Impact of filter operation on outflow water quality

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Congress Sub-themes

1. Development of water resources and infrastructure - Data, monitoring and information technology
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Abstract

Usually, rapid filters are operated under constant rate filtration, eventually constant pressure. In practice, filters cooperate each other and rate filtration urgently varied during filtration. Variable Declining Rate Filters operate with orifices located in the outlet instead of the regulators. Appropriate relations between laminar headloss of the media and turbulent headloss of the orifices let to keep declining filtration velocity between limited values. Lower velocity in the end of filtration under Variable Declining Rate system guarantees rarer backwashes of the filters and financial profits. Smooth change of declining velocity during the run and low value in the end of filtration cause that quality of total outflow from Variable Declining Rate Filtration plants should not be poorer than from traditionally operated filter plants. Experimental research has confirmed that theory. Poorer filtrate quality do not follow economic profits of Variable Declining Rate Filters. Results, even revealed that quality of filtrate produced under Variable Declining Rate Filtration was better for higher ratio of maximum to average rate filtration. Similar conclusions were received from numerical simulation realized based on dynamic model connecting equations describing hydraulic work of declining rate filters and filtration kinetic equations compiled from theory of limited trajectory. The computer simulation considered particle size distribution analysis, for Variable Declining Rate operation led to improved removal of smaller particles, but also a decrease in removal efficiency for larger particles was noticed.

Introduction

There are several systems of rapid filters operation in water treatment plant. Constant flow-rate operation is still the most often designed in Poland. However, many reports provide information that inlets to filters, even designed originally as constant flow-rate, are located under water level during long time of the run in practice. In consequence, filters interact with each other and operate under variable flow-rate condition. Otherwise, filters are often backwashed almost at the same moment, flow-rate of working filters increases rapidly then. Filters operate under variable flow-rate, but under not optimal parameters. It would be more economic, if the filters were designed as Variable Declining Rate filters.

Construction of Variable Declining Rate Filters is only a little different from traditional. The filter inlets should be located under minimal water level, the filter medias should be similar to each other and the same resistance orifices should be installed in the outlets. Detail descriptions of Variable Declining Rate Filters construction are presented in literature (Cleasby, 1993, Akgiray, Saatci, 1998, Dabrowski 2006, Zielina, Dabrowski, Mackie 2005, Mackie, Dabrowski Zielina 2003). Economic profit is the most important advantage of Variable Declining Rate system. It is obtained through long filtration cycle and random backwashes. Several researchers reported (Arboleda, Giraldo, Snel, 1985, Cleasby, 1969, Cornwell et all, 1991, Di Bernardo, Cleasby 1980) economic profits of variable declining rate filters without deterioration of filtrate quality. First of the reports was noticed in 50th in Wyandotte, Michigen (Hudson, 1959). Hudson observed two filters, one operated under constant filtration rate 5,8 m/h and second operated under decreasing filtration rate from 6,6 m/h to 5,2 m/h. 20 % lower turbidity of filtrate was received from declining rate filter. When raw suspension was flocculated before filtration, difference between turbidities from declining and constant rate filters were even more significant, increased to 27%. Baylis (1959) also compared filtrates from constant and declining rate filters in 50th. He compared quality of filtrate from filters operated under both kind of systems in Chicago water treatment plant. Quality of filtrates were similar each other.

Cleasby (1969) observed significant improve of filtrate quality after rebuilding of filters in water treatment plant in Chan Chu Shau in Taiwan from constant to variable declining flow-rate operation. However, reason of so important improve was probably not only changing of operation system, but also lack of regulators installed in outlet of constant flow-rate filters.

