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Research on Clogging of the Sand Filter

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1. Introduction

Rapid filtration with a fixed filter bed is the most commonly used process in drinking water treatment plants (Piekarski 2011, Janczukowicz 2013, Toczyłowska 2005, Skoczko 2016). One of the most commonly used types of filters are high-pressure filters. These devices are made as closed steel tanks with bottoms (Biedron 2013, Cheremisinoff & Ferrante 1995). The use of vertical pressure filters brings many benefits. Compared to rapid gravitational filters, their design helps to reduce the costs associated with pumping water after the filtration process, as they maintain the pressure given by the raw water supply pump (Spellman 2013). They also allow for higher filtration speeds compared to open filters (Piekarski 2011). However, the main disadvantage of pressure filters is that the operator cannot observe the state of the filter bed (Johnson 2009). The inconvenience can be eliminated when the filter has an automatic sensor that switches the filter off if the permissible turbidity of the purified water is exceeded. It is also difficult to assess the effectiveness of the rinsing process (Skoczko 2011, Kumar & Singh 2006). Maintenance work is also difficult.

Filter clogging has been the subject of many studies over the years. Many theories describing the technological process of filtration arose with time. Hendricks (2016) states that the formulated filtration theories were aimed at describing variables, developing mathematical models that describe the filtration process and the explanation of the mechanism of removing particles during depth filtration. Historically, the first experimental work on the filtration mechanism appeared in the

Ph.D. thesis of Eliassen completed in 1935 at MIT (Massachusetts Institute of Technology). Subsequent studies were conducted by Stein (1940), Stanley (1955) and Ives (1962). The first issues regarding the filtration theory in the aspect of mathematical modeling were formulated by Iwasaki in 1937, while in 1962 Ives based on Iwasaki's experiments used the results of research to create a mathematical model (Hsiung 1967). In 1977, the first results of the experiments of two Israeli researchers – M. E. Rebun and A. Adin were published. Adin and Rebhun (1977, 1978, 1979) describe that the intensity of total suspended solids retention during filtration process is variable per unit of time. Initially, there is an increase to the set maximum value, then there is a decrease to zero value due to clogging of the deposit. In the initial period of the filtration cycle, total suspended solids are retained in the upper layers of the filter bed, while after their saturation, penetration into the deeper layers occurs. An increase in the concentration of pollutants also causes an increase in pressure losses.

In view of the above, experimental work has been undertaken to check the efficiency of water filtration on the sand bed in a modern model filtration column at different flow rates and at different column heights on a semi-technical scale.

2. Material and methods

Tap water was used for research works. Water was prepared by preliminary de-chlorination and subsequent dosage of iron (III) sulfate (VI), aluminum sulfate (VI), aluminum chloride, and loam containing 30% clay fraction, a minimum of 40% of the total silty, sandy and quartz fraction and 30% colloidal fraction. The solution was mixed quickly, followed by slow stirring for 30 minutes until flocs were formed. Prepared total suspended solids was introduced into a 180 liter water-filled tank and then directed to the filter bed and the filtration effect was observed. Total suspended solids concentration was about 1 g/dm^3, what let observe clogging process, water color – about 400 mg Pt/dm^3 and turbidity 65 NTU.

The tests were carried out at the CE 582 GUNT water treatment station (Figure 1 and 2).

