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ORIGINAL ARTICLE

Preparation of drinking water by carusol reagent

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In order to provide the population of Ukraine with drinking water, surface water of rivers, reservoirs, ponds, etc. are used as water sources in most cases. At the same time, the water treatment technologies, which are used in water facilities, are currently at the level of Soviet Union, when they were first developed and implemented, and it was decades ago. At that time the quality of water in the water supply sources was much better than it is now, and for many sources it was first-class. Thus, the water treatment facilities of the Public Utility "Zhytomyrvodokanal" were designed in regards to the quality of water in the "Vidsichne" reservoir, which also was the first-class. At the moment, the water quality in the water supply source is of 3rd or 4th class according to many indicators. Moreover, the existing outdated water treatment technologies cannot cope with pollutants such as colloidal suspended substances, manganese, taste, flavour, chloroform, permanganate oxidation, and others. The development of the latest methods for water purification and water treatment technologies forges ahead. Therefore, it is necessary to use all possibilities to provide the population of Zhytomyr with high-quality and safe drinking water.

The method for treatment of drinking tap water with the help of the reagent (an oxidizing agent of sodium permanganate (trade form CARUSOL)) is presented in this research. Besides, the article provides information on stable forms of manganese, which are important for use in drinking water treatment, and also on the chemical and physical properties of permanganates in general and on the CARUSOL reagent, in particular. The results of a series of laboratory experimental studies conducted in November-December 2015 are presented. The experimental studies were related to the introduction of a new reagent, an oxidizing agent CARUSOL, in the technology of water treatment at water supply facilities of the Public Utility "Zhytomyrvodokanal". The obtained data testify to the expediency of using this reagent for purification of drinking water from excess concentrations of pollutants, such as manganese, permanganate oxidation and chloroform, since its ecological and economic efficiency is confirmed. Namely, the use of the Carusol reagent leads to a reduction in the dose of coagulant, and accordingly the total amount of coagulant used in the technological process of water treatment. It significantly reduces the concentration of trihalomethanes, manganese and permanganate oxidation in drinking water and leads to the saving of chlorine, since the phase of preliminary pre-oxidation on first lift is eliminated. The recommended point, at which the CARUSOL reagent should be applied, is proposed in the study; it should be done at the first lift as a stage of pre-oxidation of river water from the "Vidsichne" reservoir.

Keywords: Drinking water quality; chlorine; sodium permanganate; water treatment; chloroform; manganese; permanganate oxidation

Introduction

At present, most of the water supply companies in Ukraine use the chlorine treatment method for decontamination during the process of drinking water treatment at their water treatment plants. However, this method of decontamination with chlorine-containing disinfectants has very significant disadvantages. First of all, it is the formation of by-products of chlorination in drinking water, such as halogen-containing compounds, a significant part of which are trihalomethanes: chloroform, dichloromethane and bromoform, which are of carcinogenic and mutagenic nature. At the same time, the requirements for the quality of drinking water are constantly increasing due to the process of continuous research and scientific study of carcinogenic and mutagenic effects of by-products of chlorination on the human body. According to WHO recommendations, halogen-containing compounds are included in the list of mandatory quality indicators of drinking water, which are monitored in France, the United States, Canada and other countries. Since 2015 in Ukraine, indicators that characterize the contamination of drinking water with by-products of chlorination (dibromochloromethane, trihalomethanes (sum: chloroform, bromoform, dibromochloromethane and bromodichloromethane) and chloroform have come into effect in accordance with the regulative document of SSRR (State Sanitary Rules and Regulations) 2.2.4-171-10 "Hygienic Requirements for Drinking Water Intended for Human Consumption". Since 2020, 4 indicators of this group have been added to the quality

