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IMPACT OF RAW WATER QUALITY ON OPERATION OF VARIABLE DECLINING RATE FILTER PLANTS

According to some numerical models of variable declining rate filters in a bank changes in raw water quality do not interfere with values of flow rates through filters as long as subsequent backwashes in a plant start always for the same water surface level above filter media. This simple operational rule was previously tested numerically. Now some results of experimental tests are also presented. Laboratory experiments confirm the operational rule predicted theoretically and supported by numerical computations.

1. INTRODUCTION

Despite intensive development of modern membrane techniques such as micro- and ultrafiltration [1, 2], traditional rapid filters are still widely used in water treatment to remove natural suspended matter or that produced in the process of coagulation, as well as iron and magnesium compounds [3]. In the first drinking water treatment plant applying Pall Aria™ membrane technology in Poland (Sucha Beskidzka), rapid filtration is used as a water pretreatment process which was recognized to be necessary for economical operation of 0.1 μm hollow fibre membranes. Lack of using chemicals for cleaning purposes makes rapid filtration not only economical, but also environmentally friendly technology. Though perhaps low-pressure membrane processes will dominate water purification systems in the future, yet their widespread use is limited due to their short life caused by fouling [1, 2]. Rapid filters owing to simple backwash system are allowed to work for long time at adequate pressure and capacity. However, frequent washing of rapid filters disrupts stable work of the station and causes sudden changes in flow -rate and pressure. VDR filters operation system significantly reduces these changes giving economic benefits by lengthening filter cycle and decreasing backwash frequency.

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Variable declining rate filters (VDRF) are equipped with orifices installed at outflows of filtrate from each filtration unit. These orifices create head losses of turbulent nature. Inflows to all filters are located below the lowest possible water level above filter media. The friction to flow created by pipes and valves should be negligible in comparison with the head loss of flow through the plants so water surface above filters fluctuates in time but essentially the same above all filters in any moment. Filters are backwashed in the same order. The backwash of the next filter starts when water surface above filters reaches a given level which should be calculated. Flow rates through all filters change rapidly just after each subsequent backwash in the plant which is illustrated in Figs.1, 2. During a backwash one of units is out of service, thus the remaining filters accept more raw water. The consequence of the sharp water level rise is a sudden increase in filtration velocities. After a backwash, the clean filter is put into the service again and is operated with the highest flow rate in the plant. As each of the filters is backwashed at different moments, they are operated under different flow rates. More details about VDRF construction and operation can be found elsewhere [4–8].

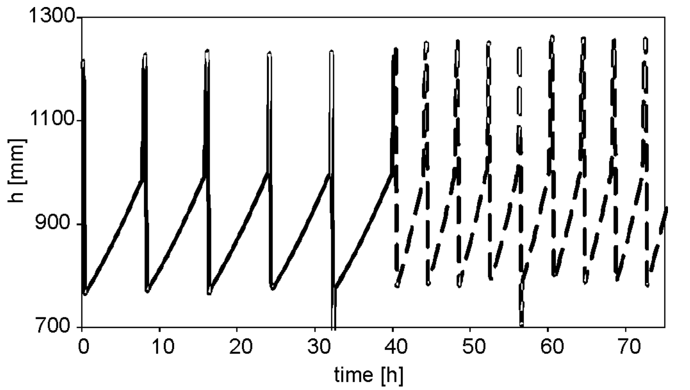

Fig. 1. Water table fluctuations for a sudden change of supply from a reference suspension I (solid line) to suspension II (dashed line) of different size gradations and concentrations according to computations published previously [9] and based on a simple UBE model of variable declining rate filters [11, 12]

Variable declining rate filters control systems are designed for stable operational conditions including temperature and quality of raw water. Such stable conditions are fulfilled only when deep groundwater is being treated, are somewhat realistic for filtering infiltration water and totally unfeasible for treatment of surface water. The discrepancies between theoretical assumptions considered at the designing step and reality do not stimulate application of theory into routine design methods. However, in our recent papers [9, 10] we have deduced that according to two different mathematical models as long as the raw water temperature is constant, the flow rates are practically the same after sudden change in raw water quality if only the backwashes start for the same water level above all filters.