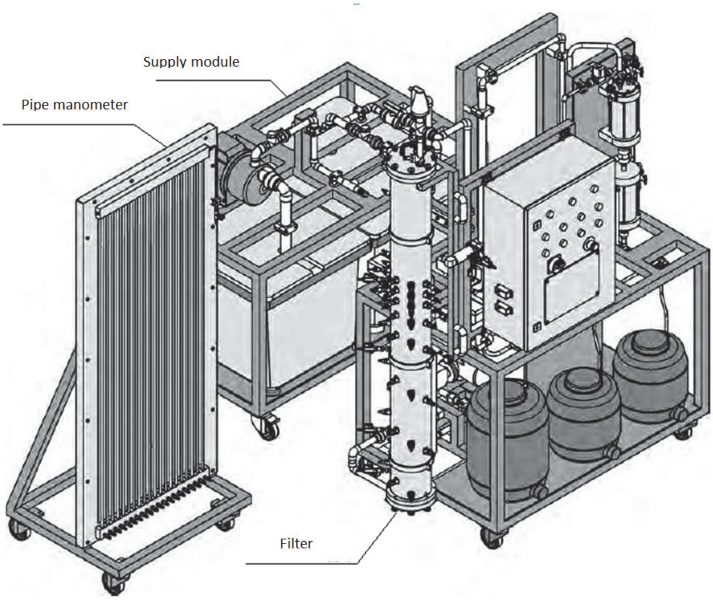


Fig. 1. Main elements of research stand CE 585
Rys. 1. Główne elementy stanowiska badawczego CE 582

The most important part of the model was a filtration column with dimensions: external diameter Ø: 164 mm, internal diameter Ø: 150 mm, height: 1610 mm.

The research involved filtration at a specific speed of the amount of prepared raw water, which allowed to observe changes in filtrate quality and sampling from various depths of the deposit (Table 1). Clogging of the filter was observed with different volume of water 1,2, and 3 m^3 filtrated through the filter. During the filtration at a given speed, a series of samples were taken after filtering each subsequent cubic meter of prepared water. After each completed filtration step, the filtration bed was washed, and filtration was started at a different speed. In the samples taken, parameters were determined such as pH, conductivity, color, turbidity and total suspended solids. The test was carried out for the following filtration rates: 10, 15, 20, 25, 30 and 35 m/h.

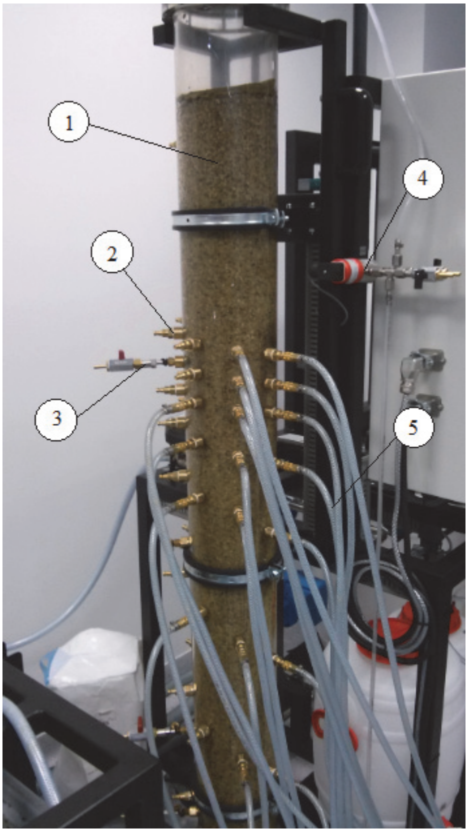


Fig. 2. Sand filter – view: 1 – filer column, 2 – pressure measurement terminal, 3 – water intake terminal, 4 – pressure sensor, 5 – flexible cable joining pipe-manometer

Rys. 2. Widok na filtr piaskowy: 1 – kolumna filtracyjna, 2 – przyłącza do pomiaru ciśnienia, 3 – przyłącze do poboru próbek, 4 – czujnik ciśnienia, 5 – przewody elastyczne łączące manometr rurkowy

Table 1. Depths where were pollution indicators measured

Tabela 1. Głębokości, na których prowadzono pomiary wskaźników zanieczyszczeń

Measurement Point	Filter depth from the surface (cm)
1	43
2	77
3	117
4	137

3. Results and discussion

As part of the research work, filtration of contaminated water was carried out on the GUNT research model with six different speeds. During the filtration at a given speed, a series of samples were taken from various depths of the bed after filtering each subsequent cubic meter of prepared water. The obtained results are shown in Figures 3, 4 and 5.

The pH tests for each of the measured series at each speed showed very slight increase in the pH in relation to the value determined for the prepared raw water. The minimum parameter value was 6.38, while the maximum 6.76. The average value for all measurement series was 6.52 and the standard deviation 0.078. In general, it can be concluded that the pH of water in each series was neutral with a slight predominance of hydrogen ions. Conductivity tests showed that the minimum value of this parameter was 0.39 μS/cm, the maximum 0.57 μS/cm, average – about 0.51 μS/cm, while the standard deviation – 0.02 μS/cm. Very small dispersion of results was observed both in the case of pH and conductivity in relation to the average.