control of drinking water: 1.2-dichloroethane, tetrachloride, trichlorethylene and tetrachlorethylene (sum) (Mishhanchuk et al., 2015; Prokopov, 2016).
According to the results of the monitoring of the quality of drinking tap water in Ukraine during 2013-2017, it has been found out that the concentrations of trihalomethanes in certain periods of the year exceed the statutory indicators set by SSRR 2.2.4-171-10 by several times. Zhytomyr is not an exception. The average annual indicators of chloroform concentration in drinking water during 2004-2017 ranged from 0.063 ± 0.037 to 0.139 ± 0.091 mg/dm^3, which in comparison with the statutory concentration (0.06 mg/dm^3) is by 1.1-2.3 times higher than the established hygienic norm of SSRR 2.2.4-171-10 (State sanitary norms and rules, 2010) . Its average content exceeded the established standard even in the winter. The maximum concentrations of chloroform in drinking water for 2004-2017 exceeded the norm by 2.6-6.1 times and amounted to 0.165-0.37 mg/dm^3 (Bashyns'ka, 2018).
Taking into consideration the situation with the content of chloroform in drinking tap water, both in Ukraine and in Zhytomyr, it is necessary to intensify the search for new modern methods or combined technologies of water decontamination, which will reduce the number of negative consequences for people and the use of which will help solve the problem of the formation of chlor-organic compounds in drinking water. In order to reduce the presence of chlorine-organic compounds in drinking tap water when surface water is used as a water source, it is imperative that natural water is purified from organic matters by means of oxidation before the chlorination stage. Correctly selected combinations of methods of oxidation and decontamination of drinking water will make it possible to provide a higher antimicrobial effect and minimize the presence of by-products of chlorination and, simultaneously, will lead to a synergistic effect that is characterized by a more effective final disinfectant effect.
It is known that the reagent, an oxidizing agent of sodium permanganate, has long been used in water-treatment and sewage treatment technologies in countries such as Poland and Spain. In Ukraine, for the first time, laboratory studies on the introduction of a reagent, an oxidizing agent of sodium permanganate (CARUSOL), into water treatment technology were conducted in the chemical and bacteriological laboratory of TOV (LLC) “BILOTSERKIVVODA” in 2014 (Andrijchuk, 2014; Fedorchenko, 2015).
The Ros River, which is used as a source of water supply by this enterprise, is one of the regulated rivers in Ukraine. The quality of water in it varies depending on the season and the degree of influence of negative anthropogenic factors on it. Due to that the task was set to eliminate the unpleasant flavour and smell of drinking tap water, which is determined by the presence of the colourless organic molecular substances in the natural water, which include products of inner water biological processes (carboxylic acids, phenols, etc.). As a result of laboratory studies, a positive result was obtained and the following conclusions were formulated:

- Absence of foreign smell of drinking tap water. The use of sodium permanganate promotes the complete removal of substances with an unpleasant smell from the drinking water.
- 10-30% economy of chlorine was obtained.
- The use of sodium permanganate does not influence the change of water pH.
- Its use in water treatment technology does not contribute to side effects other than the high content of manganese when using an overdose of CARUSOL, which leads to a pink color of water. That is why accurate dosing of the reagent with the help of dosing pumps is required.

Materials and methods

The purpose of our research was to establish the expediency and effectiveness of introducing a new reagent, an oxidizing agent of sodium permanganate (trade form CARUSOL) into water treatment technology at water supply facilities of the Public Utility “Zhytomyrvodokanal”.
The task was to carry out laboratory experiments with CARUSOL and to analyse the obtained experimental data on the use of sodium permanganate for purification of drinking tap water from the contents of high concentrations of chloroform, manganese and permanganate oxidation.
Preparation of solutions of liquid sodium permanganate CARUSOL for use in experimental laboratory studies was carried out in accordance with “Methodology of Test Tube Analysis for Water or Wastewater Treatment. Preparation of standard solutions of liquid CARUSOL permanganate for laboratory use” as follows:

1. Preparation of the concentrated CARUSOL solution out of the market product (content of active substances 20%) (No1), 10 gram $NaMnO_4$/l:
- 25 g of liquid CARUSOL permanganate was measured using the analytical balance;
- 25 g of CARUSOL was put into a 500 ml capacity measuring flask;
- distilled water was added until the mark 500 ml was reached and everything was mixed thourougly.
2. Preparation of the standard CARUSOL solution A (No2), 1 gram $NaMnO_4$/l:
- 10 ml of concentrated CARUSOL solution (No1) was put into a 100 ml capacity measuring flask with the help of a measuring or graduated pipette;
- distilled water was added until the mark 100 ml was reached and everything was mixed thourougly;
- (this solution is used for purification of water of medium pollution level, namely when using technical sewage water or drinking water containing iron, manganese or organic carbon).
3. Preparation of the standard CARUSOL solution B (No3), 0.1 gram $NaMnO_4$/l:
- 1 ml of concentrated CARUSOL solution (No1) was put into a 100 ml capacity measuring flask with the help of a measuring or graduated pipette with 1 ml capacity;

- distilled water was added until the mark 100 ml was reached and everything was mixed thourougly;
- (this solution is used for purification of water of low pollution level (non-purified drinking water with low content of organic carbon)).

