Baltic Coastal Zone No. 10	
(147-166) 2006	Institute of Biology and Environmental Protection Pomeranian Pedagogical University Słupsk

INFLUENCE OF FLOCCULATING AGENTS ONTO THE WATER COAGULATION COURSE

Daniela Wira, Jerzy Wira

Department of Water Environment Engineering, Technical University of Szczecin, Aleja Piastów 50, 70-311 Szczecin, Poland

Abstract

Tests were done on the model station situated on the territory of Szczecin–Pomorzany Water Treatment Plant. The tested water came from Kurowski Channel. Kurów is the river bank water intake from Kurowski Channel – an artificial arm of Western Odra River. Pumping station is situated 300 m far from the Kurowski Channel. Water is supplied to the intake chamber of the pumps using the pipeline Φ 1400. Three pumps of Flyght CP 3305 type in the alternating system force the raw water through two pipelines Φ 700 PE to Pomorzany Water Treatment Plant situated 3 km far from it.
Kurowski Channel is supplied from the main stream of Odra River and the inflowing underground waters of Wysoczyzna. Average composition of the water coming from Kurowski Channel is much more better than the water taken directly from Odra River.

Key words: flocculating agents, water coagulation, raw water

METHODOLOGY OF DETERMINATIONS MADE

PRESENTATION OF COAGULATION PROCESS

Coagulation was performed using the equipment named FLOCCULATOR KEMIRA NR 190, composed of six beakers with the capacity of 1 dm^3 each and agitators connected to that equipment. Coagulation process was conducted using 1 minute of rapid mixing with the intensity of 120 rpm and 20 minutes of slow mixing with the intensity of 30 rpm. After coagulation, samples of model solutions (prepared on the water from Kurów Intake and subject to the preliminary chlorination) were left for the period of 1 hour in order to remove floccules in the sedimentation process. Thereafter the samples were filtered. To the filtration were used the filter papers of average hardness, the action of which corresponds to the effect same as after having passed through the sand filters of this model station.
In the raw water as well as after coagulation in accordance with Polish Standards, it was determined: PH reaction, colour and oxygen consumption. Tests were per-

formed at the natural reaction. In the interpretation of results, as the criterion of the satisfactory treatment effectiveness, it was assumed: colour ≤ 20 $mgPtdm^{-3}$ in accordance with the Ordinance of the Minister of Health and Social Welfare dated 4th May 1990 titled "Organoleptic and physico-chemical conditions, which should be satisfied by the drinking water and water for household purposes".

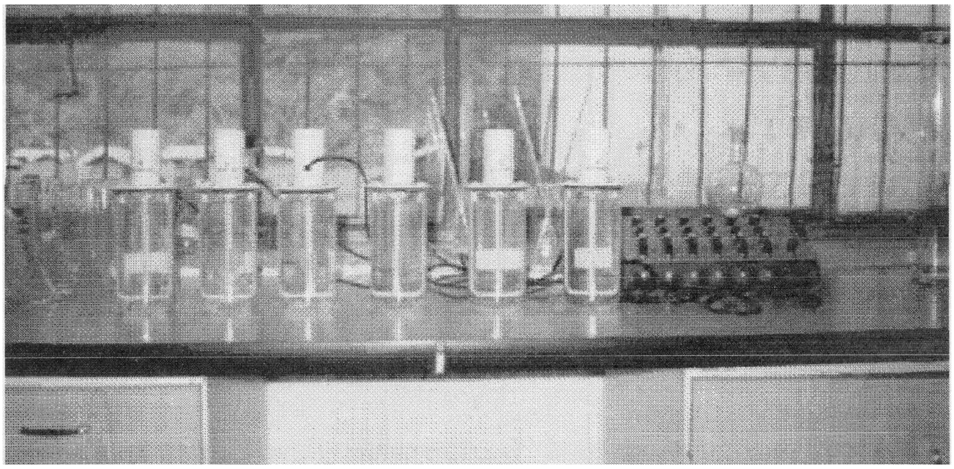

Fig. 1. Water coagulation equipment

COLOUR DETERMINATION

Colour determination was performed basing on the Polish Standard PN-72/C-04558 titled: “Colour Determination”.

Determination of colour in the water using comparative method.

The determination consists in the visual comparison of the colour of the tested water sample in white light with the examples prepared according to the platinum-cobalt scale or dichromate-cobalt scale and in the determination of its intensity or indicating the colour in $mgPtdm^{-3}$ (Hazen colour units) (Kowal and Świderska-Bróż 1979).

Colour of the samples tested was determined according to the examples of the platinum-cobalt scale and the result was given in $mgPtdm^{-3}$. The determination was performed as follows: to Nessler cylinder is poured 100 cm^3 of the tested water; it is put into the comparator and through comparison it is selected an example from the scale corresponding to the water colour. Colours comparison is made looking from above through the liquid column and holding the comparator over the white background (white plate) (Dojlido 1982).

OXYGEN CONSUMPTION

Oxygen consumption was performed basing on the Polish Standard PN-72/C-04578 sheet 02 titled "Determination of Chemical Oxygen Demand (COD) using permanganate method" (so called oxygen consumption).
That analysis consists in the determination of the quantity of milligrams of potassium permanganate in conversion to O_2, consumed at the temperature of the boiling water bath for the oxygenation of organic compounds and some easily oxygenated inorganic compounds present in the analysed water. Analysis was performed in the acid environment (Dojlido 1987, Kowal 1977).
Determination performance:
To the conical flask with the capacity of 300 cm^3 was measured from the previously mixed sample 100 cm^3 of the sulphuric acid solution (1+3) as well as it was measured also 10 cm^3 of potassium permanganate solution. The flask, after having mixed its contents, was immediately immersed in the boiling water bath so, the bath water level was a little above the level of the solution in the flask, and warmed up for 30 minutes keeping the bath in the boiling point.
After having removed the flask from the bath, it was immediately measured to it from the burette 10 cm^3 of sodium oxalate solution; the flask contents was mixed and after having been discoloured it was hot titrated with the potassium permanganate solution until the slightly pink colour having been obtained lasting for 1÷2 minutes.