Figures 3a, 3b and 3c present a comparison of color test results for various filter bed depths and tested filtration speeds after filtration of a given volume of raw water – 1 m^3, 2 m^3 and 3 m^3, respectively.

At the early stage of the filtration cycle, i.e. after filtration of 1 m^3 of prepared water, the highest color removal efficiency of 77% was recorded for the lowest tested speed of 10 m/h. As the filtration speed increased, the cleaning effect decreased. It was respectively 65% for 15 m/h, 46% for 20 m/h, 29% for 25 m/h, 34% for 30 m/h and only 25% for 35 m/h. The color value of water decreased in a very even manner along the filter bed for the lowest speeds. In the case of higher speeds, e.g. 35 and 25 m/h, the low removal efficiency of the bed layers at the depth of 77-137 cm was visible. In the later stage, after filtering 2 m^3 of water, the highest color removal efficiency – 69% was noted for speeds of 15 m/h and 10 m/h. The lowest effect was noted for the highest filtration speeds in the range of 23-25%. After filtration of 3 m^3 of raw water, the highest color removal efficiency was recorded at a speed of 10 m/h, equal to 62%, while the weakest efficiency was 14% for the filtration speed of 35 m/h. Along with the increase in the volume of filtered water, the efficiency of purification decreased in the case of the vast majority of measurement series carried out for the tested speeds. The tests after filtration successively 2 m^3 and 3 m^3 show a tendency of decreasing the efficiency of removing the water color in the upper layers of the filter bed, which has an impact on the decrease of the overall purification efficiency.

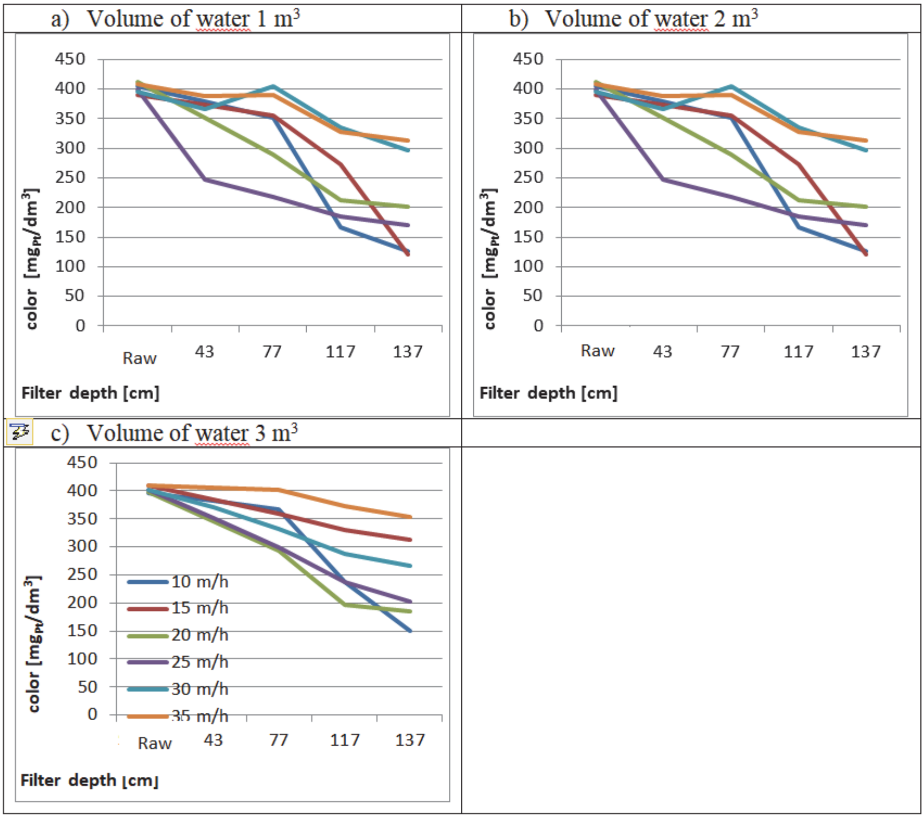


Fig. 3. Water color changes along filtration column for different filtration speeds

Rys. 3. Zmiany wartości barwy wzdłuż złoża dla poszczególnych prędkości filtracji

Figures 4a, 4b and 4c present a comparison of turbidity test results for various filter bed depths and tested filtration speeds after filtering a given volume of raw water – 1 m^3, 2 m^3 and 3 m^3, respectively.

