludge from the septic tank at regular intervals is important for the long-term operation of sand filters. This is because if excess sludge reaches the filter bed, the sludge can quicken filter colmatation [2]. Sand filters are recommended to treat wastewater from single households as well as from groups of houses. Moreover, they can be used in low-capacity municipal wastewater treatment plants [3]. In anoxic parts of the filter bed, denitrification may also occur [4].

Table 1 shows typical values of the parameters of wastewater treated using vertical sand filters.

Table 1

Typical composition of the wastewater treated using vertical sand filters [5], [6]

Type of sand filter	Outflow pollutant concentration ($mg \cdot dm^{-3}$)	
	BOD_5	Total suspended solids
Covered	<10	<10
Open	<10	<10
Open recirculating	<15	<15

Wastewater treated using sand filters is colourless, odourless, and can be discharged to a ditch, a river, or a lake and is safe for the underground environment.

There is no literature on the influence of vertical flow sand filters' grain size diameter on wastewater treatment efficiency. Grain size replacement values given by different authors refer mainly to American [7] and German analyses [8]; thus it is important to test these dependencies also for Polish conditions. This information can then be beneficial for designing household wastewater treatment plants.

2. RESEARCH PROCEDURES

This article presents the analysis and results of determining the optimal filter grain size in vertical flow sand filters.

The analyses were conducted using a column model installation simulating the operation of vertical flow sand filters. Wastewater used for this research, initially treated wastewater, came from the septic tank outflow of a household wastewater treatment plant, located near Kraków. The model installation consisted of five PVC columns with a 200 mm diameter and 1100 mm height. Five different filter bed grain sizes in the range between 0.28 and 4.28 mm were analyzed (figure 1b).