WATER REACTION DETERMINATION

Determination of the reaction was performed using the device HANNA HI 8314 and it consisted in the automatic determination of pH reaction of the analysed sample.

CHARACTERISTICS OF REAGENTS TESTED

To determine the flocculants influence on the water coagulation process course the following coagulants were used:

Aluminium sulphate

It is the main coagulant used at Pomorzany Water Treatement Plant and it constitutes a reference for the other reagents tested. More detailed characteristics of aluminium sulphate $Al_2(SO_4)_3*18H_2O$ is presented in item 4.1. To determine the effectiveness of the agent in question, the following doses were selected for the tests: 50, 60, 70, 80, 90, 100 $mgdm^{-3}$, and among them were selected as the optimal for the further analyses the following doses: 60, 70, 80 $mgdm^{-3}$. This is such quantity of coagulant, when the best pollutions removal degree is obtained, as well as the chemical stability of the water after coagulation (Jodłowski 1994, Kowal and Świderska-Bróż 1972).

Sachtoklar[r] 39

This is coagulant, whose distributor in Poland is the Company: Chlor Service of Poznań. That product is the transparent, yellow-coloured liquid and the general formula $Al_n(OH)_mCl_{3n-m}$ That coagulant is applied to the potable water treatment and the sanitary water as well as in the wastewater treatment.

TECHNICAL DATA: pH value < 1.4
density at 20°C 1.37+/-0.03 $kgdm^{-3}$
viscosity acc. to Brookfield < 60 mPa.s
alkalinity 37 +/- 3%
contents of: Al_2O_2 16.8 +/- 0.6% by weight
Al 8.9 +/- 0.3 % by weight
CI 22.0 +1-1.0 % by weight
SO_4 < 1.0% by weight

Sachtoklar[r] 39 is dosed without dilutions. Doses recommended by the manufacturer i.e. 3÷30 g/m^3 proved to be too low for the tested water, therefore for the cases, when that coagulant was tested alone, the doses were as follows: 40, 50, 60, 70, 80, 90 $mgdm^{-3}$.
However in the analyses, where it was supported by the flocculent the following optimal doses were selected: 70, 80, 90 $mgdm^{-3}$.

Sachtoklar[r] 27 S

This is coagulant, whose distributor in Poland is the Company Chlor Service of Poznań. That agent is the newly developed coagulant with the general formula $Al_n(OH)_mCI_{3n-m}$. Sachtoklar[r] 27 S having the form of a colourless to slightly turbid fluid. It is also defined as the polyaluminium chloride (PAC). It is used to the potable and sanitary water treatment, to the wastewater treatment as well as to the water treatment in the swimming pools (Jodłowski 1994, Kowal and Świderska-Bróż 1972).

TECHNICAL DATA : pH value about 3.0
density, 20°C 1.24 +/- 0.02 $kgdm^{-3}$
alkalinity about 65
contents of: Al_2O_3 9.6-10.0 % by weight
Al. 5.2 +/- 0.1 % by weight
Cl 12.0 +/- 0.5 % by weight
SO_4 1.5 +/- 1.0 % by weight

That coagulant is dosed without dilutions. Also in that case, the doses recommended by the manufacturer i.e. 5-50 gm^{-3} proved to be too low for the tested water, therefore for the cases, when that coagulant was tested alone, the doses were as follows: 30, 40, 50, 60, 70, 80 $mgdm^{-3}$. However in the analyses, where it was supported by the flocculent the following optimal doses were selected: 50, 60, 70 $mgdm^{-3}$.

The objects of tests were also the following flocculants:

Praestol 644 BC

Praestol 2540

Flocculants PRAESTOL are polymers with the high molecular weight, obtained through the organic synthesis on the basis of poly (acrylamids). Those flocculants appeared both in the form of granulates, as well as in the liquid form, as emulsions. The tested flocculants are granulates. They are grainy products of white colour, loose, with the low dust contents, grain sizes within the limits from 1 to 0.1 mm. They are easily soluble, creating colloidal systems. To the tests was used 0.1% flocculent solution (Kowal and Świderska-Bróż 1974, Maćkiewicz 1987).

Praestol 2540 – is the flocculent belonging to the group of flocculants of anion type. They are acrylamide co-polymers with the prevailing acrylate groups contents, which give negative charges to the polymers in the water solution, and due to that fact – the anion character, being able to bind heavy metals cations. The flocculent in question acts within the range of pH 6 ÷13.

Praestol 644 BC – is the flocculent belonging to the group of flocculants of cation type. They are acrylamid co-polymers with the prevailing cation monomer. The cation groups appearing as result in that polymer have the positive charges in the water solution. The are able to bind the compounds of the acid character (e.g. cyanides). Ion activity of that flocculent is defined as the strong, it acts within the range pH 1÷14.

Flocculants PRAESTOL have in the water solution the chemically active groups, which show the strong affinity in relation to numerous colloidal substances, with the ability to precipitate settlings. Depending on the character of the suspension, contained in the treated material, flocculent binds it in two ways: solid parts of hydrophobic agents using the hydrogen bonds and ion compounds using electrostatic forces. Destabilisation and coagulation of the big quantity of single particles lead to the appearance of floccules of the big capacity, which are easily separable from the suspension.