After filtering 1 m^3 of raw water, the highest turbidity removal efficiency of approximately 82% was recorded for the lowest tested speed of 10 m/h. It can be assumed that with the increase of filtration speed, the efficiency of the parameter removal decreased. They were respectively 71% for 15 m/h, 54% for 20 m/h, 32% for 25 m/h, 47% for 30 m/h and only 29% for 35 m/h. After filtering 2 m^3 of raw water, the highest cleaning efficiency of approximately 78% was obtained again for the filtration speed of 10 m/h. The lowest one was recorded for the highest filtration speeds, i.e. 26% for 30 m/h and 29% for 35 m/h. The comparable efficiency of turbidity removal in the range of 40-60% was obtained for speeds of 15 m/h, 20 m/h and 25 m/h. At the final stage of the filtration cycle, the highest turbidity removal efficiency of approximately 73% was obtained at a speed of 10 m/h. The low effect was still obtained at the highest speeds – 34% for 35 m/h and 28% for 30 m/h. It can be noticed that the removal of water color and turbidity proceeded with a similar tendency on the filter bed under test. The efficiency of turbidity removal decreased as the volume of filtered water increased. In the final stage of filtration, a decrease in the efficiency of turbidity removal in the upper bed layers was observed for the majority of tested speeds, while the largest reduction in the parameter was recorded in the 77-137 cm depth range.

Figures 5a, 5b and 5c present comparison of the results of the total suspended solids testing for various depths of the filter bed and tested filtration speeds after filtration of a given volume of raw water – 1 m^3, 2 m^3 and 3 m^3, respectively.

The results from total suspended solids tests show that as the volume of filtered water increased, the effect of water purification did not change significantly. There was also no significant change in the efficiency of total suspended solids removal with the change of filtration speed. In the case of the vast majority of measurement series in the upper layer of the filter bed (in the range of 0-43 cm depth), the efficiency of removing the parameter equal to 50% was obtained. In the case of majority of measurement series, the effectiveness of the total suspended solids removal in the range of 75-100% was found.