Gregory and Yadav carried out pilot scale research (Arboleda, Giraldo, Snel, 1985) in England. They compared filtrate qualities produced by four Declining Rate filters and a single Constant Rate filter. Both systems operated on surface water, which had been pretreated by coagulation and sedimentation. The systems were automated. Filters for both systems were backwashed upon reaching the same clogging head loss of 0.93, and operated at the same mean flow rate of 8.8 m/h. The run length for CR filter was about seventy five percent of the run length for the DR filters. The filtrate quality for DR filters was generally as good as for the CR filter. The ratio of maximum to minimum filtration rate was quite high, from 2.5 to 4.0. This high ratio may have detracted the mean filtrate quality of the DR filters.

Di Bernardo and Cleasby (1980) compared a four filter DR system with a single CR filter at a lime softening plant treating a ground water in Ames, Iowa. The starting rate of a clean filter was limited to 1.5 times the mean rate of the DR filters. The filtration runs were carried out at three filtration rates of 7.2, 12.2 and 17.1 m/h. In both cases, the CR filter and the DR system were operated to the same clogging head loss. The study reported 30 to 60 percent lower average turbidity and 19 to 100 percent longer filter cycle for DR system.

Several years later, Hilmoe and Cleasby (1986) compared results of pilot scale, direct-filtration experiments of a four DR filters and single CR filter. Filters were supplied by surface water coagulated by alum or cationic polimer. Mean filtration rates of 7.7 and 13.4

m/h were included. There was no difference in filtrate quality between CR filter and DR system.
Similar experiments (Cornwell et all, 1991) were conducted at the Williams Water Treatment Plant in Durham, North Carolina. The plant treats a reservoir water with alum addition, rapid mixing, flocculation, sedimentation and filtration assisted by nonionic filter aid polymer. Data were presented for experiments at three mean filtration rates, 9.7, 14.6 and 19.5 m/h. Both systems produced excellent filtered water quality. There was no evidence terminal breakthrough. There was no difference in filtrate quality for both systems.
Described experiments compare VDR and CR filter systems based on turbidity parameter that are accepted by international standards. Today, results of many experiments (Gregory 1998, Hatukai, Ben-Tzur 1997, Zielina, Hejduk 2007, Zielina 2007) suggest more adequate estimation of filtrate quality by suspended particles size distribution and counting. Particle size is one of the most important parameter influencing on depth filtration process (Mackie, Bai 1992, Mackie, Zhao, 1999, Vigneswaren, Aim, 1985, Vigneswaren, Jing, Janssens, 1999). Different impact of rate filtration on removal efficiency dependent on particle size was also proved (Zielina, 2007). Consequently, filter plant system operation impacts on filtrate quality predicted based on suspension concentration or turbidity as particle size distribution. Dependence of particle size distribution on filter operation system was numerically analyzed (Mackie, Zielina, Dabrowski 2003) A little better removal of finest particles was observed for variable declining rate filters, for higher head loss and filtration velocity through the backwashed filter. Similar observation was noticed for total volume of suspended particles. In the other hand, bigger suspended particles were better removed when filter was operated under constant rate filtration. However, generally very similar filtrate quality was observed for both systems.

Laboratory

The research experiments were carried out in laboratory set up located on Krakow University of Technology area. The set up includes water tank for preparing suspension equipped with mixing system against suspended particles sedimentation. Prepared suspension was pumped to the overflow tank guarantying constant inflow to the flocculators. Alum coagulant was dozen to flowing suspension. The flocculators were designed for 22 minutes keeping time and velocity equal 13 rotations per minute. After flocculators, suspension arrived to four filtration columns filled with sand medium. 10 centimeters diameter of Plexiglas column guaranteed small impact of wall effect. The medium inside the column was 80 centimeters high and 40 % porous. Inlets to the filters were located under minimum level of water. The same orifice was located after each of the filters. Three orifice resistances were applied for experiments: 0,007699 [mm/(m/d)2], 0,011674 [mm/(m/d)2], 0,0109 [mm/(m/d)2]. Suspension was modeled based on kaolin particles scattered in filtered tap water. Temperature was kept for all experiments between 15 and 17 Celsius degrees.