DATA AS REGARDS THE ECOLOGY

Data concerning the disposal (resistance to biodegradation and the biodegradation ability):

- No to allow penetrating the waters by the concentrated product without the previous biological treatment;
- Basing on the product properties knowledge, diluted solutions assigned to the use are not considered as any danger to the waters;
- Product does not practically subject to any biodegradation because of the highly polymeric structure.

Toxic action on the environment:

- Acute toxicity to fish about 140 $mgdm^{-3}$;
- Acute toxicity to daphnia about 300 $mgdm^{-3}$;
- Acute toxicity to alga about 26 $mgdm^{-3}$.

Magnafloc LT-31

Magnafloc LT-35

They are flocculants supporting the coagulation process of the equivalent activity effectiveness. They belong to the group of synthetic, non-toxic, water-soluble resins, with the high molecular weight and the ability to flocculate suspensions.
Addition of Magnafloc LT accelerates the floccules creation, improves its structure. Optimal dose of Magnafloc LT-31 and LT-35 was determined within the range 0.5+1.0 $mldm^{-3}$. Flocculants have the form of dense, oily fluid of light yellow to light-red colour.

Synthofloc 8022 H-PWG

That flocculent is the strong anion flocculating agent of the high molecular weight. Synthofloc 8022 H-PWG has a form of the transparent fluid. It can be used for the praparation of the potable water, to the clarification of turbid solutions in acid and alkaline environment, in chemical processes, industrial wastewaters in processing of iron and aluminium salts.

SPECIFICATION OF RESULTS OF ANALYSES

COAGULANT TESTED: ALUMINIUM SULPHATE $Al_2(SO_4)_3$

AVERAGED VALUE:

Table 1

Water temperature: 18.2ºC

Coagulant dose ($mgdm^{-3}$)	50	60	70	80	90	100	Raw water
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	9.8	8.6	7.0	6.6	6.2	5.4	18.8
Reaction (pH)	7.2	7.3	7.1	7.0	7.0	6.9	7.6
Oxygen consumption [COD] (mgO_2dm^{-3})	6.5	6.0	5.6	5.0	5.0	4.8	7.9

Observations: Sedimentation time amounted to 1 hour, and the sedimentation went slowly. The higher coagulant dose (Table 1) the bigger floccules appeared, however they were so big to accelerate the sedimentation course.

COAGULANT TESTED: ALUMINIUM SULPHATE $Al_2(SO_4)_3$
FLOCCULENT TESTED: PREASTOL 644 BC

AVERAGED VALUE:

Table 2

Water temperature: 17.3°C

Coagulant dose ($mgdm^{-3}$)	60	70	80	60	70	80	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	8.0	7.3	6.7	7.0	6.3	5.3	17.3
Reaction (pH)	6.9	6.9	6.8	7.0	7.0	7.0	7.6
Oxygen consumption [COD] (mgO_2dm^{-3})	5.1	4.8	4.5	5.0	5.0	4.6	6.6

Observations: The flocculent was added 2 minutes after the coagulant having been added. It was noticed, that in case of the bigger flocculent dose (Table 2) the size and quantity of floccules was increased, which are good bound and created large conglomerations and in this connection the quantity of the deposit has increased. Floccules are so heavy, that they settled faster and in this connection the sedimentation time is shorter, what has the economical aspect too.

COAGULANT TESTED: ALUMINIUM SULPHATE $Al_2(SO_4)_3$
FLOCCULENT TESTED: PREASTOL 2540

AVERAGED VALUE:

Table 3

Water temperature: 16.3°C

Coagulant dose ($mgdm^{-3}$)	60	70	80	60	70	80	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	6.0	5.3	5.0	5.3	5.3	5.7	16 s
Reaction (pH)	7.1	7.0	7.0	7.3	7.0	7.0	7.3
Oxygen consumption [COD] (mgO_2dm^{-3})	4.6	4.4	4.1	4.7	4.7	4.7	4.7

Observations: Flocculent (Table 3) was added 2 minutes after the coagulant having been added. Appeared floccules are small, they caused the water turbidity in case of the lower flocculent dose, and in this connection the sedimentation time has prolonged up to above 1 hour. However, in the case of bigger doses the floccules appeared are slightly bigger, they created bigger agglomerates and in case of those samples the sedimentation went faster.

COAGULANT TESTED: ALUMINIUM SULPHATE $Al_2(SO_4)_3$
FLOCCULENT TESTED: MAGNAFLOC LT-31

AVERAGED VALUE:

Table 4

Water temperature: 19.3ºC

Coagulant dose ($mgdm^{-3}$)	60	70	80	60	70	80	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	16.7	15.7	14.0	22.3	19.7	18.7	25.7 s
Reaction (pH)	7.1	7.0	7.0	6.9	6.8	6.7	7.7
Oxygen consumption [COD] (mgO_2dm^{-3})	10.4	10.3	10.2	10.8	10.6	10.4	7.5

Observations: Flocculent (Table 4) was added 2 minutes after the coagulant having been added. Floccules appeared after about 5 minutes of the slow mixing and they are very small causing the water turbidity irrespective of the dose added. So small floccules are difficult for removal, and in this connection the sedimentation time has been prolonged.

COAGULANT TESTED: ALUMINIUM SULPHATE $Al_2(SO_4)_3$
FLOCCULENT TESTED: MAGNAFLOC LT-35

AVERAGED VALUE:

Table 5

Water temperature: 18.3ºC

Coagulant dose ($mgdm^{-3}$)	60	70	80	60	70	80	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	9.7	9.3	8.7	10.7	10.3	9.7	14 s
Reaction (pH)	7.0	6.9	6.8	6.9	6.8	6.8	7.5
Oxygen consumption [COD] (mgO_2dm^{-3})	6.6	6.1	6.0	6.3	6.5	6.8	7.0

Observations: Flocculent (Table 5) was added 2 minutes after the coagulant having been added. The floccules appeared are small, causing the water turbidity. Sedimentation is slow.

