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ANDRZEJ M. DZIUBEK*, JOLANTA MAĆKIEWICZ*

INFILTRATION WATER TREATMENT BY COAGULATION

The efficiency of infiltration water treatment was tested under pilot plant conditions, using a treatment train which included aeration, coagulation and direct filtration. Direct coagulation of pollutants in the filter bed yielded good treatment effects (deep coagulation effect) even with low flocculant doses (alum or ferric coagulant). Iron concentration in finished water fell below 0.05 g/m^3. Organic matter concentrations were also low.

1. INTRODUCTION

Conventional trains for groundwater treatment generally include aeration and filtration (combined with catalytic oxidation of manganese compounds on the filter bed), sometimes concomitant with pH adjustment and chemical oxidation as a prior step to the filtration process. Coagulation has been incorporated only occasionally, i.e., in the presence of troublesome pollutants (e.g., very high concentrations of iron compounds; iron colloids; iron compound–organic compound complexes) [1], [2].

The objective of this study was to determine the technological parameters for the treatment of infiltration water so as to provide the highest possible efficiency of the process (in terms of sanitary safety). In this way, it will be possible not only to decrease the required doses of disinfectants, but also to eliminate the undesirable phenomenon of iron precipitation in water-supply pipes, which is quite frequent now. Another objective of the study was to find out how the inclusion of coagulation (which was applied after the aeration process) affected the quality of treated water (which was characterized by very low concentrations of pollutants) [3].

The investigations were carried out under laboratory conditions by the jar-test method, as well as under through-flow conditions in a model pilot plant.

* Institute of Environment Protection Engineering, Technical University of Wrocław, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland.

2. METHODS

2.1. JAR TESTS

The tests were run at the following parameters: rapid mix, 2 min; slow mix, 20 min; sedimentation, 30 min. Filtration was carried out at a bed depth of 1.2 m and a grain diameter (d_{10}) of 1.0 mm. Filtration rate varied from 5 to 15 m/h. The coagulation process was run with alum ($Al_2(SO_4)_3 \cdot 18H_2O$) or Roflok-WP ($FeCl_3 \cdot 6H_2O$) as a flocculant. Coagulant doses varied from 10 to 40 g/m^3.

2.2. THROUGH-FLOW SYSTEM

To verify the results of the jar tests, investigations were conducted in a pilot-plant system comprising two processes – sludge blanket coagulation and filtration. The water stream had been treated with an appropriate coagulant dose before it was passed to the central part of the vertical settling tank. The thickness (depth) of the sludge blanket layer varied from 1.0 to 1.5 m. Water flow velocity in the settling tank ranged between 0.5 and 0.7 mm/s. The ripened sand bed had the depth of 1.2 m (sand samples were collected from the filter beds of the 'Na Grobli' Waterworks of Wrocław). Filtration rate was varied from 6 to 11 m/h. The system was fed (through pipes) with infiltration water after passage through a multiple-tray aerator. The treatment train included:

filtration of raw water,
sludge-blanket coagulation and filtration,
direct filtration.

3. PARAMETERS OF INFILTRATION WATER

Physicochemical composition of water was analyzed in raw samples following aeration in a multiple-tray aerator. The infiltration water under study was found to be of moderate hardness and mineralization as well as of neutral pH. Turbidity, coloured matter content, iron and manganese concentrations showed elevated levels. The concentrations of nitrogen compounds indicated that the infiltration water was polluted by organic substances. COD_p and TOC were not very high, and there was no correlation between them. The occurrence of humic acids was an indication that precursors of halogen compounds were also present. Aggressive carbon dioxide occurred in very small amounts, because a major portion of it had been removed during aeration. Although heavy metals were detected only occasionally, a continual control of their concentrations both in raw and treated water is recommended. The presence of phosphates substantiated the increased stabilization of the pollutants and the potentiality for treatment problems. Some major parameters of the infiltration water are listed in tables 1 and 3.

Table 1

Efficiency of water coagulation at coagulant dose 5–40 g/m^3

Parameter, unit	Raw water	Alum coagulation	Roflok-WP coagulation
pH	7.3–7.6	7.0–7.5	6.6–7.3
Alkalinity, val/m^3	2.1–3.3	1.6–2.5	1.6–2.3
COD (permanganate), g O_2/m^3	2.7–4.5	2.1–3.1	2.1–3.2
Colour, g Pt/m^3	10–20	5–10	5–12
Turbidity, g/m^3	5–10	3–5	3–5
Total iron, g Fe/m^3	0.6–2.6	< 0.15	< 0.10
Manganese, g Mn/m^3	0.64	0.10	–

4. TECHNOLOGICAL EFFECTS OF COAGULATION AND FILTRATION

As shown by the results obtained (table 1), the technological effects were similar, irrespective of the coagulant applied. According to our previous results [3], the increase of the coagulant dose did not improve the efficiency of the process. Recommended doses ranged between 10 and 15 g/m^3.