Experiments and conclusions

Four run experiments were carried out in laboratory. Filters operated under variable declining rate system keeping ratio of backwashed bed filtration velocity to average filtration velocity (q_1/q_{avr}), respectively for the run equaled 1,09;1,34;1,44. Filtration rates started from 7,2m/h; 8,8m/h; 9,5m/h after backwashed and gradually declined during the runs, but average filtration rate was all the time the same as during constant rate filtration run and equal 6,6 m/h. Total flow-rate through four variable declining rate filters was 0,182 m^3/h, flow-rate through one constant rate filter was four times lower. The velocity and headloss changes during the experiments are presented in figures 1a and 1b for (q_1/q_{avr}) = 1.44 and H = 139 cm. Turbidity reduction through the variable declining filters are shown in the figures 2,3,4 for three different backwashed rate filtration (q_1) and for constant rate filter in figure 5. Generally, turbidity of filtrate was deteriorating after backwash and improving during filtration. It is easy to explain by poor removal ability of clean porous medium. Generally, individual declining rate filter produced higher filtrate turbidity than constant rate filter in the beginning. It is caused by higher filtration velocity flowing through the backwashed variable declining rate filter than constant rate filter. The quality of filtrate from individual declining rate filter improved more significant than from constant rate filter, because filtration rate through the declining rate filter decreased. In the end of the cycle turbidity from individual declining rate filter was much lower than from constant rate filter (fig. 2,3,4,5). Only (fig. 4) for the highest ratio of (q_1/q_{avr}) =1.4, filtrate quality a little deteriorates in the end of the run The differences between filtrate quality from constant and individual declining rate filters are deeper for higher ratio of (q_1/q_{avr}).

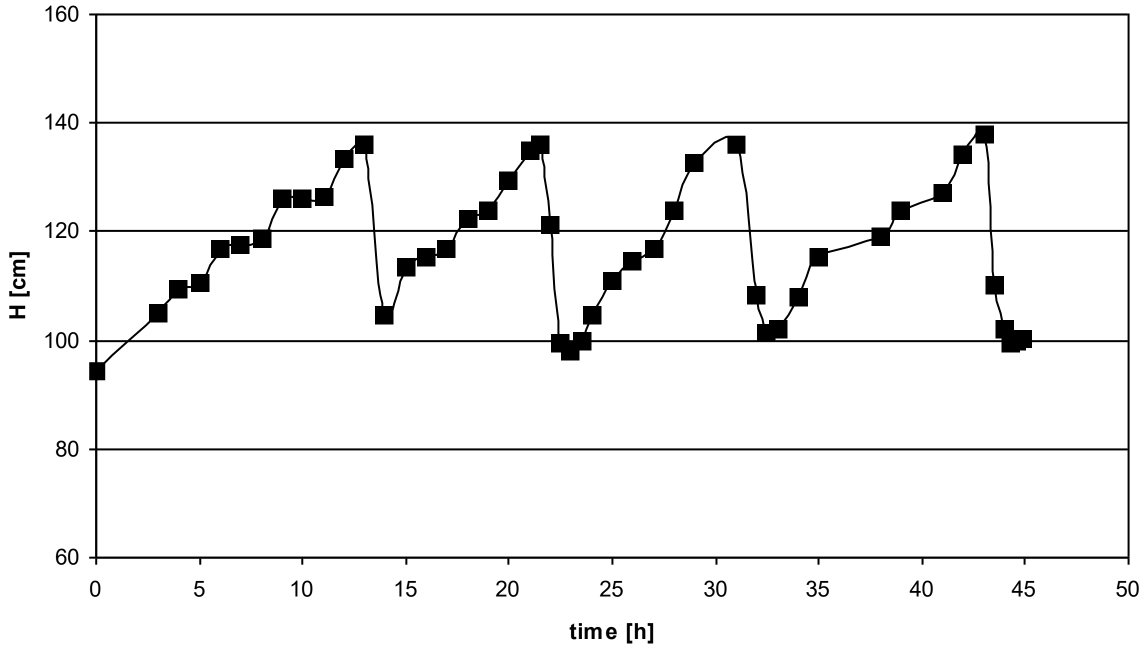

Figure 1a Total headloss through VDR filter plant for q_1/q_{avr} = 1.44, H= 139 cm

