Environment Protection Engineering

Vol. 26 2000 No. 3

WOJCIECH ADAMSKI*, JULITA MARKIEWICZ*, TRACY CAMMILLARE**

53-62
B.S 2.5

UP-FLOW DIRECT FILTRATION THROUGH ACTIVATED CARBON BED

The up-flow direct filtration through adsorption bed for water with low turbidity and elevated organic compounds' concentration was tested. The effects of coagulation in GAC with a sequence of volume coagulation and adsorption were investigated separately, and the advantages of the method proposed in comparison to conventional ones were presented. The attractiveness of the method was presented even when the coagulant dosage was periodical.

NOTATION

B_0 – initial colour [mg Pt/dm^3],
d – geometrical diameter of carbon grains [m],
d_a – diameter of adsorbate particle [m],
D – coefficient of molecular diffusion [m^2/s],
D_k – coagulant dose [mg/dm^3],
G – velocity gradient [s^{-1}],
K – Boltzmann constant [J/K],
L – height of filtration bed [m],
t_D – diffusion time [s],
T – temperature [K],
V_f – linear velocity [m/h].

GREEK LETTERS

ε – filtration bed porosity,
η – dynamic viscosity coefficient [kg/m^{3}s].

ABBREVIATIONS

COD_p – chemical oxygen demand,
GAC – granular activated carbon,
TOC – total organic carbon.

*Institute of Environment Protection Engineering, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland.
**Natural Sciences Department, Staffordshire University, College Road, Stoke on Trent, Staffordshire, ST4 5NG, England.

1. INTRODUCTION

Conventional methods of surface water treatment include coagulation, flocculation, sedimentation, filtration and sometimes adsorption, usually applied as separate processes. The treatment of groundwater is achieved by aeration and filtration alone. In comparison to surface waters, groundwater is superior in terms of colour, turbidity and total organic compounds and inferior in terms of iron and manganese compounds [1]. More recently, to the natural characteristics of groundwater (e.g. humic substances from the degradation of dead organic matter and from metabolic processes of living organisms) there are added those which originate from anthropogenic sources [2].

As legislation in drinking water continues to make demands on water treatment, some groundwaters require more complicated treatment than aeration and filtration. As a result different methods of such treatments are sought. Although in general groundwater is superior to surface water in certain respects, it cannot be processed in the same way due to its low turbidity. One of the methods that are currently of interest in the removal of organic pollutants from waters is the use of GAC beds.

The common interest in using GAC with regard to natural waters for drinking water treatment is continually increasing. Using activated carbon offers a highly effective removal of both humic substances and dissolved organic compounds [3], [4]. GAC processes generally require low energy and are reasonably easy to operate and maintain.

However, the changes in legislation go hand in hand with a cost benefit analysis and so new methods must be both advantageous and cost effective.

Direct filtration is a water treatment process where no chemical treatment in separated reactors is given prior to filtration, except non-chemical pretreatment if necessary [5]. Direct filtration consists in coagulant addition, rapid mixing, flocculation and filtration. According to the American Water Works Association direct filtration has several advantages over conventional methods. Primarily it has lower capital costs, i.e. no sedimentation tanks, lower coagulant doses, which result in lower costs of sludge treatment and disposal. However, the disadvantage of a direct filtration is that it cannot handle waters with combinations of high turbidity and colour [6].

For economical and practical reasons, which are outlined above, it seems logical to combine both GAC with direct filtration in the treatment of low turbidity water.

2. AIM AND SCOPE

Based on the recent literature on coagulation in sand filters and adsorption in the GAC bed the decision was taken to try and combine these processes in one unit. The aim of this paper was to evaluate the effectiveness of a novel idea in combining GAC and up-flow direct filtration in the treatment of water to be used for drinking [7]. In addition to the above, the advantages of the utilisation of this treatment process were to be outlined.

The investigations were carried out under laboratory conditions in order to test volume coagulation (jar test), dynamic adsorption (batch test with mixing) and water treatment in a model pilot plant (column test). The column test encompassed the treatment of natural water for complete filtration cycle in a GAC bed using continuous coagulation, coagulation only for 30 minutes and filtration without coagulant addition.

3. TECHNOLOGICAL ASPECT AND METHODOLOGY

3.1. WATER PARAMETERS

The system was treated with natural groundwater from the intake at Koźmin town. The water was characterised by intense colour, high concentration of organic component and low turbidity. A significant portion of iron was removed during aeration and sedimentation.