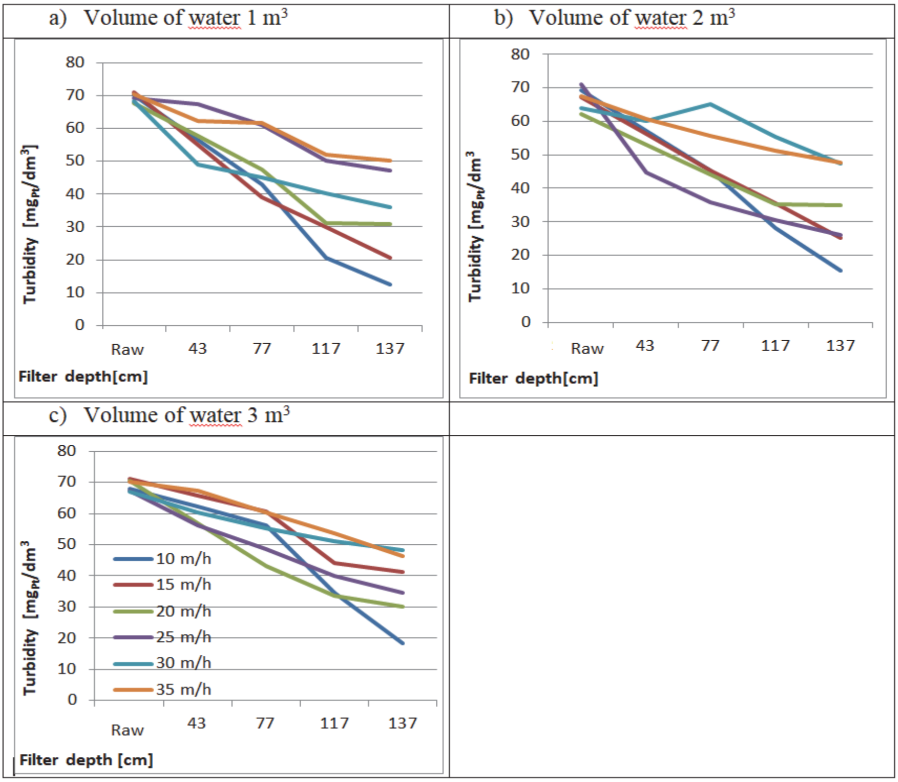
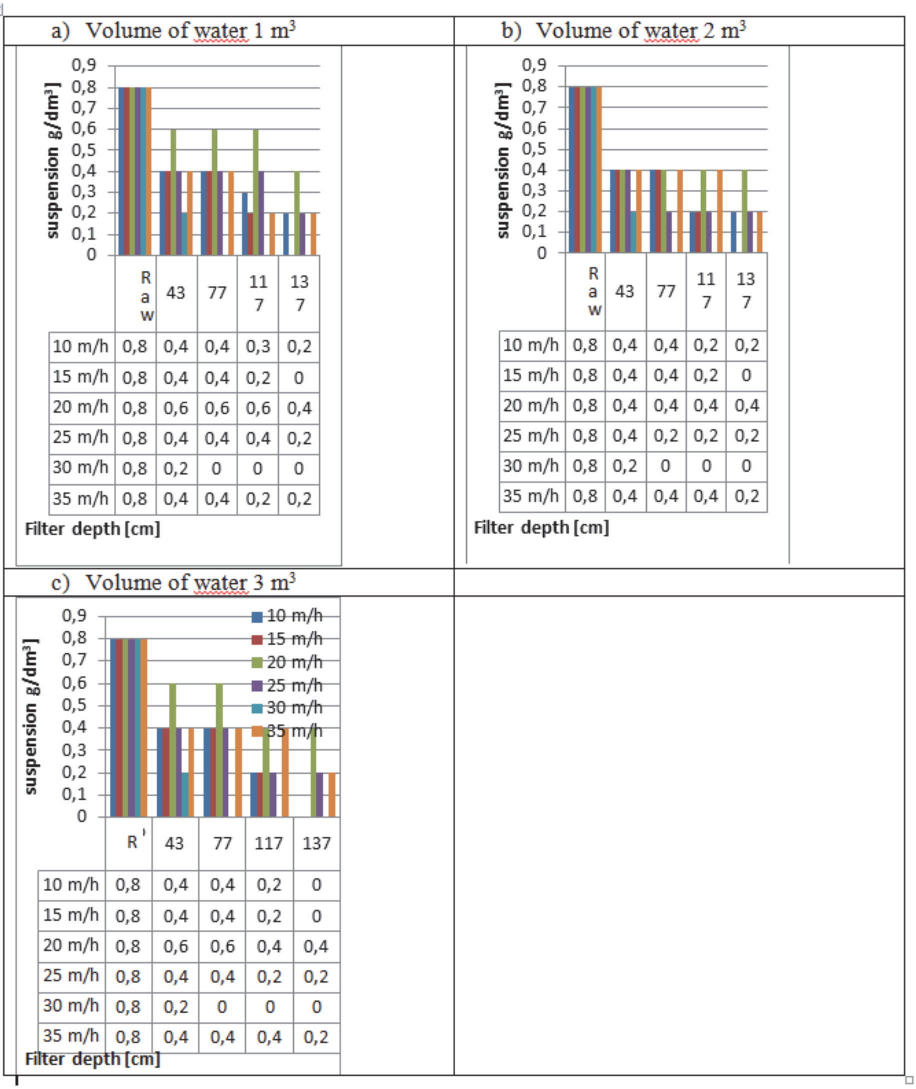


Fig. 4. Water turbidity changes along filtration column for different filtration speeds