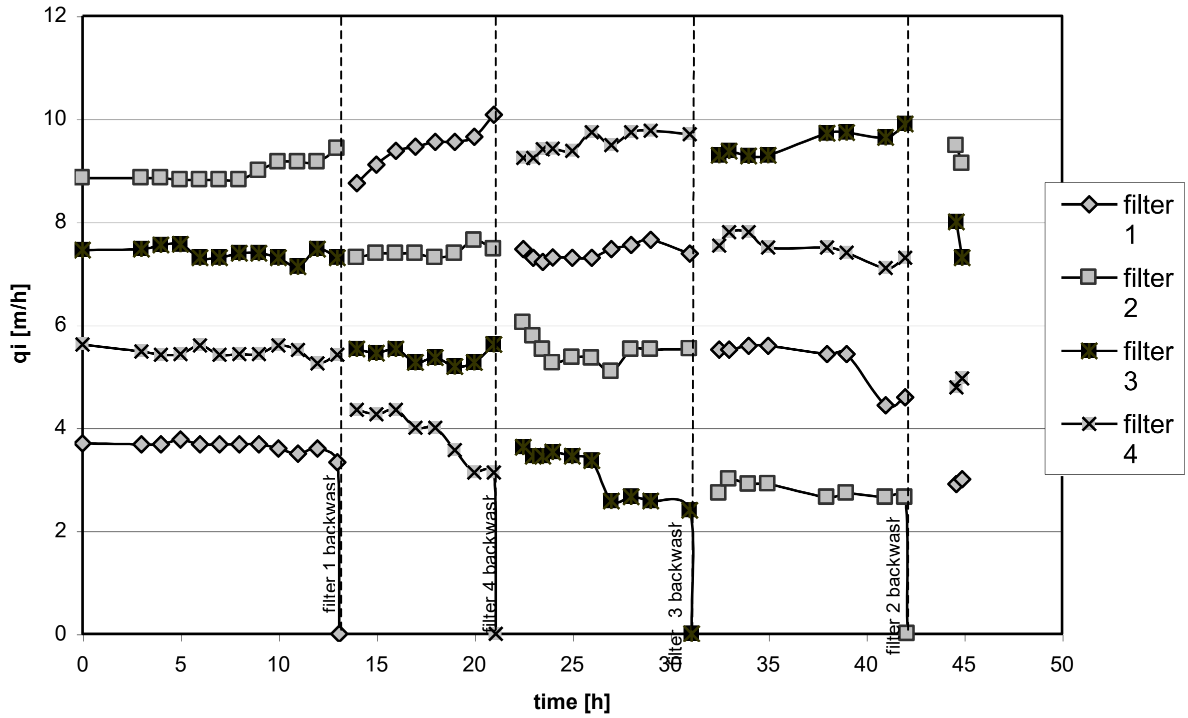

Figure 1b Filtration rate through each of the VDR filter versus the time

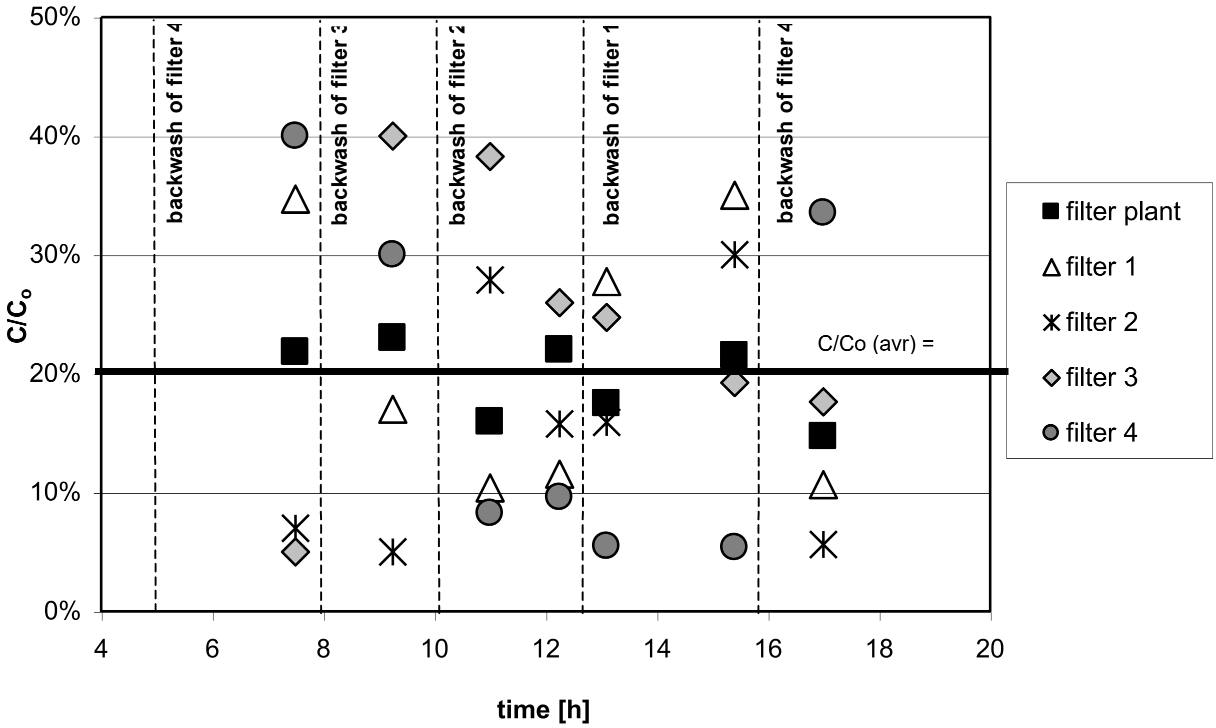

Figure 2 Remaining turbidity in outflow from each of the VDR filter and from VDR filter plant for q_1/q_{avr} =1,09 and H=80 cm