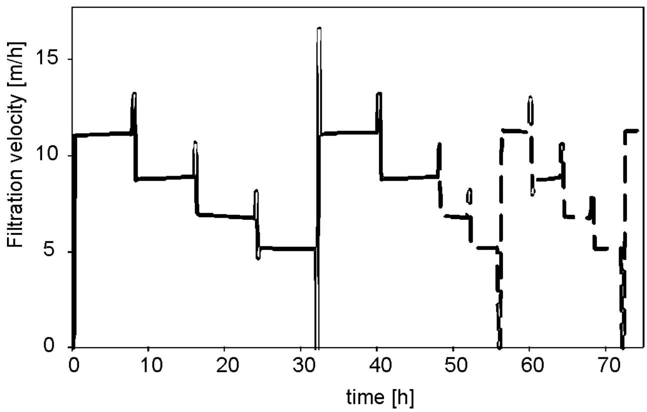

Fig. 2. Distribution of filtration velocities among four VDR filters before and after change of supply from reference suspension to suspension II (dashed line) of various size grades and concentrations according to computations [9] done based on a UBE model [11, 12] of variable declining rate filters

A rule for the operation of variable declining rate (VDR) filter plants under conditions of sudden changes in influent water turbidity has been tested using a mathematical model based on the unit bed element (UBE) approach. A UBE model developed by Mackie and Zhao [11] and adapted for Variable Declining Rate operation was used to investigate a plant behaviour in response to rapid changes in raw water quality. Two different cases have been considered. In the former, only the concentrations of solid particles were the subject of change and in the latter the particle size distribution changed as well. Numerical simulations were carried out under backwashing starting when the water level above the filters reached the same level (Fig. 1). It was found that this resulted in almost identical flow rates through each of the filters, but the length of filter runs, and the effluent quality were significantly different (Fig. 2). In conclusion for waters of stable temperature but different turbidities, backwashing should start for the same water level above the media, even if the raw water quality changes. None reliable mathematical models exist applicable for coagulated suspension flow through porous media, thus this conclusion has to be verified experimentally.

2. LABORATORY SET-UP

A four filtration column pilot plant has been constructed at the Cracow University of Technology. The columns were equipped with orifices installed at outflows and operated in a variable declining rate manner. Two photographs of the laboratory set-up are presented in Figs. 3 and 4.