Rys. 4. Zmiany wartości mętności wzdłuż złoża dla poszczególnych prędkości filtracji



a) Volume of water 1 m^3

	Raw	43	77	117	137
10 m/h	0,8	0,4	0,4	0,3	0,2
15 m/h	0,8	0,4	0,4	0,2	0
20 m/h	0,8	0,6	0,6	0,6	0,4
25 m/h	0,8	0,4	0,4	0,4	0,2
30 m/h	0,8	0,2	0	0	0
35 m/h	0,8	0,4	0,4	0,2	0,2

b) Volume of water 2 m^3

	Raw	43	77	117	137
10 m/h	0,8	0,4	0,4	0,2	0,2
15 m/h	0,8	0,4	0,4	0,2	0
20 m/h	0,8	0,4	0,4	0,4	0,4
25 m/h	0,8	0,4	0,2	0,2	0,2
30 m/h	0,8	0,2	0	0	0
35 m/h	0,8	0,4	0,4	0,4	0,2

c) Volume of water 3 m^3

	R'	43	77	117	137
10 m/h	0,8	0,4	0,4	0,2	0
15 m/h	0,8	0,4	0,4	0,2	0
20 m/h	0,8	0,6	0,6	0,4	0,4
25 m/h	0,8	0,4	0,4	0,2	0,2
30 m/h	0,8	0,2	0	0	0
35 m/h	0,8	0,4	0,4	0,4	0,2

Fig. 5. Total suspended solids changes along filtration column for different filtration speed
Rys. 5. Zmiany wartości zawiesiny ogólnej wzdłuż złoża dla poszczególnych prędkości filtracji

Similar research was carried out by Eliassen (1941), who conducted filtration of prepared water on a bed of 60 cm depth and grain granulation of 0.46 mm. The filtration was performed at one constant speed of 4.88 m/h. Results of testing the total suspended solids in the time range of 9-120 h for different depths of the bed were recorded. At the earliest recorded filtration stage (after 9 hours), the filtration efficiency was 90%. With the passage of filtration time, the efficiency of removing the parameter decreased. In the final stage of filtration, after 119 hours, the efficiency decreased to 66%. Movement of the filtration front was also noticeable. In the initial stage, the largest parameter reduction took place in the top layers of the bed, while saturation of the upper layers of the bed occurred with time. In the final stage of filtration, after 119 hours at the deposit depths of the 0-10 cm, there was a saturation zone and very low efficiency of parameter reduction was noted in these layers. Research conducted within the framework of this study covered a similar time range of 12-120 h, with the efficiency of water treatment depending on the volume of filtered water and not on the working time of the bed. It should be clearly stated that the tested GUNT filtration model allowed for filtration studies on a semi-technical scale using such filtration rates that are used on real plants of the treatment station. The shifting of the clogging top was observed for all the contamination indicators measured. The conducted research allowed to notice that the clogging of the deposit for color, turbidity and total suspended solids did not occur at the same depth of the deposit. Own research coincided with the research by Eliassen when observing the clogging top only for turbidity, while in the case of color and total suspended solids, they differed significantly.

Ives (1962) also performed filtration tests for the removal of total suspended solids. It carried out filtration of prepared raw water on a 60 cm deep bed and granulation of 0.54 mm grains. The filtration was conducted at 4.88 m/h. Samples were taken from various depths of the bed. The tests were carried out for a period of 24 hours. In the earliest recorded stage, after 20 minutes of filtration process, the efficiency of removing the total suspended solids close to 100% was obtained already at a depth of 30 cm. In the early stages of the filtration process, from 20 min to 4 hours, the efficiency of removing the total suspended solids in the upper bed layers was recorded, while after about 5 hours, gradual saturation of the upper bed layers associated with deterioration of the total suspended solids removal efficiency in these layers, was noted. After 24 hours, in the final stage of testing, the saturation zone reached a depth of 20 cm. Like Eliassen, Ives conducted filtration at low speeds and low bed heights that deviated significantly from real conditions. In addition, Ives' studies included a short period of time compared to the studies described in this paper. The obtained results of the total suspended solids as well as in the case of studies by Eliassen and Ives indicate that 50% reduction in the parameter in the case of majority of measurement series was obtained in the top layers of the deposit. However, there was no significant change in the effectiveness of total suspended solids removal over time. Deterioration of removal efficiency was noticeable in the final stages of testing for parameters such as color and turbidity, which may indicate saturation of these layers due to the accumulation of contaminants.