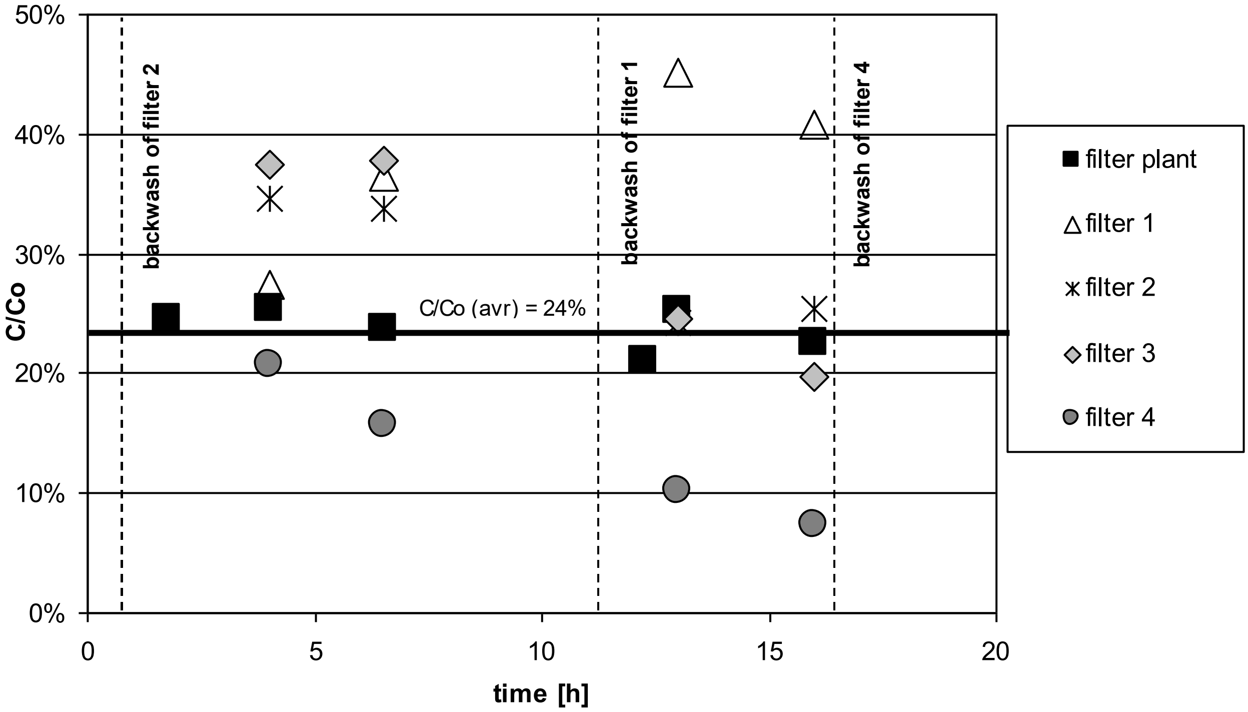

Figure 3 Remaining turbidity in outflow from each of the VDR filter and from VDR filter plant for q_1/q_{avr} =1,34 and H=118 cm