Water from Koźmin was considered to be characteristic and compatible with this method of treatment, since this method was not effective to treat waters of intense colour and very low turbidity in order to obtain the required standards as in a conventional water treatment. The major parameters of the water are listed in table 1.

Table 1

Characteristics of natural groundwater after aeration and sedimentation

Parameters	Minimum value	Maximum value	Mean value
pH	7.61	7.85	7.65
Alkalinity, mval/dm^3	5.8	6.1	6.0
Colour, mg Pt/dm^3	51.60	65.55	60.00
Turbidity, mg/dm^3	0.99	1.59	1.36
UV254, abs	1.25	1.43	1.38
TOC, mg C/dm^3	8.42	12.85	9.05
COD, mg O_2/dm^3	7.4	10.5	9.0
Iron, mg Fe/dm^3	0.312	0.922	0.546
Manganese, mg Mn/dm^3	0.02	0.07	0.01
Aluminium, mg Al/dm^3	~0	0.03	0.02

3.2. ACTIVATED CARBON CHARACTERISTICS

In the investigation, the carbon used was of HKW1 type, produced from bituminous coal by the Chemviron Company.

Table 2

Characteristics of activated carbon

Characteristics	Value
Total surface area, m^2/g	950–1050
Bulk density, kg/m^3	445
Surface area per unit volume, m^2/cm^3	518
Particle density wetted in water , g/cm^3	1.3–1.4
Effective size, mm	1.5– 2.0
Uniformity coefficient	1.75
Pore volume, cm^3/g	0.85

All investigations were carried according to the recommendations given in the Standard Methods for the Examination of Water and Wastewaters [8], at natural pH.

3.3. VOLUME COAGULATION

Volume coagulation was carried out in the jar tests in two liter containers in PN-700^{TM} JARTESTER produced by Phipps & Bird. Rapid mixing was carried out during two minutes at 200 r.p.m, and slow mixing during 30 minutes at 30 r.p.m. The samples were then left to sediment for 1 hour. The coagulation was carried out with alum ($Al_2(SO_4)_3 \cdot 18H_2O$) using 6 different coagulant doses which ranged from 6.8 to 108 mg/dm^3.

In the volume coagulation process, the following parameters were analysed: pH, alkalinity, COD (permangate value), TOC, UV254 abs (this parameter offers a useful measure of organic constituents in freshwaters [9]), colour, turbidity, total iron, manganese and residual aluminum concentration. The aim of the volume coagulation was to obtain the optimal dose of coagulant, which could be used in the column tests.

3.4. ADSORPTION IN BATCH TESTS

After obtaining the optimal coagulant dose (27 mg/dm^3), it was used to treat natural water in the process of adsorption. The portion tests were conducted in one liter bottles with different quantities of activated carbon.

The purpose of the batch tests was to imitate the conditions in the filtration bed. The velocity gradient of the batch test mixing was similar to the velocity gradient of the solution mixing in the GAC (V_f = 6 m/h). The effectiveness of the process was analysed by measuring TOC, colour and UV254 absorption after 5 and 6 hours. Previous experiments showed that after the sixth hour the adsorption equilibrium was reached and the changes in the parameters were negligible.

3.5. COLUMN TESTS

Column test was carried out at a filter bed height of 0.5 m, the geometrical diameter of carbon was equal to 2 mm and the filtration bed porosity – 0.45. The filtration linear velocity was approximately 6 m/h, which is the standard velocity used in coagulation in a sand filter bed.

The value of the hydraulical load was selected within the range of linear velocity typical of contact coagulation in a sand filter bed. This range reduced the risk of bed destabilization under the influence of up-flow direct filtration and ensured such contact time that excluded the diffusion of large colloids onto the sorption surface and thus prevented the blockage of the carbon pores.

Diffusion time (t_D) can be calculated on the basis of the following formula:

$$t_D = \frac{r^2}{2D}. \tag{1}$$

Coefficient of molecular diffusion (D) is defined by Stokes–Einstein equation:

$$D = \frac{KT}{3\pi\eta d_a}. \tag{2}$$

The radius of intergranular capillary can be empirically calculated using the following equation:

$$r = \frac{\varepsilon d}{6(1-\varepsilon)}. \tag{3}$$

Using the average values of particles diameters for dissolved organic components and colloidal particles [2], based on equations (1)–(3), diffusion times were calculated. The diffusion time of dissolved organic compounds to the interface in the presented example was 30 s, and for colloidal particles was in the range from 0.5 to 55 hrs.

The linear velocity that was decided to be used (6 m/s) for the height of the carbon bed (0.5 m) provided a contact time (t_c) of the treated solution at 5 minutes, which ranged from 0.5 to 30 minutes.