To determine the optimal doses of reagents (sodium permanganate, coagulant, flocculant and chlorine), a laboratory flocculator (Figure 1) was used for water purification in laboratory conditions; this flocculator is intended for mixing of water with established speeds.

Figure 1. Laboratory flooculator.

The selection of water samples, which underwent experimental research, took place on the first lift of the water-intake chamber of the "Vidsichne" reservoir, which is located 6 km from Zhytomyr.
All experimental studies were carried out in the control and measuring laboratory in compliance with the sanitary and hygienic norms of water supply of the Public Utility "Zhytomyrvodokanal".
Determination of water quality indicators before and after the experiments was carried out according to generally accepted methods: organoleptic parameters: chromaticity and turbidity were measured according to the methodology GOST (State Standard) 3351-74; oxidation of permanganate-GOST (State Standard) 23268.12-91; manganese-"Method for Measuring the Mass Concentration of Aluminum, Iron, Cadmium, Cobalt, Manganese, Copper, Molybdenum, Nickel, Lead, Strontium, Chromium and Zinc in Drinking Water", for the atomic absorption spectrophotometer "Saturn-3-P1"; chloroform-procedural guidance No. 0052-98 "Gas-chromatographic Determination of Trihalomethanes (Chloroform) in Water". The assessment of the quality of drinking water was carried out by comparing the actual data with the norms of SSRR 2.2.4-171-10 "Hygienic Requirements for Drinking Water Intended for Human Consumption". The processing of statistical data was performed using the Microsoft Excel and Statistica 6.0 application package.

Results

The reservoir "Vidsichne" is used as the source of drinking water supply in Zhytomyr. Every year the situation with the deterioration of water quality in the reservoir is intensified. This is due to several reasons. First and foremost, it is over-regulation of the "Vidsichne" reservoir. As a result, the natural water exchange in the reservoir slows down, which reduces the ability of natural water to self-purify, decreases the flow rate and increases the area of shallow water along the banks. And in spring, due to the rise in temperature of air and water, "blooming" of water occurs, that is, an increase in the amount of phytoplankton, which becomes a threat of water pollution and the appearance of toxins in it. The second reason for the deterioration of water quality in the reservoir is the lack of spring water passage. Namely, during the spring flood it is necessary to open the gateways on hydraulic structures to change the composition of water, which would significantly affect the exchange of qualitative composition of water in the reservoir. However, such measures are carried out extremely rarely and not in full volume, which leads to stagnant phenomena and the formation of storage zones. The third reason is the dumping of crude or insufficiently treated sewage water from the sewage treatment facilities of the urban-type settlement

Vysoka Pich and sanatorium “Deneshi”. Sewage water contains phosphates, which contribute to the intensive growth of blue-green algae. After they die, there is a rotting process, which is accompanied by a saturation of water with unpleasant smells and flavours. The products of rotting, in turn, contribute to the development and rapid multiplication of pathogenic bacteria, as well as increase the concentration of colloidal suspended matters.

According to the results of our previous studies (Bashyns'ka, 2018; Bashyns'ka, 2018), it was established for the years 2004-2017 that the water quality in the “Vidsichne” reservoir with an average organic contamination level corresponded to Class 2-3 of water quality, and with the maximum content-to Class 4, according to the State standard of Ukraine 4808 : 2007 (State standard of Ukraine, 2007). During the research period, the stable content of organic matter was fixed in accordance with the requirements of the Sanitary Rules and Norms 4630-88 (Sanitarnye pravila i normy, 1988), in particular, the average long-term content of the biochemical oxygen demand ($BOD_п$) was 5.03 ± 0.12 mg O_2/dm^3, which 1.7 times higher than the norm 3.0 mgO_2/dm^3 (Figure 2), the average perennial content of chemical oxygen demand (COD) was 26.0 ± 2.0 mgO_2/dm^3, which is also 1.7 times exceeded the standard of the Sanitary Rules and Norms 4630-88 (15 mgO_2/dm^3), and the value of the average perennial permanganate oxidation content was 10.7 ± 0.12 mgO_2/dm^3 (Figure 3), which corresponded to Class 3 of water quality according to the State standard of Ukraine 4808 : 2007. That is, the "Vidsichne" reservoir was characterized by medium and high (in summer months) levels of organic pollution.