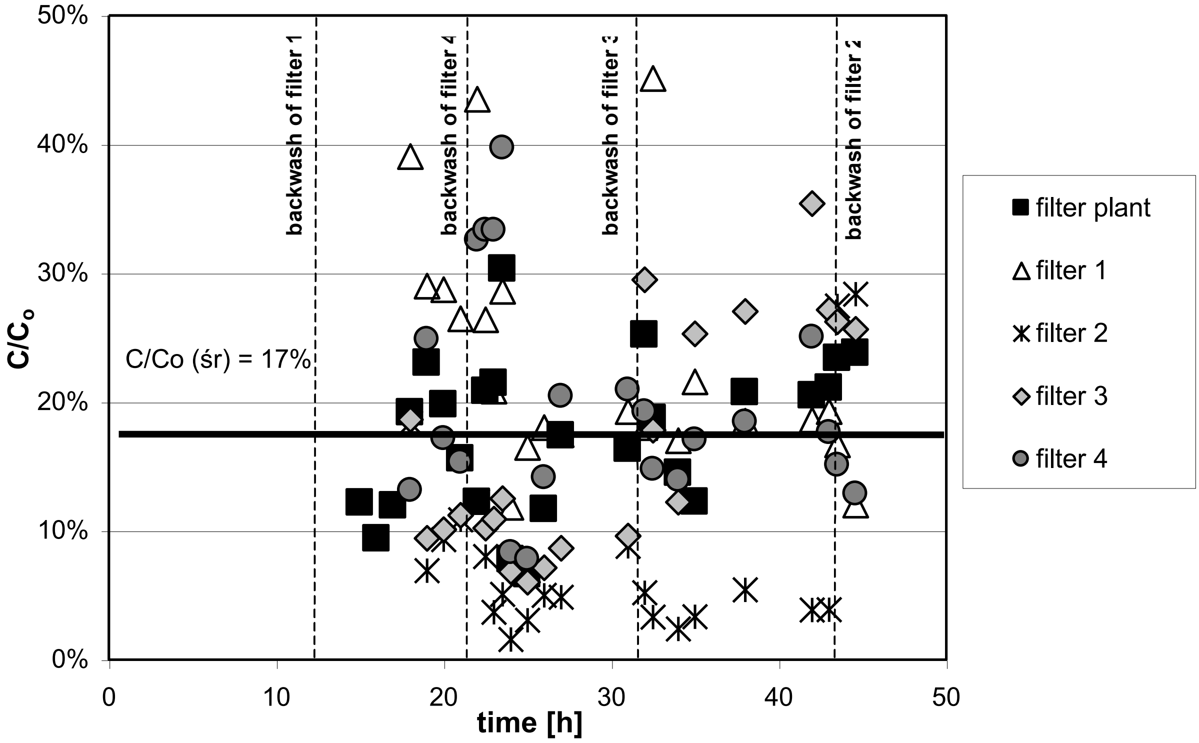

Figure 4. Remaining turbidity in outflow from each of the VDR filter and from VDR filter plant for q_1/q_{avr} =1,44 and H=136,5 cm

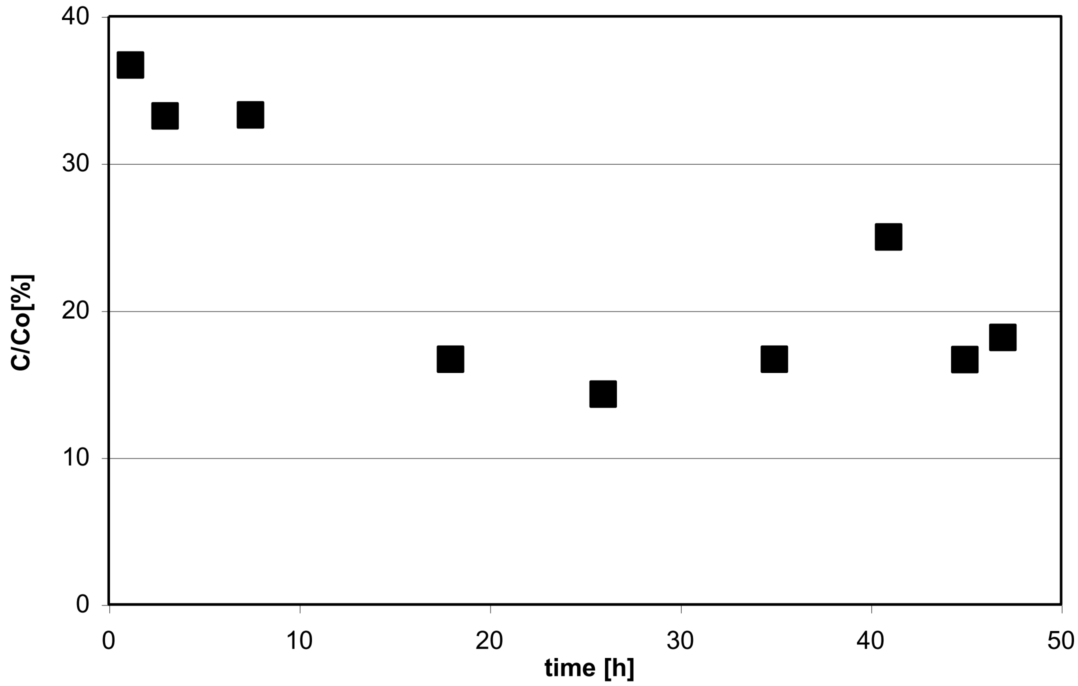

Figure 5. Remaining turbidity in outflow from constant rate filter

The average filtrate turbidities from variable declining rate filter plant were generally similar for all ratios (q_1/q_{avr}) and also similar to average turbidity produced from constant rate filter plant. The quality of filtrate from variable declining rate filters plant operated under ratio (q_1/q_{avr}) equal 1.4 seems to be a little bit better than rest, even that turbidity deteriorated in the end of this cycle.

We did not notice deterioration of total filtrate turbidity from the plant after backwashing another filter in the plant and improving of total filtrate between backwashes of filters, what was observed during numerical experiments.