The treatment effects obtained by raw water filtration are listed in table 2. As shown by these data, the process brought about a decrease of iron compound concentrations to about 0.5 g Fe/m^3, a complete removal of manganese and considerable reduction of turbidity and COD_p (COD_p was found to decrease with the increasing filtration rate). The remaining water quality parameters did not follow such a pattern. There was no removal of coloured matter by filtration.

Table 2

Efficiency of water filtration at v_f = 5–15 m/h

Parameter, unit	Raw water filtration	Filtration after coagulation with Roflok-WP dose 30 g/m^3
Colour, g Pt/m^3	15	< 5
Turbidity, g/m^3	3	3
COD (permanganate), g O_2/m^3	2.1–3.2	1.7–2.0
Total iron, g Fe/m^3	0.5	0.01–0.03
Manganese, g Mn/m^3	0.0	0.0

Table 2 shows the effects of filtration after Roflok-WP coagulation at a 30 g/m^3 flocculant dose and a filtration rate from 5 to 15 m/h. Thus, the removal of iron compounds (Fe_{res} = 0.01 to 0.03 g/m^3) and coloured matter (≤ 5 g Pt/m^3) was noticeably higher than that obtained by raw water filtration (the efficiencies of manganese and turbidity removal being almost the same). COD_p removal was also greater, and the contribution of the coagulation process increased with the increasing filtration rate [3].

The results of laboratory tests revealed that a treatment train with no coagulation yielded an effluent displaying quality parameters similar to those of potable water. However, the inclusion of the coagulation process not only upgraded the efficiency of iron removal (residual iron concentration being only 0.1 g Fe/m^3, or below) but also decreased COD_p and colour (residual colour concentration amounting to ≤ 5 g Pt/m^3, which is normally achieved by deep coagulation).

5. TECHNOLOGICAL RESULTS

5.1. FILTRATION OF RAW WATER

Raw water was filtered through a ripened sand bed (covered with iron and manganese oxides) at the rate of 6 m/h or 11 m/h (table 3). The quality of the filtrate was similar, irrespective of the filtration rate applied. Colour and turbidity decreased, whereas iron, manganese and ammonia nitrogen concentrations amounted to 0.20–0.28 g Fe/m^3, 0.00–0.07 g Mn/m^3 and 0.00–0.06 g N/m^3, respectively.

Filtration rate had little effect on the decrease of organic matter content, but its contribution to head loss increment was considerable (from 0.93 to 1.20 m after 24-hour filtration run at v_f = 6 m/h, and 2.50 m after 8.5-hour filtration run at v_f = 11 m/h).

Summing up, filtration through a ripened sand bed yielded water of the desired quality.

Table 3

Comparison of water filtration efficiencies

Parameter, unit	Raw water	Raw water filtration		Filtration after coagulation, v_f = 6 m/h		Direct filtration v_f = 6 m/h	
		6 m/h	11 m/h	15 g**/m^3	50 g**/m^3	3.5 g**/m^3	5 g*/m^3
pH	7.0–7.4	–	–	–	–	7.1–7.2	7.1–7.2
Alkalinity, val/m^3	2.0–2.5	–	–	–	–	2.3	2.3
Colour, g Pt/m^3	10–25	5–10	5–10	5–8	5–8	5	5
Turbidity, g/m^3	7–30	< 3	< 3	3–5	3–5	< 3	3
COD (permanganate), g O_2/m^3	3.5–5.1	3.1–3.6	4.1	1.7–2.3	1.7–2.3	2.7–3.1	3.5
Total iron, g Fe/m^3	1.8–4.0	0.2–0.3		0.01–0.03	0.3–1.7	0.02–0.04	< 0.02
Manganese, g Mn/m^3	0.4–0.9	0.0–0.07		0.0–0.07	0.14–0.36	0.03–0.08	< 0.04
Ammonia nitrogen, g N/m^3	0.1–0.2	0.0	0.06	0.0–0.05	0.12	0.0	0.0
Filtration run, h	–	24	8.5	3	24	24	30
Head loss, *m* H_2O	–	1.0–1.2	2.5	–	1.2	1.8	1.7

*$Al_2(SO_4)_3\cdot 18H_2O$,
**$FeCl_3\cdot 6H_2O$.