3.5.1. GAC BED ADSORPTION AND UP-FLOW DIRECT FILTRATION

The water stream was treated with a definite coagulant dose prior to the delivery to the activated carbon bed. The colloids were destabilised in the pipe, which fed water to the sorption up-flow column. Prior to the water contact with the GAC bed the process of hydrolysis occurred, thus decreasing the stability of the colloids. The neutralization of electrokinetic potential, flocculation and filtration of the created agglomerates took place during the passing of the solution from the bottom to the top of the column. This resulted in the benefit of catalytic properties of the solid phase. At the same time organic components could be removed by the created sludge.

At the moment when the limit of head loss of filtration was exceeded or if the quality of the water became unacceptable, the inflow of the natural water was turned off and the column was backwashed.

The maximum filtration cycle depends on the water quality and the coagulant dose. In the case of the contact filters, the cycles are shorter than in conventional filters, which necessitates frequent backwashing of the filter bed. Regular purging over short periods of time causes an increased risk of abrasion, and so activated carbon of good quality and high mechanical resistance was used.

6. RESULTS AND DISCUSSION

In regard to the intensity of a final colour, TOC, turbidity, COD, UV254 and residual alumimiun concentration after the volume coagulation process, the optimum dose of the alum was decided at $3.5\sqrt{B_0} = 27$ mg/dm^3 ($B_0 = 60$ mg Pt/dm^3).

Increase in the coagulant dose above 27 mg/dm^3 did not increase the efficiency of the process, e.g. COD and TOC reduction were not significant. Colour and turbidity remained approximately the same. The residual concentration of aluminium in all doses was quite high (e.g. 0.88 mg Al/dm^3 in the case of 108 mg/dm^3 of coagulant). Due to a very low water turbidity the coagulation process was not very effective, suspended solids were light and settled badly. The colour was removed in 50–55%, and turbidity in 40–42%. Decrease in UV254 absorption was about 45%, TOC 30–35% and COD_p 36–40%. Manganese was removed completely and total iron in 85–90%. The residual aluminum concentration was in the range of 0.5–0.65 mg Al/dm^3 so the usage level of coagulant was about 70–77%.

Initial concentrations of organic compounds measured as colour, UV254 absorption and TOC were decreased in the process of volume coagulation and adsorption in the batch tests, averaging 77%, 61% and 54%, respectively.