Literature

[1] Akgiray O., Saatci, A critical look at declining rate filtration design, Water Science & Technology, 1998, 38, 6, 89-96.

[2] Arboleda J., Giraldo R., Snel H., 1985, Hydraulic behaviour of declining rate filtration, J.Am.Water Works Assoc, 77, 12, 67-74.

[3] Baylis, J.R. , 1959, Variable Rate Filtration, Pure Water, 11, 5-18.

[4] Cleasby, J.L., 1969, Filter Rate Control Without Rate Controllers. J.Am.Water Works Assoc., 61, 4,181-184.

[5] Cleasby J.L. Status of declining rate filtration design, Water Science & Technology, 1993, 27,10,151-164

[6] Cornwell, D.A., Bishop M.M., Bishop, T.R., McTigue, N.E., Rolan A.T., Bailey, I.W., 1991, Full-Scale Evaluation of Declining and Constant Rate Filtration, Research Foundation and American Water Works Association, Denver, CO,.

[7] Dąbrowski W., The progression of flow rates in variable declining rate filter systems, Acta hydrochimica et hydrobiologica, 2006, 34, 442-452.

[8] Di Bernardo, L., Cleasby, J.L., 1980, Declining-rate versus constant-rate filtration, Journal of the Environmental Engineering Division, ASCE, 106,EE6,1023-1041.

[9] Gregory J., Turbidity and beyond, Filtration &Separation, 1998, 35, 1, 63-67.

[10] Hatukai S., Ben-Tzur Y., M. Particle counts and size distribution in system design for removal of turbidity by granular deep bed filtration, Water Science & Technology, 1997 36, 4, 225-230,

[11] Hilmoe, D.J.,Cleasby, J.L., Comparing constant-rate and declining-rate direct filtration of a surface water, Journal AWWA, 1986, 78, 12, 26-34.

[12] Hudson H.E., Declining rate filtration, Journal AWWA, 1959, 51, 11, 1455-1463.

[13] Mackie R.I., Bai R. Suspended particle size distribution and the performance of deep bed filters. Water Research. 1992, 26, 12, 1571-1575.

[14] Mackie Ian, Dąbrowski Wojciech, Zielina Michał, Numerical study of a rational rule for the operation of Variable Declining Rate filter plant in response to changes in raw water quality, Environment Protection Engineering, 2003, 29, 1, 45-51.

[15] Mackie Ian, Zielina Michał, Dąbrowski Wojciech, Filtrate quality from different filter operations, Acta Hydrochimica et Hydrobiologica, 2003, 31, 1, 25-35.

[16] Mackie R.I., Zhao Q., A framework for modelling removal in the filtration of polydisperse Suspensions, Water Research, 1999, 33, 3, 794-806.

[17] Vigneswaren S., Aim R. B. The influence of suspended particle size distribution in deep-bed filtration. A.I.Ch.E.J. 1985, 3, 321-324.

[18] Vigneswaren S., Jing S.Ch, Janssens J.G. Experimental investigation of size distribution of suspended particles in granular bed filtration. Water Research. 1990, 24, 7, 927-930.

[19] Zielina Michał, The impact of the filtration rate on particle removal efficiency, Polish Journal of Environmental Studies, 2007, 16(2A), part II, 2007, 165-168.

[20] Zielina Michal, Dabrowski Wojciech, Mackie Ian, Laboratory and full scale verification of an optimisation approach to VDR Filter plants, Proceedings on the International Conference & Exhibition for Filtration and Separation Technology "FILTECH", Wiesbaden 2005, 1, 386-393

[21] Zielina Michał, Experimental research into depth filtration, Environment Protection Engineering, Vol. 33, No 2, 2007, 249-256.

[22] Zielina Michał, Hejduk Leszek, Measurement of the depth filters for water treatment, Filtration, 7(3), 2007, 225-228.