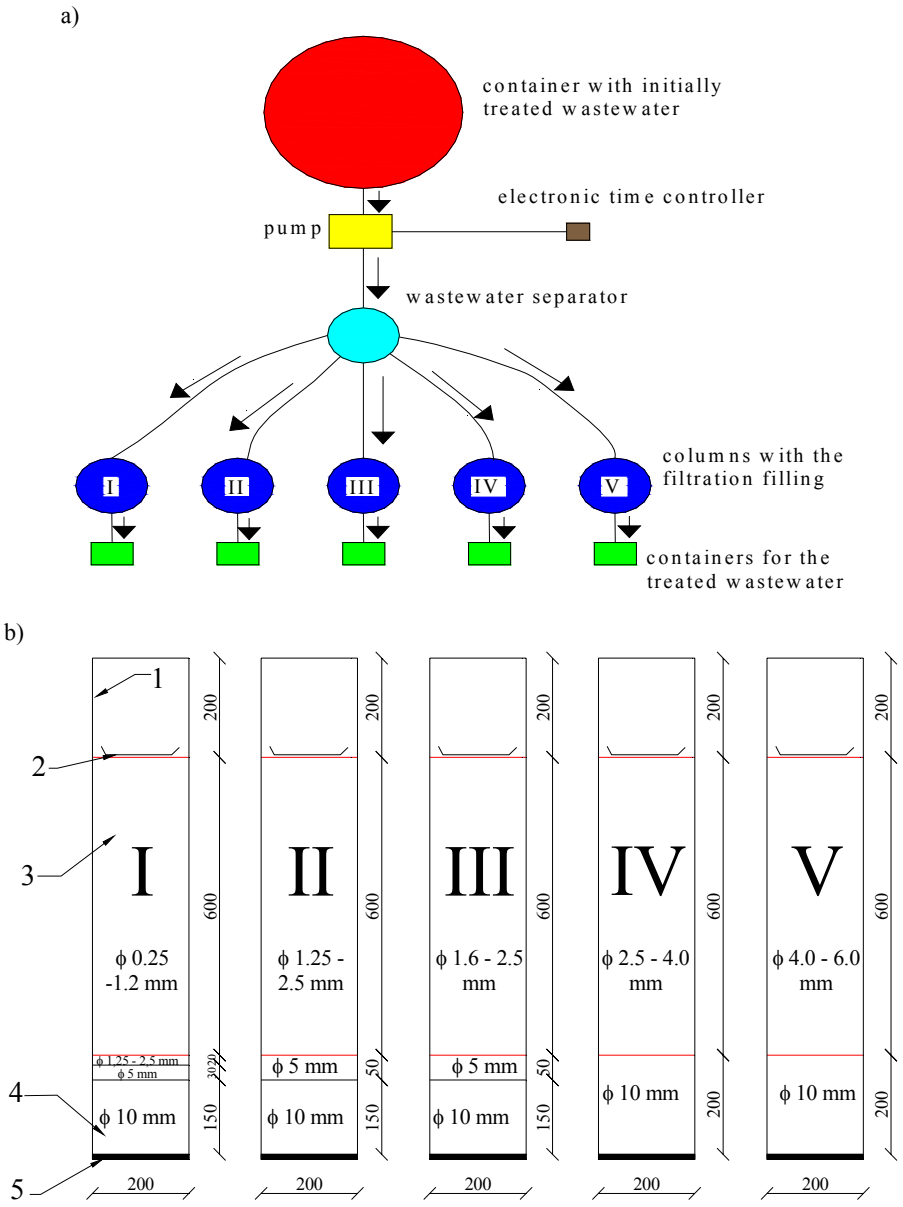

Fig. 1. Column model installation:
a) technological scheme of wastewater flow, b) columns with the filling material
(1 – PVC column, 2 – perforated pad, 3 – filter layer, 4 – catching layer, 5 – supporting grid)

The number of pollutant index values exceeding admissible levels as defined in the Ordinance of the Ministry of Environment [9] were analyzed in detail.

3. RESULTS

There are presented the results of the analyses concerning the initially treated and filter-treated wastewater pollution indexes: BOD_5, COD_{Cr} and total suspended solids. Table 2 shows the pollution concentration in the initially treated wastewater.

Table 2

Values of pollutant indexes of initially treated wastewater comprising the inflow for the model installation "K5" columns

Index	Unit	Mean concentration	Minimal concentration	Maximal concentration	Range	Standard deviation
BOD_5	mg $O_2 \cdot dm^{-3}$	204.50	60.00	350.00	290.00	68.93
COD_{Cr}	mg $O_2 \cdot dm^{-3}$	319.06	133.09	631.96	498.87	152.96
Total suspended solids	mg $O_2 \cdot dm^{-3}$	134.45	57.40	405.20	347.80	102.20

Table 3 shows basic parameters including BOD_5, COD_{Cr} and total suspended solids in treated wastewater for the tested replacement values of the filter bed grain size diameter d_{10}.

The BOD_5 analysis was performed in 51 testing series, amounting to 255 treated wastewater samples, while the COD_{Cr} analysis was performed in 12 testing series, amounting to 60 wastewater samples. The analysis of the total suspended solids' concentration was performed in 12 testing series, amounting to 60 wastewater samples.

Table 3

Comparison of basic descriptive statistics of treated wastewater BOD_5, COD_{Cr} and total suspended solids for the analysed replacement value d_{10}, the filter bed grain size diameter

Index	Descriptive statistics	Unit	Replacement value of filter bed's grain size diameter				
			d_{10} = 0.28 mm	d_{10} = 1.29 mm	d_{10} = 1.65 mm	d_{10} = 2.84 mm	d_{10} = 4.28 mm
BOD_5	Quantity of samples	Pcs.	51	51	51	51	51
	Mean value	mg $O_2 \cdot dm^{-3}$	4.25	8.94	16.86	25.45	45.61
	Minimal value	mg $O_2 \cdot dm^{-3}$	2.00	2.00	6.00	8.00	18.00
	Maximal value	mg $O_2 \cdot dm^{-3}$	10.00	20.00	34.00	60.00	98.00
	Number of exceeding values*	Pcs.	0	0	0	7	30
	Range	mg $O_2 \cdot dm^{-3}$	8.00	18.00	28.00	52.00	80.00
	Standard deviation	mg $O_2 \cdot dm^{-3}$	1.99	3.70	7.02	12.69	18.17