COAGULANT TESTED: ALUMINIUM SULPHATE $Al_2(SO_4)_3$
FLOCCULENT TESTED: SYNTHOFLOC 8022 H-PWG

AVERAGED VALUE:

Table 6

Water temperature: 16ºC

Coagulant dose ($mgdm^{-3}$)	60	70	80	60	70	80	Raw water
Flocculent dose ($mldm^{-3}$)	0.2	0.2	0.2	0.5	0.5	0.5	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	11.0	9.0	7.0	8.7	8.0	7.0	19.7 s
Reaction (pH)	7.1	7.1	7.0	7.1	7.0	7.0	7.6
Oxygen consumption [COD] (mgO_2dm^{-3})	6.7	6.3	5.8	6.0	6.2	6.8	7.9

Observations: Flocculent was added 2 minutes after the coagulant having been added. In case of lower dose of the flocculent (Table 6) the appeared floccules are smaller and their sedimentation went slower. However in the case of adding the higher flocculent dose the floccules are considerably bigger, they created big agglomerates and their sedimentation went faster.

COAGULANT TESTED: SACHTOKLAR^R 27 S

AVERAGED VALUE:

Table 7

Water temperature: 17.6ºC

Coagulant dose ($mgdm^{-3}$)	30	40	50	60	70	80	Raw water
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	13.4	12.0	11.2	12.6	9.0	8.4	15.6 s
Reaction (pH)	7.6	7.6	7.5	7.5	7.4	7.4	7.7
Oxygen consumption [COD] (mgO_2dm^{-3})	7.0	7.4	7.2	7.2	7.6	7.2	7.8

Observations: The higher dose of the coagulant (Table 7) the faster the floccules appeared, are bigger and they sedimentation went more rapidly. The worst coagulation process was at the coagulant dose amounted to 50 $mgdm^{-3}$, the floccules created in that sample are very small and their sedimentation was visibly worse than in the other samples, where the doses were higher.

COAGULANT TESTED: SACHTOKLAR[R] 27 S
FLOCCULENT TESTED: PRAESTOL 644 BC

AVERAGED VALUE:

Table 8

Water temperature: 16ºC

Coagulant dose ($mgdm^{-3}$)	50	60	70	50	60	70	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	7.7	7.0	6.3	6.7	6.7	6.0	18 s
Reaction (pH)	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Oxygen consumption [COD] (mgO_2dm^{-3})	5.2	5.0	7.9	5.4	5.3	5.1	7.1

Observations: Flocculent was added 2 minutes after the coagulant having been added. The coagulation process (Table 8) went better with the higher flocculent doses. The floccules were firm and heavy enough, the sedimentation process to take place at the end of the slow mixing phase. That is why the sedimentation time was shortened by half almost.

COAGULANT TESTED: SACHTOKLAR[R] 27 S
FLOCCULENT TESTED: PRAESTOL 2540

AVERAGED VALUE:

Table 9

Water temperature: 19.7ºC

Coagulant dose ($mgdm^{-3}$)	50	60	70	50	60	70	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	16.0	15.3	14.3	17.3	16.0	15.3	26.3 s
Reaction (pH)	7.7	7.6	7.6	7.7	7.7	7.6	7.8
Oxygen consumption [COD] (mgO_2dm^{-3})	7.7	7.4	7.1	8.0	7.9	7.5	8.0

Observations: Flocculent was added 2 minutes after the coagulant having been added (Table 9). The higher flocculent dose the quantity of floccules increased, however they are small and the sedimentation was slower. The coagulation process went in the best way in comparison with the other samples in the cylinder where the coagulant dose amounted to $60mg/dm^3$.

COAGULANT TESTED: SACHTOKLAR^R 27 S
FLOCCULENT TESTED: MAGNAFLOC LT-31

AVERAGED VALUE:

Table 10

Water temperature: 14.3°C

Coagulant dose ($mgdm^{-3}$)	50	60	70	50	60	70	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	13	11.7	10.3	14.7	13.3	15.3	14.7 s
Reaction (pH)	7.4	7.4	7.3	7.3	7.2	7.2	7.5
Oxygen consumption [COD] (mgO_2dm^{-3})	10.8	10.6	10.3	10.7	10.4	10.2	6.6

Observations: Flocculent was added 2 minutes after the coagulant having been added (Table 10). The floccules appeared are small, they caused the water turbidity and their sedimentation is difficult. The floccules settling time has been prolonged by above one hour.

COAGULANT TESTED: SACHTOKLAR^R 27 S
FLOCCULENT TESTED: MAGNAFLOC LT-35

AVERAGED VALUE:

Table 11

Water temperature: 14.3°C

Coagulant dose ($mgdm^{-3}$)	50	60	70	50	60	70	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	13.3	11.3	11.3	11.7	11.7	11.7	14.3 s
Reaction (pH)	7.5	7.5	7.4	7.4	7.4	7.4	7.6
Oxygen consumption [COD] (mgO_2dm^{-3})	7.5	6.6	6.5	7.9	7.2	7.6	7.4

Observations: Flocculent was added 2 minutes after the coagulant having been added (Table 11). The floccules appeared are small, they caused the water turbidity and their sedimentation is difficult. Flocculent magnafloc LT-35 influenced on the coagulation process course in the similar way as its predecessor magnafloc LT-31.