Based on our own research, it can be assumed that the most satisfactory results of all tested parameters were obtained for the lowest filtration speed of 10 m/h. Regarding the results of the studies by Eliasssen and Ives and the conclusions formulated by Ives regarding the grain diameter, it can be assumed that an improvement in filtration efficiency could be obtained by using a bed with smaller grain diameter. However, in real conditions, during the filtration process, due to the accumulation of impurities in the bed and the increase in the concentration of suspended matter on the grain surface, there is a gradual increase in the equivalent diameter and at the same time, reduction in porosity and change in the specific surface area (Grabarczyk 2010). Over the years, attempts have been made to define methods for describing the course of filtration process, and no comprehensive answer has been provided so far, which would explain the method of filtration media clogging. In the case of commonly used filtration rates, phenomena such as dispersion and changes in the concentration of suspended matter inside the pores are negligible. Modern filtration models (like GUNT used in own research) contradict this. In the case of grains with larger diameter, a lower filtration coefficient is obtained, and thus a lower efficiency of contamination reduction. The efficiency of removing the contaminants is directly related to the flow rate. It follows that the smaller the granulation of deposit, the faster the clogging, while the time of the filtration cycle is shortened.

4. Conclusions

- The highest efficiency of total suspended solids, turbidity and color removal was obtained for the lowest tested filtration speed of 10 m/h, while the lowest efficiency was recorded for higher speeds of 30 m/h and 35 m/h.
- Along with the increase in the volume of water filtered through the bed, there was a decrease in the efficiency of color and turbidity removal in the upper filtration layers in the range of 0-43 cm depth, which may indicate their saturation with impurities. The decrease in the efficiency of removal in these layers had an effect on reducing the overall efficiency of color and turbidity removal.
- The breakthrough of the tested deposit occurred after 30 hours of prepared water filtration. The drop in the efficiency of purification on the filter bed was around 50%.

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References

Adin, A. et al. (1979). The application of filtration theory to pilot-plant design. *Journal of AWWA, 71(1)*, 17-27.

Adin, A. & Rebhun, M. (1977). A model to predict concentration and head loss profiles in filtration. *Journal of AWWA, 69(8)*, 444-453.

Adin, A. & Rebhun, M. (1978). Solution of granular bed filtration equations. *Journal of EED, 104(12)*, 34-46.

Adin, A. & Rebhun, M. (1979). Model of prediction and concentration and head loss profile in granular bed filtration. *Journal of AWWA, 66(2)*, 109-112.

Biedroń, I. et al. (2013), Wpływ rodzaju materiału filtracyjnego na zmiany wartości wybranych wskaźników jakości wody podziemnej, *Rocznik Ochrona Środowiska, 15*.

Cheremisinoff, P., Ferrante, L. (1995). Process Engineering Data Book. Technomic Publiching Company Inc.

Eliassen, R. (1941). Clogging of rapid sand filters. *Journal of AWWA. 33(5),* 926-942.

Grabarczyk, C. (2010). *Hydromechanika filtrowania wody*. Wydawnictwa Naukowo-Techniczne.

GUNT GmbH (2012). Instrukcja obsługi instalacji do przetwarzania wody CE582

Hendricks, D. (2016). Fundamentals of Water Treatment Unit Processes: Physical, Chemical, and Biological.

Hendricks, D. W. (2006). Water Treatment Unit Processes: Physical and Chemical. CRC Press.

Hsiung, K. (1967). Prediction of performance of granular filters for water treatment. Retrospective Theses and Dissertations. Paper 3941.

Ives, K.J. (1962). Filtration using radioactive algae. *Journal of SED, 87*, 372-390.

Iwasaki, T. (1937). Some Notes on Sand Filtration. *Journal of AWWA, 29*.

Janczukowicz, W. i in. (2013). Wpływ procesu filtracji na relację między ilością substancji organicznych i związków biogennych w ściekach mleczarskich. *Rocznik Ochrona Środowiska, 15*.