COD_{Cr}	Quantity of samples	Pcs.	12	12	12	12	12
	Mean value	mg $O_2 \cdot dm^{-3}$	47.27	60.57	81.06	88.65	114.12
	Minimal value	mg $O_2 \cdot dm^{-3}$	11.00	26.10	51.21	60.00	96.77
	Maximal value	mg $O_2 \cdot dm^{-3}$	67.97	85.77	104.7	114.7	128.5
	Number of exceeding values*	Pcs.	0	0	0	0	0
	Range	mg $O_2 \cdot dm^{-3}$	56.97	59.67	53.57	54.70	3.67
	Standard deviation	mg $O_2 \cdot dm^{-3}$	18.12	22.58	17.87	17.89	8.62
Total suspended solids	Quantity of samples	Pcs.	12	12	12	12	12
	Mean value	mg $\cdot dm^{-3}$	27.43	34.93	41.10	64.10	113.2
	Minimal value	mg $\cdot dm^{-3}$	2.40	2.80	8.00	5.60	50.40
	Maximal value	mg $\cdot dm^{-3}$	69.20	80.00	110.4	142.8	198.8
	Number of exceeding values*	Pcs.	1	2	3	7	12
	Range	mg $\cdot dm^{-3}$	66.80	77.20	102.4	137.2	148.4
	Standard deviation	mg $\cdot dm^{-3}$	21.17	24.97	29.62	42.93	51.02

* – in relation to the Regulations of the Ministry of Environment [9].

4. DISCUSSION

Table 3 shows that with small grain size diameters (d_{10} = 0.28 mm), the BOD_5 outflow value was between 2 and 10 mg $O_2 \cdot dm^{-3}$, whereas for the largest analyzed grain size diameters (d_{10} = 4.28 mm), the tested index was in the wide range from 18 to 98 mg $O_2 \cdot dm^{-3}$. The difference between the minimum and maximum values increased with an increase in the grain size diameter (d_{10}), ranging from 8 mg $O_2 \cdot dm^{-3}$ for d_{10} = 0.28 mm to 80 mg $O_2 \cdot dm^{-3}$ for d_{10} = 4.28 mm. When the filter bed grain size diameter d_{10} is increased, the standard deviation of BOD_5 for treated wastewater increased as well.

Mean COD_{Cr} values in treated wastewater ranged between 47.27 mg $O_2 \cdot dm^{-3}$ for d_{10} = 0.28 mm and 114.12 mg $O_2 \cdot dm^{-3}$ for d_{10} = 4.28 mm. With small grain size diameters (d_{10} = 0.28 mm), the COD_{Cr} outflow value was from 11.00 to 67.97 mg $O_2 \cdot dm^{-3}$, whereas for the largest grain size diameter tested (d_{10} = 4.28 mm), the tested index value ranged between 69.77 and 128.50 mg $O_2 \cdot dm^{-3}$.

As shown in table 3, small grain size diameters (d_{10} = 0.28 mm) produced outflow total suspended solids values ranging from 2.40 to 69.20 mg $\cdot dm^{-3}$, whereas for the largest analyzed grain size diameter (d_{10} = 4.28 mm), the tested index was in a wide range, specifically from 50.40 to 198.8 mg $\cdot dm^{-3}$. The difference between the minimum and maximum values increased together with the grain size diameter d_{10} varying from 66.80 for d_{10} = 0.28 mm to 148.40 for d_{10} = 4.28 mm.