COAGULANT TESTED: SACHTOKLAR® 27 S
FLOCCULENT TESTED: SYNTHOFLOC® 8022 H-PWG

AVERAGED VALUE:

Table 12

Water temperature: 19.7ºC

Coagulant dose ($mgdm^{-3}$)	50	60	70	50	60	70	Raw water
Flocculent dose ($mldm^{-3}$)	0.2	0.2	0.2	0.5	0.5	0.5	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	8.7	7.0	5.3	5.3	5.6	6.3	14.6 s
Reaction (pH)	7.5	7.5	7.5	7.5	7.5	7.5	7.4
Oxygen consumption [COD] (mgO_2dm^{-3})	6.4	5.4	4.9	4.7	5.4	5.6	6.9

Observations: Flocculent (Table 12) was added 2 minutes after the coagulant having been added. In case of the higher flocculent dose the quantity of floccules increased, the coagulation process went better and the sedimentation was faster.

COAGULANT TESTED: SACHTOKLAR® 39

AVERAGED VALUE:

Table 13

Water temperature: 14ºC

Coagulant dose ($mgdm^{-3}$)	40	50	60	70	80	90	Raw water
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	9.4	8.0	7.4	14.0	7.0	6.0	18.2 s
Reaction (pH)	7.3	7.3	7.2	7.1	7.1	7.0	7.5
Oxygen consumption [COD] (mgO_2dm^{-3})	6.0	5.6	5.2	4.9	4.6	4.2	7.1

Observations: With the coagulant dose increase (Table 13) the floccules quantity has increased, however they were smaller and smaller. At 40 $mgdm^{-3}$ it can be noticed slightly bigger agglomerates but already at doses of 80, 90 $mgdm^{-3}$ the created floccules resulted in the turbidity of the water. Irrespective of that, it did not delay the sedimentation course.

COAGULANT TESTED: SACHTOKLAR^R 39
FLOCCULENT TESTED: PRAESTOL 644 BC

AVERAGED VALUE:

Table 14

Water temperature: 17.7ºC

Coagulant dose ($mgdm^{-3}$)	70	80	90	70	80	90	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	9.3	7.3	6.3	8.7	7.7	7.0	27.0 s
Reaction (pH)	7.1	7.0	7.0	7.0	7.0	6.9	7.4
Oxygen consumption [COD] (mgO_2dm^{-3})	4.7	4.3	4.5	4.5	4.2	4.3	6.9

Observations: Flocculent (Table 14) was added 2 minutes after the coagulant having been added. The coagulation process went better for the higher flocculent doses. The floccules were firm and heavy enough, the sedimentation process to take place at the end of the slow mixing phase. Therefore the sedimentation time was shortened by half almost, what gives the possibility to produce bigger amount of the water.

COAGULANT TESTED: SACHTOKLAR^R 39
FLOCCULENT TESTED: PRAESTOL 2540

AVERAGED VALUE:

Table 15

Water temperature: 18.7ºC

Coagulant dose ($mgdm^{-3}$)	70	80	90	70	80	90	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	10.3	8.7	7.0	9.0	7.7	7.3	26.3 s
Reaction (pH)	7.1	7.0	7.0	7.1	7.1	7.1	7.4
Oxygen consumption [COD] (mgO_2dm^{-3})	5.1	4.8	4.2	4.6	4.4	4.2	7.4

Observations: Flocculent (Table 15) was added 2 minutes after the coagulant having been added. The higher flocculent dose, the bigger quantity of floccules, however they were small and their sedimentation is difficult.

COAGULANT TESTED: SACHTOKLAR[R] 39
FLOCCULENT TESTED: MAGNAFLOC LT-31

AVERAGED VALUE:

Table 16

Water temperature: 18ºC

Coagulant dose ($mgdm^{-3}$)	70	80	90	70	80	90	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	6.7	6.3	5.7	6.0	5.3	5.0	16.0 s
Reaction (pH)	7.1	7.0	7.0	7.2	7.1	7.1	7.5
Oxygen consumption [COD] (mgO_2dm^{-3})	10.4	10.1	9.9	10.7	10.5	10.1	7.0

Observations: Flocculent (Table 16) was added 2 minutes after the coagulant having been added. The appeared floccules were small, they caused the water turbidity and their sedimentation was difficult. That is why the sedimentation time was prolonged up to more than hour.

COAGULANT TESTED: SACHTOKLAR[R] 39
FLOCCULENT TESTED: MAGNAFLOC LT-35

AVERAGED VALUE:

Table 17

Water temperature: 14.3ºC

Coagulant dose ($mgdm^{-3}$)	70	80	90	70	80	90	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	9.7	8.3	8.3	9.3	9.3	8.3	17.3 s
Reaction (pH)	7.3	7.1	7.0	7.1	7.0	6.8	7.3
Oxygen consumption [COD] (mgO_2dm^{-3})	7.3	7.2	7.0	7.4	7.3	7.5	7.3

Observations: Flocculent (Table 17) was added 2 minutes after the coagulant having been added. The appeared floccules were small, they caused the water turbidity and their sedimentation was difficult. The coagulation and sedimentation process went in the way similar as in the case of use of the flocculent magnafloc LT-31.

COAGULANT TESTED: SACHTOKLAR^R 39
FLOCCULENT TESTED: SYNTHOFLOC^R 8022 H-PWG

AVERAGED VALUE:

Table 18

Water temperature: 15.7ºC

Coagulant dose ($mgdm^{-3}$)	70	80	90	70	80	90	Raw water
Flocculent dose ($mldm^{-3}$)	0.5	0.5	0.5	1.0	1.0	1.0	
Slow mixing (min.)	1	1	1	1	1	1	
Rapid mixing (min.)	20	20	20	20	20	20	
Colour ($mgPtdm^{-3}$)	7.3	6.7	6.3	7.0	6.7	5.7	7.6
Reaction (pH)	7.4	7.2	7.2	7.3	7.1	7.0	7.6
Oxygen consumption [COD] (mgO_2dm^{-3})	6.2	6.0	5.7	5.6	5.5	5.1	7.0

Observations: Flocculent was added 2 minutes after the coagulant having been added. In the case of higher flocculent dose (Table 18) the quantity of floccules increased, the coagulation process went better and the sedimentation was faster.