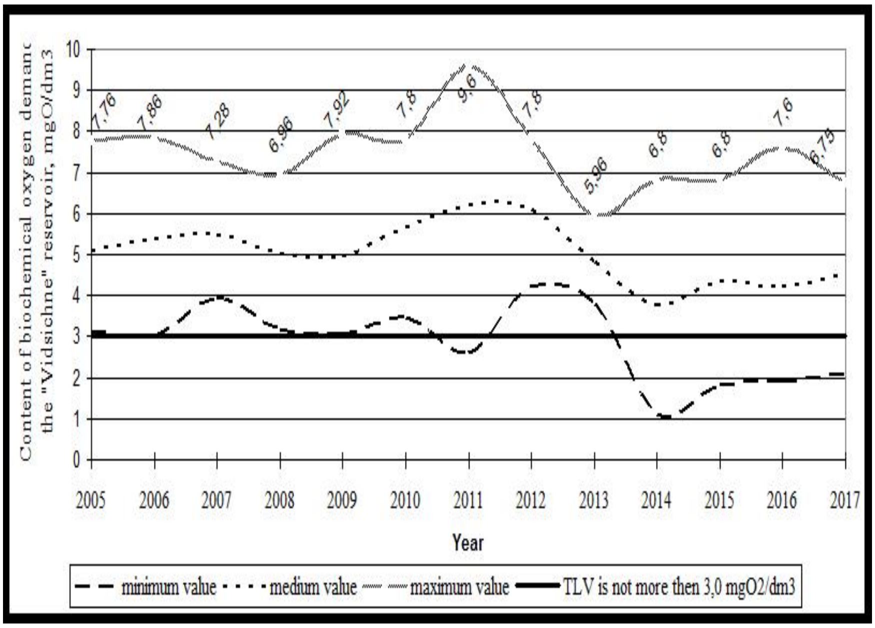

Figure 2. Results of the statistical research of the biochemical oxygen demand in the "Vidsichne" reservoir for 2005-2017.

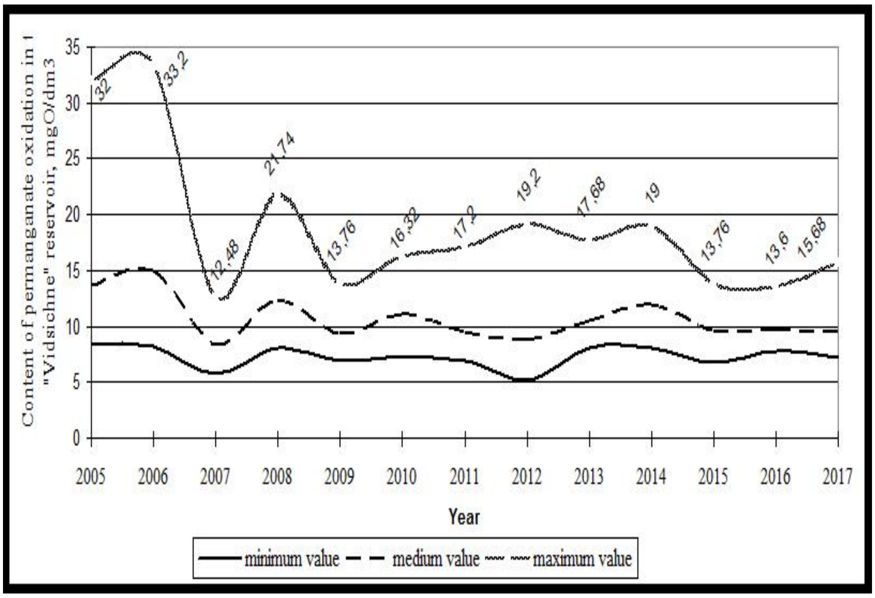

Figure 3. Results of the statistical research of the content of permanganate oxidation in the "Vidsichne" reservoir for 2005-2017.

For the years 2005-2017, the average annual content of phytoplankton in the surface water of the reservoir corresponded to Class 3-4 of water quality according to the State standard of Ukraine 4808 2007, and with maximum content-to Class 4. In particular, the average annual content of phytoplankton was 89.510 ± 210.5 thousands cells/dm3, which corresponded to Class 3 of water quality according to the State standard of Ukraine 4808 : 2007, and its maximum value was recorded in September 2017 and amounted to 2022.15 thousands cells/ dm3, which 20 times exceeded the minimum value of belonging to Class 4 of water quality (>100 thousands cells/ dm3).