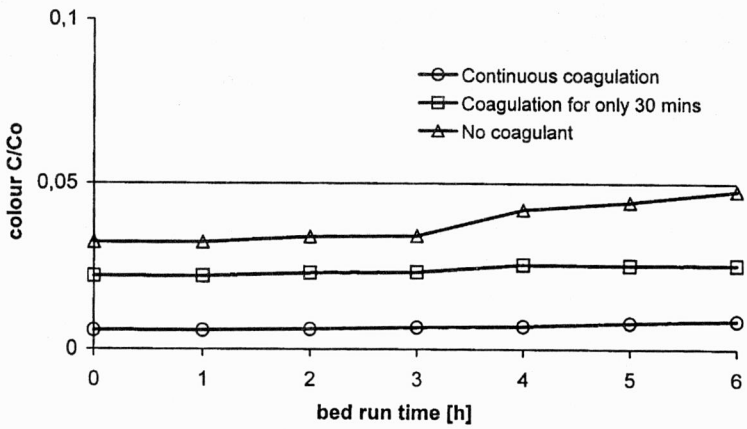

Fig. 1. Breakthrough curve of the column for colour

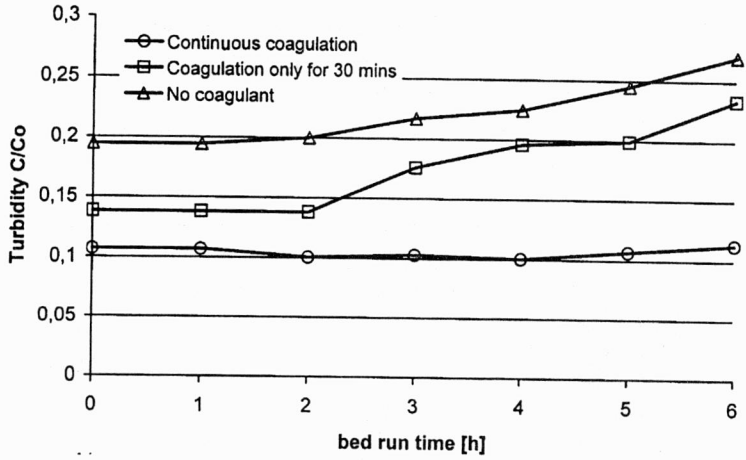

Fig. 2. Breakthrough curve of the column for turbidity

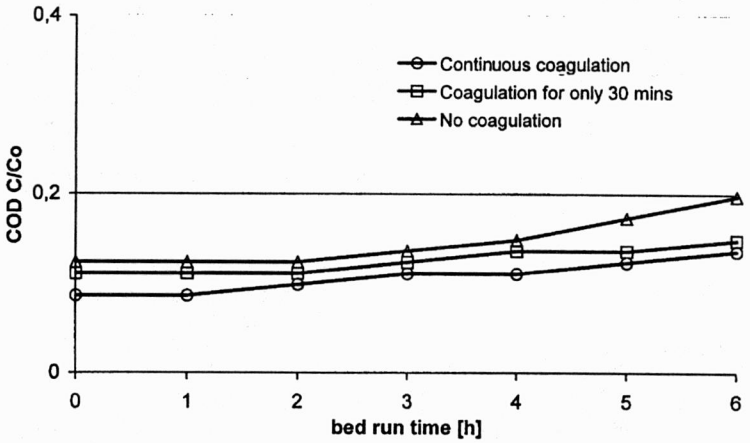

Fig. 3. Breakthrough curve of the column for COD_p

The results of column tests without coagulation, with continuous coagulation and only with coagulation during the first 30 minutes of the filtration bed run are presented as the breakthrough curves in figures 1, 2 and 3.

The value of pH after the process of filtration through the GAC bed ranged from 7.45 to 7.61 and alkalinity – from 5.7 to 5.9 mval/dm^3. The average value of manganese was under the value of 0.03 mg/dm^3 and total iron under 0.05 mg/dm^3.

Coagulation (D_c = 27 mg/dm^3) in GAC bed resulted practically in a complete removal of total iron and manganese, and residual concentration of aluminium was less that 0.1 mg/dm^3, so the usage of alum was 95% in this section of the experiment. The value of filtrate pH was stable after the process in all samples and reached 7.4. The alkalinity was in the range of 5.1–5.7 mval/dm^3.

Periodical coagulation in the GAC bed gave the following results: manganese was removed completely and the total iron concentration was lower than 0.03 mg/dm^3, pH was in the range from 7.5 to 7.6 and alkalinity – from 5.8 to 5.9. The average concentration of residual aluminium in the filtrate was 0.02 mg/dm^3. The rest of the results are shown in figures 4 and 5.

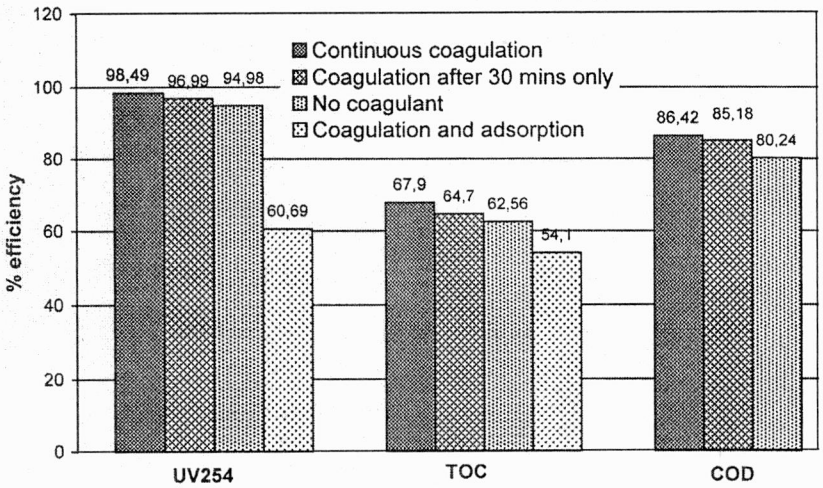

Fig. 4. Efficiency of the processes investigated (organic compounds)