DISCUSSION OF THE TESTS RESULTS

Effectiveness of the presented coagulants and flocculants in the water treatment process

In the tests performed on the presented reagents it was determined the influence and kind of the coagulants and flocculants doses on the degree of reduction of colour, pH reaction, and oxygen consumption of the water taken from Odra River in months May and June.

During the assessment of the usability of the agents tested it has appeared, that the flocculating agents has supported the coagulants in the considerable degree, causing faster creation of floccules, but not always they result in the improvement of the physico-chemical parameters.

Comparison of the effectiveness of aluminium sulphate now in use in Pomorzany Water Treatment Plant, (which constituted a reference in the analyses performed) with the tested reagents was in favour of sulphate. Usefulness of that coagulant in removal of the colour and organic pollutants is sufficient. Its colour and oxygen consumption reduction degree has increased according to the dose and amounted to 4-5 mg $Ptdm^{-3}$ for the dose of 100 $mgdm^{-3}$. However it was selected as the optimal doses 60, 70, 80 $mgdm^{-3}$, since it was stated, that they can secure the satisfactory effect of pollutants removal reducing at the same time the quantity of the reagent used.

However, after having added the flocculating agents to it, the coagulation process went faster, bigger floccules were created but the physical and chemical analyses have shown, that they were not more effective in the pollutants removal than aluminium sulphate alone. As a rule they are the agents acting on and improving the single parameter. Their effectiveness increased as the dose was increased too. Such situation was in the case of almost all tested flocculants. The most favourable in connection with aluminium sulphate proved to be the flocculent PRAESTOL 2540. Its effectiveness in the removal of colour and oxygen consumption has slightly exceeded the effectiveness of aluminium sulphate. At the sulphate dose of 60 $mgdm^{-3}$ and the flocculent dose of 0.5$mldm^{-3}$ the reduction degree of colour, oxygen consumption and reaction (pH) was on the same level as in the case of use sulphate alone but using doses of 70, 80 $mgdm^{-3}$. As it is seen, the flocculent PRAESTOL 2540 not only has improved the course of the water coagulation process, improved in the considerable degree the parameters of the coagulated water but also reduced the quantity of the basic coagulant used. However the worst result achieved the flocculent MAGNAFLOC LT-31, which was of the low effectiveness in the removal of colour and it increased the oxygen consumption of the water.
Analysing the other two coagulants, their effectiveness both with the addition of the supporting agents and without its addition was similar. The colour reduction degree was on the level of: 9.8 $mgPtdm^{-3}$ i.e. about 40% reduction, but the oxygen consumption: 7.6 mgO_2dm^{-3} what means about 10% reduction. Effectiveness of the particular reagent depending on the dose was as follows: as the reagent dose was increased, the effectiveness has increased too however the examinations have shown, that it is not the satisfactory effect in the pollutants removal using such quantities of reagents.

ECONOMICAL ANALYSIS OF REAGENTS TESTED

Various water treatment techniques are commonly in use throughout the world – depending on the water parameters on the inlet and effects, which should be achieved.
The problem relates also to the choice of the appropriate reagents, which influences in the considerable degree on the quality of the treated water. Selection of the optimal agent should be considered taking various aspects into account. One of them is the economic aspect and as such it is the subject matter of considerations concerning financing.
Comparisons presented relate to the tested coagulants and flocculants in relation to reduction of the particular parameters, sedimentation time and the costs of the particular reagents.
Purpose of the tests was to determine the achievable treatment effect at low outlays and within short time.
Annual costs of application of the particular reagents at the average annual daily flow of $Q_{dśr}$ = 10 000 m^3d^{-1} amount to:

- yearly consumption of **aluminium sulphate** in dose 80 gm^{-3} amounts to 292 tons, what gives, with the unit price of 630 PLN t^{-1}. incl. VAT, the total costs of 184 000 PLN;

- consumption of the coagulant **sachtoklar 27** in dose 70 gm^{-3} would amount to 256 tons, what gives, with the unit price of 850 PLN t^{-1}, totally 217 180 PLN;
- consumption of the coagulant **sachtoklar 39** in dose 90 gm^{-3} would amount to 328 tons, what gives, with the unit price of 950 PLN t^{-1}, totally 312 100 PLN;
- consumption of the flocculent **praestol 644 BC** for a year would amount to 3.7 tons what gives, with the unit price of 18 000 PLN t^{-1}, the amount of 65 700 PLN;
- consumption of the flocculent **praestol 2540** for a year would amount to 3.7 tons what gives, with the unit price of 15 000 PLN t^{-1}, the amount of 56 000 PLN;
- consumption of the flocculants **magnafloc LT-31** and **magnafloc LT-35** for a year would amount to 4,8 tons what amounts, with the price of 16 000 PLN t^{-1}, to 76 000 PLN;
- consumption of the flocculent **synthofloc 8022 H-PWG** for a year would amount to 1,5 tons what gives, with the unit price of 18 000 PLN t^{-1}, the amount of 26 300 PLN.

Information concerning the prices of coagulants SACHTOKLAR 27, SACHTOKLAR 39 and SYNTHOFLOC 8022 H-PWG came from the representative of WEDECO – Poznań Company – Mr. Michał Sawicki Eng.

Other prices were given together with the other information concerning the reagents' data.