5.2. COAGULATION AND FILTRATION

The efficiency of Roflok-WP coagulation followed by filtration through a ripened sand bed (v_f = 6 m/h) is shown in table 3. Colour, turbidity and COD_p were found to decrease. At the Roflok-WP dose of 15 g/m^3, residual concentration of manganese amounted to ≤ 0.07 g Mn/m^3. The 50 g/m^3 Roflok-WP dose deteriorated the efficiency of manganese removal with a residual concentration ranging between 0.14 and 0.36 g Mn/m^3. The same holds for the efficiency of iron removal which was better at the 15 g/m^3 Roflok-WP dose, yielding a residual concentration of 0.015–0.035 g Fe/m^3. The application of the 50 g/m^3 dose brought about a residual iron concentration of 0.28 g Fe/m^3 at the beginning of the filtration run, and accounted for a further rise up to 1.7–2.4 g Fe/m^3 after 24 hours (after about 8 hours of the filtration cycle, residual iron concentration totalled 1.2 g Fe/m^3). The potentiality for breakthrough was found to occur after about 24 hours of filtration. This should be attributed to an insufficient sedimentation of the iron compounds which entered the filter beds together with the water stream. The residual concentration of ammonia nitrogen was also found to increase (up to 0.12 g N/m^3), but – compared to the initial value – there was still a noticeable decrease of this parameter.

On the basis of the results obtained the following generalizations can be made:

The increased coagulant dose deteriorated the quality of the filtrate from the ripened sand bed in terms of iron and manganese removal.

The duration of the filtration run was dramatically shortened, even though the head loss increment suggested that the filtration process might have been continued.

The application of an increased coagulant dose provided a better removal of organic pollutants (COD_p, organic nitrogen).

The quantity of the coagulant dose had no effect on the behaviour of the remaining parameters of water quality.

Of heavy metals, chromium and lead occurred in trace amounts only. Copper, zinc, nickel, cobalt and cadmium were absent.

5.3. DIRECT FILTRATION

The process was carried out in a ripened sand bed with the aim to verify the technological effect obtained by the jar-test method. Coagulants were dosed directly to the filter bed. Table 3 includes the results of filtration of water treated with Roflok-WP (3.5 g/m^3) or alum (5.0 g/m^3) when the filtration rate was 6 m/h. The filtrate was characterized by the following parameters: colour, 5 g Pt/m^3; turbidity, < 3 g/m^3; COD_p, < 3.5 g O_2/m^3; iron concentration, < 0.04 g Fe/m^3; and manganese concentration, < 0.08 g Mn/m^3. Ammonia nitrogen was absent. A 3.5 g/m^3 Roflok-WP dose provided water of desired quality throughout the 24-hour filtration cycle at a head loss varying from 0.2 to 1.8 m. A 5.0 g/m^3 alum dose yielded similar effects at almost identical head loss (1.7 m), but filtration run was extended to about 30 hours. Residual alum concentration in the filtrate did not exceed 0.1 g Al/m^3. At increased doses, both Roflok-WP and alum brought about a slight deterioration of the filtrate quality. Residual alum concentration in the filtrate was never higher than 0.3 g Al/m^3, even at a dose of 20 g/m^3. When alum was applied as a flocculating agent, the quality of the filtrate varied only slightly throughout the filtration run, and there was no noticeable deterioration at the end of it.

The pilot-plant study substantiated the usefulness of alum and ferric chloride coagulants in water treatment, but the application of the alum coagulant had the advantage of providing longer filtration cycles.

6. SUMMARY

The infiltration water, which was to be taken in for drinking purposes, required satisfactory removal of iron and manganese compounds, turbidity, colour and micropollutants.

Aeration and filtration in a ripened sand bed provided a satisfactory efficient treatment of the infiltration water (except removal of micropollutants).

When the treatment train included coagulation as a unit process, it was possible to achieve considerably higher removal efficiencies for iron and manganese compounds, organic substances and nitrogen compounds.

Sludge blanket coagulation was found to be inefficient. Better treatment effects were obtained by direct coagulation in the filter bed, irrespective of whether Roflok-WP or alum was used as a flocculant. High efficiencies of removal were achieved with low coagulant doses (3.0–5.0 g/m^3), but the application of Roflok-WP (ferric coagulant) noticeably shortened the filtration cycle.

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UZDATNIANIE WÓD INFILTRACYJNYCH W PROCESIE KOAGULACJI

Omówiono wyniki badań nad zastosowaniem procesu koagulacji do uzdatniania wód infiltracyjnych, które polegało na napowietrzaniu i filtracji na złożach wypracowanych. Podczas badań przeprowadzonych w układzie przepływowym na modelowej stacji pilotowej stwierdzono, że koagulacja zanieczyszczeń prowadzona solami glinu i żelaza w dawkach 3–5 g/m^3 bezpośrednio w złożu filtracyjnym umożliwia uzyskanie efektu tzw. głębokiej koagulacji, a także istotnie zwiększa stopień usuwania żelaza i związków organicznych z wody.