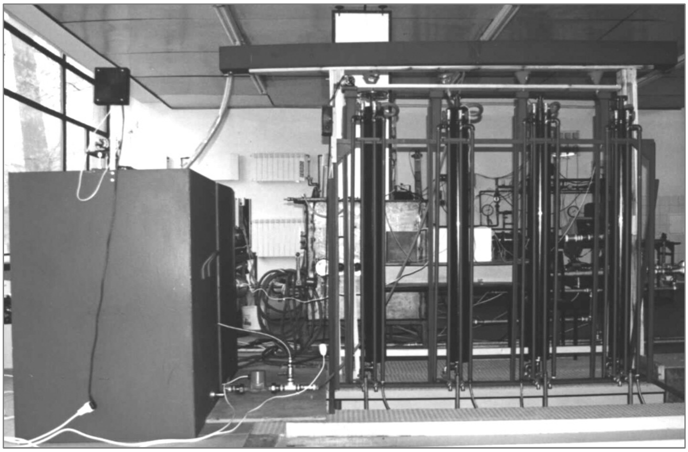

Fig. 3. Suspension tanks and flocculators located at the upper floor

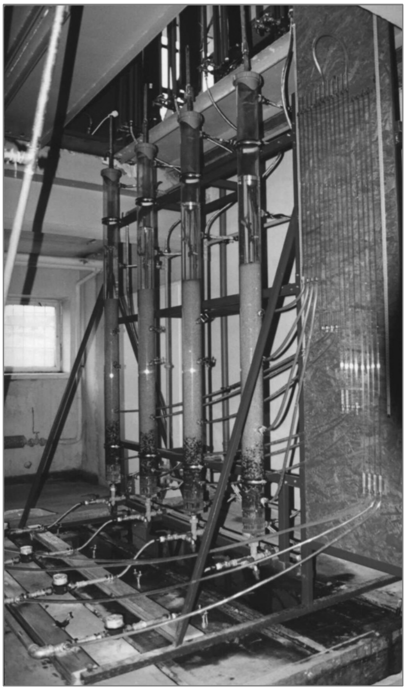

Fig. 4. Filtration columns located at the lower floor (below flocculators)

Suspensions kept in three tanks were in continuous movement due to internal recirculation and mechanical stirring. Three different suspensions, all of the same temperature equal to 16 °C but of different concentrations of suspended solids were prepared and used one by one. Each time suspension was pumped to a device controlling flow rate. This device was equipped with an orifice of an adjustable position enabling a precise adjustment of flow rate to a requested value. Then aluminium sulfate (5 wt. %) was injected to suspension streams just before four flocculators. The doses of coagulant were previously predicted in jar tests in function of concentration of clay suspension. Mechanical flocculators were divided into three compartments. The Stein–Camp gradient of mixing was about 80 s^{-1} at the last compartment. After flocculation, suspension was directed to the system of filtration columns operated under a variable declining rate control system. The inside diameter of the columns was 0.098 m. Each column was equipped with a flowmeter and the total outflow from the plant was recorded again to verify the readings. The relative errors of flow rate measurements were below 0.5% in the range of flow rates from q_1 to q_4, where subscripts refer to the number given to each of filtration column starting from the one just after a backwash q_1 and ending at the one just before its backwash q_4.

Table 1

Media sand gradation

Fraction diameters [mm]	Content [%]
0.4–0.5	10.0
0.5–0.63	18.8
0.63–0.8	31.2
0.8–1.0	36.1
1.0–1.25	3.9

The gradation of sand used in the experiments is summarized in Table 1. The sand is quite fine in comparison with Polish standards and it follows rather British guidelines.

3. METHOD

The experimental filter plant was supplied with clay suspension of the concentration of suspended solids of 7 mg/dm^3 coagulated with 7.5 mg/dm^3 of aluminium sulfate $Al_2(SO_4)_3 \cdot 14H_2O$ for a period covering three backwashes of each of the column. This introductory period was necessary to prepare the filter media resistance to flow, different for each of the filtration columns and corresponding to values appropriate for the variable declining rate operation with a given value of the total head loss of flow through the media, the drainage and the orifice just before a subsequent backwash in a plant H and to the height of water surface fluctuations above filter media between backwashes h_0. Values of H and h_0 were the same during the introductory period and then identical till the end of the experiments. Flow rates through filtration columns after completing the third backwash for each of the column were almost identical to flow rates after completing the second backwash thus it seemed that the columns were ready for starting the major part of the experiment. In this part, clay suspensions of various origins, solids gradation and suspended solids concentrations were supplied from each of three suspension tanks one by one. The dose of alum was adjusted to each of the three suspensions as predicted previously in jar tests. These doses had much more visible impact on head losses development in filtration columns than the concentrations of clay suspended solids used in the experiments. The rotation speed of the stirrer was the same the whole time but due to different doses of coagulant it was expected that flocculation produced flocs of different sizes, thus also of different densities [13]. Some microscope observations of floccules and flocs supported this hypothesis.

4. RESULTS

The operation of the laboratory filtration plant was conducted starting the backwashes from the same value of H as applied in the primary part of the experiments. The water surface level was subject to dynamical changes and backwashed intended to be uniquely long but in practice they differed a little, thus the lowest head loss of flow through filtration columns equal to $H - h_0$ not always was exactly the same. The differences did not exceed however the average value by ±2 cm. Moreover, the same period of taking one of the filters out of service for backwash resulted in different clogging of remaining filter media depending on suspension actually used for the plant supply. A pattern of the fluctuations of water surface and changes in flow rates in time are presented in Figs. 5 and 6.