It results from the above data, that the most economic proved to be aluminium sulphate. It is confirmed by the analyses, which presented the reduction degree of the tested parameters of aluminium sulphate in comparison to the other coagulants and flocculants. It was also taken into account the sedimentation time of the tested agents in relation to the water quality after coagulation. Though after having added

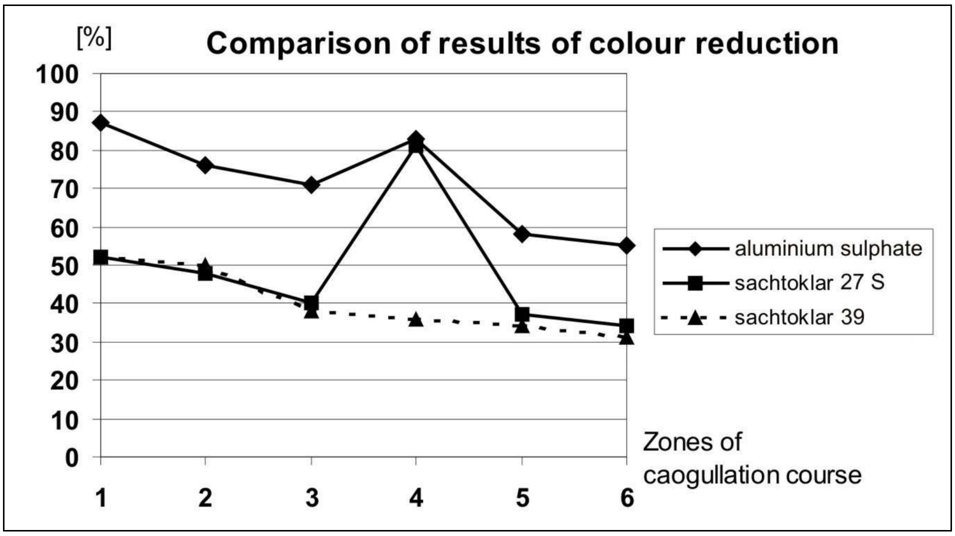

Fig. 2. Comparison of results of colour reduction

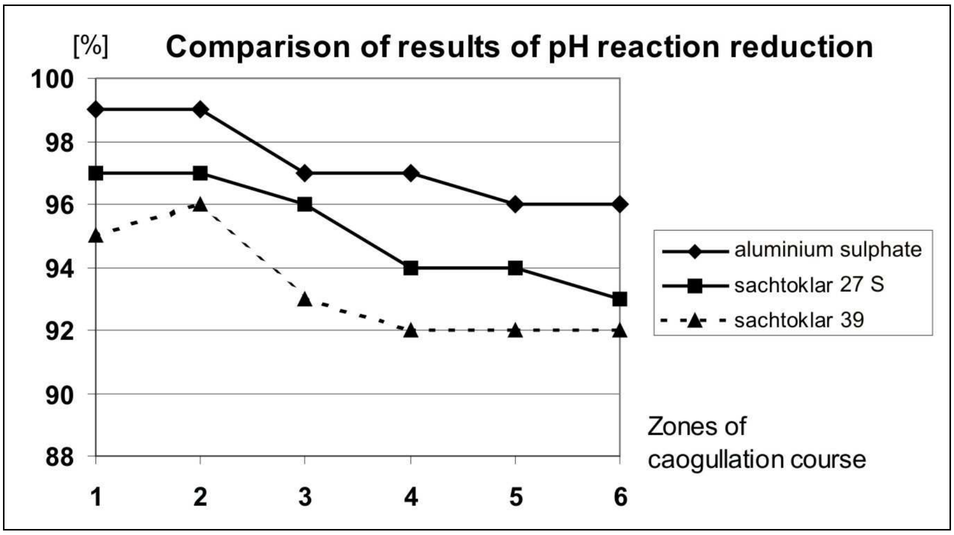

Fig. 3. Comparison of results of pH reaction reduction

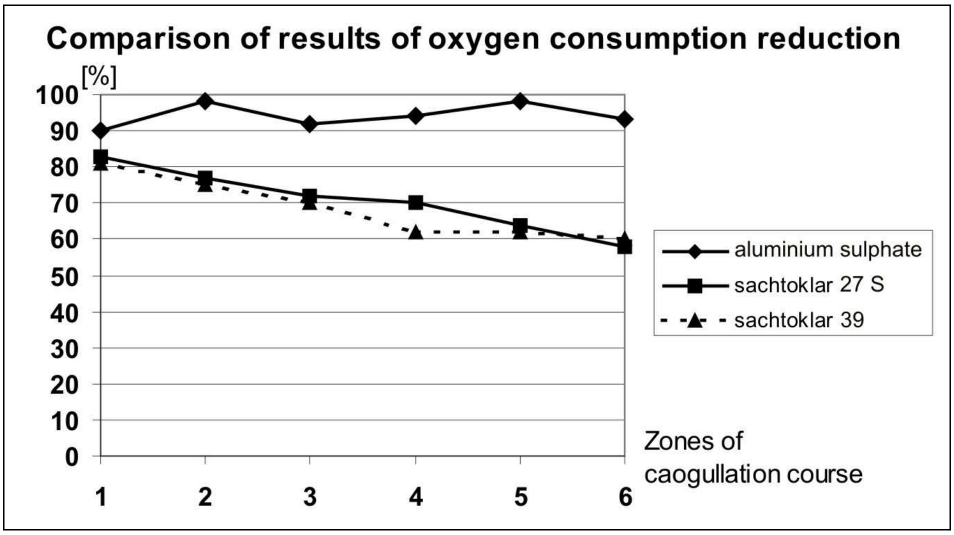

Fig. 4. Comparison of results of oxygen consumption reduction

the supporting agents the coagulants, the sedimentation time was shorted even by about 50%. Such rapid sedimentation took place using the following flocculants: PRAESTOL 644 BC, PRAESTOL 2540 and SYNTHOFLOC 8022 H-PWG with all tested coagulants. In spite of the fact that the sedimentation process was considerably shortened, the cost of the above specified supporting agents exceeds the profit on the additionally treated water.