The filter bed grain size limit has been defined based on the analysis of tested indexes of the treated wastewater compared to admissible values as defined in the Ordinance [9]. The admissible value of BOD_5 in the treated wastewater for small wastewater treatment plants is 40 mg $O_2 \cdot dm^{-3}$. In columns I, II, and III, the BOD_5 concentration in the outflow was within acceptable limits. In column IV, 5 outflow samples exceeding the

admissible BOD_5 limit were observed. In column V, as many as 30 series exceeded the limit out of the total 51 observations. From this, one can conclude that with larger filter bed grain size diameters (columns IV and V), the normative obligations of the Ordinance [9] concerning BOD_5 in the treated wastewater cannot be fulfilled.

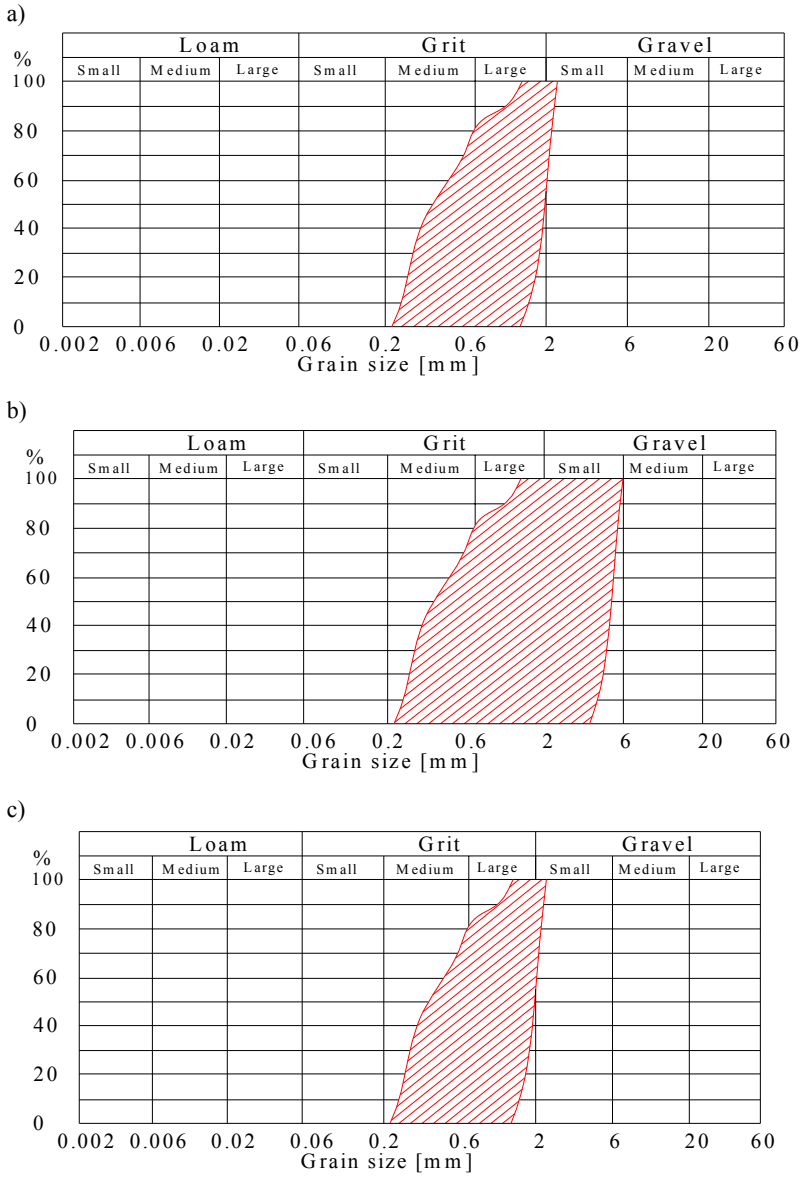

Fig. 2. Suggested diameters of grains used as a filling of the exact filter layer in the vertical flow sand filters range regarding the admissible concentration in the treated wastewater:

a) BOD_5, b) COD_{Cr}, c) total suspended solids

On the basis of the present research and the obtained BOD_5 values together with the admissible BOD_5 values for treated wastewater from Ordinance [9], the authors suggest using a vertical flow sand filter grain size between 0.28 mm and 1.60 mm diameter d_{10}. The range of optimal grain size diameters for vertical flow sand filters is shown in figure 2a.