Johnson, M. et al. (2009). Water Supply, 6th edition. Elsevier Ltd.

Kumar, R. & Singh, N (2006). Municipal Water and Waste Water Treatment

Piekarski, J. (2011), Zastosowanie metod numerycznych do modelowania procesu filtracji grawitacyjnej, *Rocznik Ochrona Środowiska, 13*.

Skoczko, I. (2011). Project and implementation experience of boiler water treatment plant for ENERGO-TECH sp. z o.o. *Rocznik Ochrona Środowiska, 13*, 1731-1742.

Skoczko, I. i in. (2016), Usuwanie z wody związków boru metodą filtracji na wybranych złożach, *Rocznik Ochrona Środowiska, 18(2)*.

Spellman, F.R. (2013). Handbook of Water and Wastewater Treatment Plant Operations, Third Edition. CRC Press.

Spellman, F.R. (2016). Handbook of Environmental Engineering. CRC Press.

Stanley, D.R. (1955). Sand filtration studies with radiotracers. Proceedings, ASCE.

Toczyłowska, B. (2005). Skuteczność usuwania zawiesin w złożach filtrów DynaSand i Dynamik. *Ochrona Środowiska, 3*.

Badania kolmatacji złoża piaskowego

Streszczenie

Jednym z podstawowych i powszechnie stosowanych procesów uzdatniania wody jest proces filtracji. Rozwój wiedzy na temat tego procesu ma swoje korzenie na przełomie lat trzydziestych oraz czterdziestych ubiegłego wieku. Do dnia dzisiejszego prowadzone są wciąż badania w zakresie filtracji przez wielu naukowców na całym świecie. Obecnie projektowanie filtrów do uzdatniania wody odbywa się na podstawie niezmiennego zbioru wytycznych. W związku z tym zasadne wydają się badania nad kolmatacją procesu filtracji, gdyż mają one wpływ na bardziej racjonalne projektowanie filtrów.

Celem niniejszej pracy było zbadanie kinetyki kolmatacji procesu filtracji wybranego złoża piaskowego. Realizowane eksperymenty polegały na filtracji przygotowanej wody ze zmiennymi prędkościami: 10, 15, 20, 25, 30, 35 m/h. Na podstawie przeprowadzonych obserwacji stwierdzono, iż efektywność usuwania zanieczyszczeń jest bezpośrednio związana z szybkością filtracji i ilością przefiltrowanej wody. Wraz ze wzrostem objętości przefiltrowanej wody przez złoże odnotowano spadek efektywności usuwania barwy oraz mętności w wierzchnich warstwach filtracyjnych w zakresie głębokości 0-43 cm. Spadek efektywności oczyszczania w tych warstwach miał wpływ na obniżenie ogólnej efektywności usuwania barwy oraz mętności. Wynika z tego, iż im mniejsza granulacja złoża w górnej warstwie, tym szybsza kolmatacja i krótszy czas cyklu filtracyjnego.

Abstract

Filtration is one of the basic and commonly used process of water treatment filtration process. The development of knowledge about this process has its roots at the turn of the thirties and forties of the last century. To this day, there are still conducted research in the field of filtration by many scientists around the world. Currently, the design of water treatment filters is based on a set of guidelines. Therefore, studies on the clogging of the filtration process, seem to be important, as they affect the more rational filter design.

The aim of this work was to investigate the kinetics of the clogging of the filtration process for the selected sand bed. Carried out experiments consisted in filtration of the prepared water with variable speeds: 10, 15, 20, 25, 30, 35 m/h. Based on the observations, it was found that the efficiency of impurities removing is directly related to the rate of filtration and the amount of filtered water. With the increase of the filtered water volume of through the bed, there was a decrease in the efficiency of color and turbidity removing in the upper filter layers in the depth range of 0-43 cm. The decrease in the efficiency of purification in these layers resulted in efficiency of removing color and turbidity. It follows that the smaller the granulation of the bed in the upper layer, the faster the clogging and the shorter filtration cycle time.

Słowa kluczowe:
filtracja, kolmatacja, oczyszczanie wody

Keywords:
filtration, clogging, water treatment