Physical, chemical and economical analyses concerning the application of the tested agents proved explicitly, that in relation to the water coming from Kurowski Channel Intake the reagent, which finds the reasonable application is aluminium sulphate. To sum up the above it should be stated, that the tested water came from the specific intake and in that case the application of aluminium sulphate, besides the desirable water treatment effects, it brings the measurable financial benefits without buying the additional supporting agents. Purchase of sulphate and additional agents supporting the coagulation process would amount to 250 000 PLN per annum, whereas the purchase of sulphate only to carry out the continuous water coagulation needs annually the outlays amounting to 184 000 PLN.

CONCLUSIONS

The above considerations give the ground to formulate the following conclusions:

- To reduce effectively colour, pH reaction and oxygen consumption aluminium sulphate proved to be the best. Optimal doses for that coagulant proved to be the following doses: 60, 70, 80 $mgdm^{-3}$.
- Among the tested coagulants and flocculants the least effective proved to be MAGNAFLOC LT-31, since it caused the water turbidity during the coagulation process, inconsiderable degree of colour removal as well as it caused the increased oxygen consumption up to 10.2 mgO_2dm^{-3}.
- Taking into account the colour removal effectiveness, the most useful among the tested flocculants proved to be SYNTHOFLOC 8022 H-PWG, which reduced the colour to 6-5 $mgPtdm^{-3}$ at the dose of 0.5 $mldm^{-3}$.
- However none of the tested reagents achieved the results, which would allow explicitly resigning of aluminium sulphate used in so far, reacting in the best way with the water coming from Kurowski Channel Intake.
- The basic coagulant to perform the coagulation process for the tested water (taken from Kurowski Channel) should remain aluminium sulphate. Its application guarantee the satisfactory effect in the pollutants removal without having introduced any supporting agents, and it gives the measurable economic favours.

REFERENCES

Dojlido J., 1987. Chemia wody. (Water Technology). Arkady, Warszawa, (in Polish).

Dojlido J., 1992. Polskie i światowe normy jakości wody do picia. (Polish and world standars of drinking water quality). XII Krajowa Konf. Nauk.-Techn., Poznań (in Polish).

Jodłowski A., 1994. Badania nad usuwaniem glonów z wody w procesie koagulacji – flotacji. (Investingation on algae removal from water in coagulation – pressure flotation prosess). Ochrona Środowiska, 3-4 (54-55), 19 (in Polish).

Kowal A. L., 1977. Technologia wody. (Water Technology). Arkady, Warszawa (in Polish).

Kowal A. L., Świderska-Bróż M., 1974. Intensyfikacja procesu koagulacji w wodzie. (Intensification of coagulation process in water). Prace Nauk. Inż. Ochr. Środ. 27, Wyd. Politechnika Wrocławska, Wrocław (in Polish).

Kowal A.L., Świderska-Bróż M., 1972. Wspomaganie procesu koagulacji domieszek wody. (Assist of coagulation process of water admixtures). Prace Nauk. Inst. Inż. Chem. i Urząd. Ciepln., 14, Wyd. Politechnika Wrocławska, Wrocław (in Polish).
Kowal A.L., Świderska – Bróż M., 1979. Wpływ odczynu wody na skuteczność redukcji barwy i utlenialności w procesie koagulacji. (Water reaction on effectiveness of colour reduction and oxygen consumption in coagulation process). GWiTS, 9, 272 (in Polish).
Maćkiewicz J., 1987. Flokulacja w procesach koagulacji i filtracji wód. (Floculation in coagulation and waters filtration process). PWN, Warszawa (in Polish).

WPŁYW ŚRODKÓW FLOKUJĄCYCH NA PRZEBIEG KOAGULACJI WODY

Streszczenie

Celem przeprowadzonych badań było określenie wpływu środków flokujących na przebieg procesu koagulacji wody. Badania przeprowadzono na stacji modelowej znajdującej się na terenie Stacji Uzdatniania Wody w Szczecinie-Pomorzany. Badana woda pochodziła z Kanału Kurowskiego będącego sztuczną odnogą Odry Zachodniej. Pompownia zlokalizowana jest w odległości ok. 300 m od Kanału Kurowskiego. Wodę do komory czerpnej pomp doprowadza się za pomocą rurociągu Φ 1400. Trzy pompy typu Flyght CP 3305 w układzie przemiennym tłoczą wodę surową dwoma rurociągami Φ 700 PE do Stacji Uzdatniania Wody Pomorzany oddalonej o około 3 km. Koagulację prowadzono przy pomocy urządzenia o nazwie FLOCCULATOR KEMIRA NR 190, złożonego z sześciu zlewek o pojemności 1 dm^3 każda oraz z mieszadeł podłączonych do urządzenia. Proces koagulacji badano stosując 1 minutę szybkiego mieszania z intensywnością 120 obrotów na minutę wolnego mieszania z intensywnością 30 obrotów na minutę. Po koagulacji próbki roztworów modelowych (przygotowanych na wodzie z Ujęcia Kurowskiego i poddanej wstępnemu chlorowaniu) zostały pozostawione na okres 1 godziny w celu usunięcia kłaczków w procesie sedymentacji. Następnie próbki sączono. Do sączenia używano sączków średniej twardości, których działanie odpowiada efektowi jak po przejściu przez filtry piaskowe na tutejszej stacji modelowej. W wodzie surowej oraz po koagulacji zgodnie z PN oznaczono: odczyn pH, barwę oraz utlenialność. Badania prowadzono przy odczynie naturalnym. W interpretacji wyników badań jako kryterium zadowalającej skuteczności oczyszczania przyjęto: barwę ≤ 20 mgPt dm^{-3}.