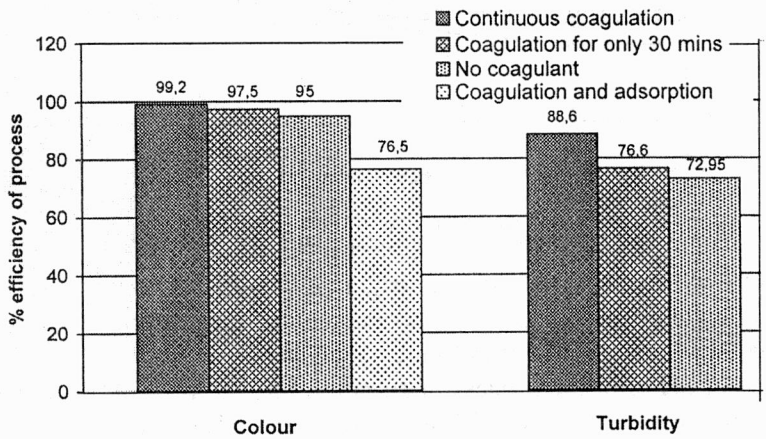

Fig. 5. Effectiveness of the processes investigated

Comparing a continuous coagulation, coagulation during 30 minutes and coagulation with no coagulant addition, one could conclude that the efficiency of the removal of colour was never less than 95%. The flocs formed during the coagulation process could adsorb, to some extent, the dissolved organic compounds and thereby aid the

GAC filter. The removal of organic components was still effective without the need of continuous coagulation for the whole filtration cycle. It is suggested that the coagulation should be applied periodically rather than continuously.

The time of filter bed run with continuous coagulation (27 mg/dm^3) was approximately 6–8 hours, for the height of bed 0.5 m. As regards the height of a sand bed (2–2.5 m), which is recommended for a direct coagulation, it can be envisaged that using the activated carbon bed of this height would give filtration cycles of approximately 24 hours.

The results obtained prove that the technological effects of coagulation in GAC bed are better than coagulation and adsorption applied separately.

Short coagulation improves the results of process in a GAC bed, which may be caused by the adsorption onto sludge surfaces in the bed.

7. CONCLUSIONS

1. The effect of water treatment in the contact coagulation GAC bed results from the superposition of the following elementary processes:

- Destabilisation of colloidal particles – coagulation.
- Flocculation of the destabilised colloidal particles – agglomeration of flocs.
- Adsorption of the dissolved organic compounds on the grains of the activated carbon.
- Adsorption of the dissolved organic compounds on the flocs formed in the bed.
- Filtration of the flocs and particles retained in the bed.

2. The column tests without adding alum in comparison to the process of continuous coagulation in the GAC bed proved that organic impurities were in dissolved forms rather than in colloidal ones.

3. The above conclusions are adequate for the treated water from the Koźmin intake.

4. The authors' research (which will be published soon) carried out for waters with higher content of colloidal organic forms showed significantly better efficiency of the up-flow direct filtration in GAC bed than without adding coagulant to the activated carbon column.

REFERENCES

[1] HAMANN C.L. et al., *Water Quality and Treatment – a Handbook of Community Water Supplies*, 4th ed, American Water Works Association, 1990, 160.

[2] KOWAL A.L., ŚWIDERSKA-BRÓŻ M., *Oczyszczanie wody*, Wydawnictwo Naukowe PWN, 1996, 55, 173.

[3] ŚWIDERSKA-BRÓŻ M., *Removal of humic substances by coagulation*, Environment Protection Engineering, 1984, Vol. 10, No. 4.

[4] EDWARDS G. A., AMIRTHARAJAH A., *Removing colour caused by humic acids*, J. Am. Water Works Assoc., 1985, Vol. 77, 50–57.

[5] De ZUANE J., *Handbook of drinking water quality*, International Thomson Publishing, 1997, 446.

[6] CLEASBY J.L., *Water Quality and Treatment – a Handbook of Community Water Supplies*, 4th ed, American Water Works Association, 1990, 507 Cleasby JL.

[7] ADAMSKI W., MARKIEWICZ J., *Sposób oczyszczania wody powierzchniowej*, zgłoszenie patentowe nr P335489 z dnia 16.09.1999.

[8] EATON A.D. et al., *Standard Methods for the Examination of Water and Wastewater*, 19th ed, APHA, AWWA, WEF, 1995.

[9] DOBBS R.A., WISE R.H., DEAN R.B., *The use of ultraviolet absorbance for monitoring the total organic carbon of water and waste water*, Water Resources, 1972, 6:1173.

KOAGULACJA KONTAKTOWA W ZŁOŻU WĘGLA

Przedstawiono efekty oczyszczania wody o małej mętności i dużym stężeniu rozpuszczonych związków organicznych w procesie koagulacji kontaktowej w złożu węgla aktywnego. Wyniki porównano z wynikami oczyszczania wody w sekwencji procesów koagulacji objętościowej i adsorpcji. Wykazano atrakcyjność metody, nawet gdy koagulant jest dawkowany okresowo.