Admissible COD_{Cr} value for wastewater in small wastewater treatment plants is 150 mg $O_2 \cdot dm^{-3}$. In the tested columns, no samples exceeded the admissible limit for this index. From this one can conclude that even with larger filter bed grain size diameters, the obligations of Ordinance [9] can be fulfilled.

On the basis of the research and the obtained COD_{Cr} values together with the admissible COD_{Cr} in treated wastewater according to Ordinance [9], the authors suggest using a vertical flow sand filter bed grain size diameter d_{10} between 0.28 mm and 4.28 mm. The range of admissible grain size diameters as regards the COD values for vertical flow sand filters is shown in figure 2b.

The admissible total suspended solids' concentration in treated wastewater for small wastewater treatment plants is 50 $mg \cdot dm^{-3}$. In each of the tested columns, this limit was exceeded. In the case of the first three columns, it was incidental; however, in the outflow of column IV, 7 out of 12 samples exceeded admissible limits. In column V, all samples exceeded the admissible value from Ordinance [9]. Very high outflow concentration of total suspended solids, especially in column V, results from oversize pores, which allow the dislodging and free flow of biological membrane particles together with the treated wastewater.

Based on the total suspended solids' concentration in the treated wastewater, data analyses, and the admissible level of total suspended solids from the Ordinance [9], the authors suggest using a vertical flow sand filter grain size diameter d_{10} ranging from 0.28 mm to 1.65 mm. The range of optimal grain size diameters as regards total suspended solids for vertical flow sand filters is shown in figure 2c.

5. CONCLUSIONS

- It is suggested that while designing vertical flow sand filters, the filter layer grain size diameter d_{10} should range from 0.28 mm to 1.65 mm. Larger filter bed grain size diameters can be the reason for inadequate efficiency in wastewater treatment, although using smaller filter bed grain sizes may lead to filter colmatation.
- All COD_{Cr} values were within acceptable limits for the tested interval of filter bed grain size diameters.
- With an increase in the filter bed grain size diameter, the treated wastewater showed a decrease in quality with regard to the tested indexes.

• A sudden increase was observed for the total suspended solid concentration in the treated wastewater from the columns with a larger filter bed grain size.

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OKREŚLENIE OPTYMALNEGO ZAKRESU ŚREDNICY ZASTĘPCZEJ d_{10} ZŁOŻA W FILTRACH PIASKOWYCH O PRZEPŁYWIE PIONOWYM

Podano zakres średnicy zastępczej, na jakim należy się opierać podczas projektowania filtrów piaskowych o przepływie pionowym. Jest to cenna informacja, gdyż średnica zastępcza złoża filtracyjnego w istotny sposób wpływa na stężenie ścieków oczyszczonych. Badania przeprowadzono, korzystając z modelu kolumnowego, który składał się z pięciu kolumn z PCV o średnicy 200 mm. Materiałem wypełniającym kolumny był piasek i drobny żwir o średnicy d_{10} od 0,28 do 4,28 mm. Badania przeprowadzono w okresie od marca 2005 r. do lutego 2006 r. Do modelu dopływały ścieki wstępnie oczyszczone w osadniku gnilnym. Badania fizykochemiczne objęły trzy wskaźniki zanieczyszczenia ścieków: BZT_5, $ChZT_{Cr}$ oraz zawiesinę ogólną. Określono zakres średnicy d_{10} uziarnienia złoża filtracyjnego dla każdego badanego wskaźnika zanieczyszczeń, a także jeden zakres średnic łącznie dla wszystkich trzech wskaźników. Na podstawie przeprowadzonej analizy danych stwierdzono, że do projektowania filtrów piaskowych
o przepływie pionowym należy stosować piasek o średnicy d_{10} w przedziale od 0,28 do 1,65 mm.