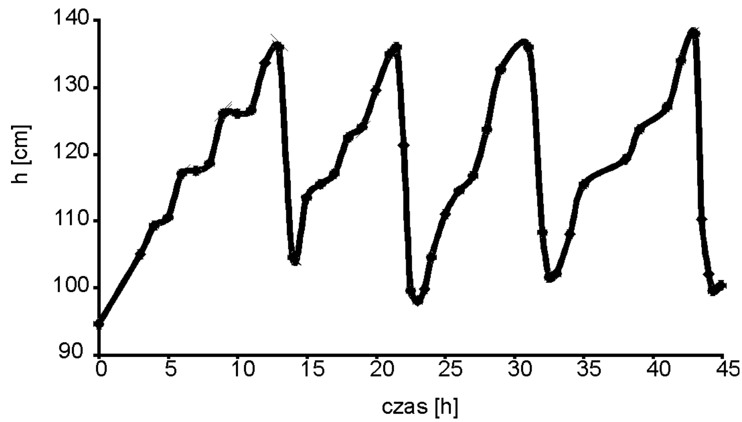

Fig. 5 Experimental time dependence of water surface fluctuations above filter media. h denotes the total head loss of flow through filter media, drainage and orifice

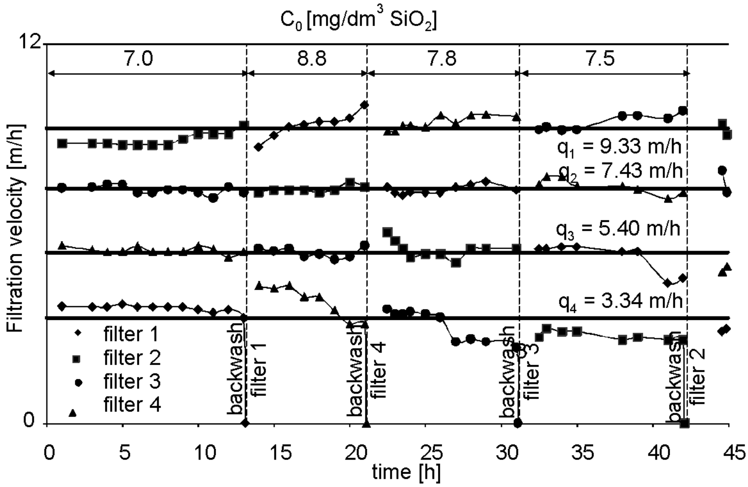

Fig. 6. Recorded time dependences of filtration velocity through filtration columns for various suspensions supplying the plant

For the plant operation based on starting backwashes when the water surface reached the same level, the flow rates illustrated in Fig.6 remained essentially the same in spite of different suspensions used and visibly different periods between subsequent backwashes in the plant. If one of flow rates tended to increase or decrease between subsequent backwashes in the plant, then at least another one behaved oppositely because the total flow ratio of inflow remained the same and the accumulation of water above filter media is limited. The average values of flow rates were denoted in Fig. 6 by horizontal solid lines.

5. CONCLUSIONS

The experiments confirmed our previous expectations [9, 10] that as long as the suspension temperature is constant changes of raw water quality do not disturb the water flow distribution among VDR filters if only all backwashes in the plant start exactly when the water surface level above filter media reaches the same value *H*. This refers to both series of experiments in which first only the concentration of suspension and then also suspended solids size diameters were subjects of changes. Thus in the same season this simple rule may be applied to keep the same flow rates through filters, and what is more important, the same pattern of filter media resistances to flow at the end of each subsequent backwashes in the plant. Unfortunately, adjusting the flow rate self control system to different temperatures (different seasons) requires more substantial changes [7] in operation as turbulent head losses in drainage and orifices do not depend on temperature but in filter media does.

ACKNOWLEDGEMENTS

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