There is also a problem of increased manganese content in the water of the reservoir. Large doses of chlorine are needed for its oxidation, which ultimately leads to the formation of large concentrations of by-products of chlorination in drinking water, namely chloroform. In the process of the disappearance of blue-green algae, which are the main species in the phytoplankton in the surface water of our reservoir, under the influence of processes occurring in water, the manganese release process is transformed into the Mn+2 form from one form of Mn+4. In accordance with the Sanitary Rules and Norms of protection of surface water from pollution (the Sanitary Rules and Norms 4630-88), the excess of TLV on manganese (0.1 mg/dm^3) average annual values during 2005-2017 was recorded-2.5-3.9 times. The results of our statistical study are presented in Figure 4.

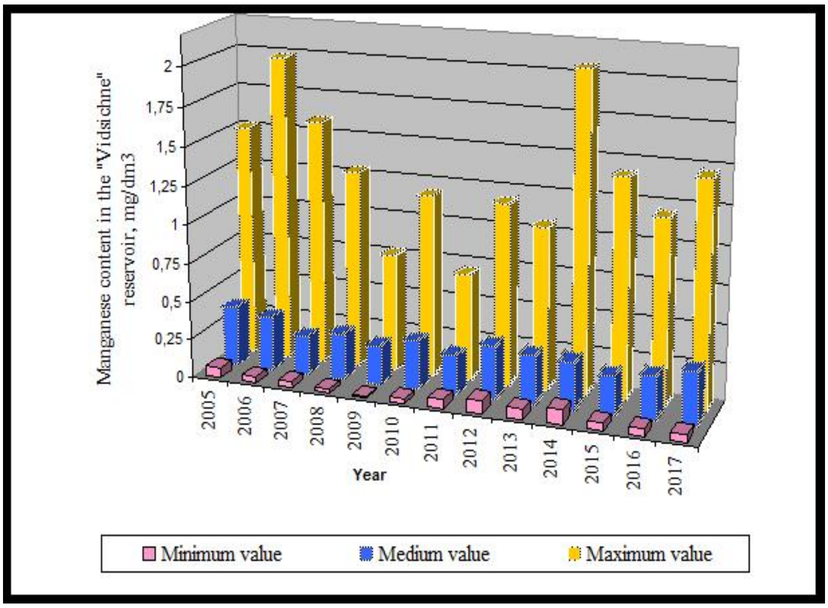

Figure 4. Results of statistical research of the manganese content in the "Vidsichne" reservoir for 2005-2017.

Over the last 5 years, the average annual manganese content in the “Vidsichne” Reservoir was 0.316 mg/dm^3 in 2013, 0.31 mg/dm^3 in 2014, 0.25 mg/dm^3 in 2015, and 0.29 mg/dm^3, in 2017-0,34 mg/dm^3, which is 3.2, 3.1, 2.5, 2.9 and 3.4 times, respectively, higher than the TLV. During the same period, the following maximum values for manganese were fixed: in 2013-1.056 mg/dm^3, in 2014-2.058 mg/dm^3, in 2015-1.42 mg/dm^3, in 2016-1.19 mg/dm^3, in 2017-1.46 mg/dm^3, which is 10.56 TLV, 20.6 TLV, 14.2 TLV, 11.9 TLV and 14.6 TLV in accordance with the standard of the Sanitary Rules and Norms 4630-88.

Taking into account the information we have received as a result of the research of water quality in the "Vidsichne" reservoir, one of the methods of peroxidation of organic matter and manganese in river water, may be a method using reagents-oxidants of potassium permanganate or sodium permanganate. Reagent-oxidant potassium permanganate (KMnO4) in Ukraine belongs to a precursor category. Precursor is a chemical used in manufacture or processing of narcotic drugs and psychotropic substances. To use it in the water treatment technology, a license and permission to work with precursors are required. The use of precursors in Ukraine is under the strict control of the State Service of Ukraine for Medicines and Drugs Control. That is, the use of potassium permanganate in the water treatment technology entails the need to solve a range of complicated issues related to transportation, storage, accounting, use and write-off of precursors.

Sodium permanganate ($NaMnO_4$) (trade form CARUSOL) is an oxidizing agent that has the same nature of action as potassium permanganate. It is used for pre-oxidation as an alternative to chlorine and chlorine dioxide and eliminates the possibility of formation of by-products of chlorination, trihalomethanes, in drinking water. The use of sodium permanganate provides an effective solution to such acute problems as the oxidation and removal of inorganic substances from the water such as iron, manganese, arsenic, radium, oxidation of natural organic substances that are present in a water supply source, removing the flavours and odours of water, improving the colour of water. The use of sodium permanganate also gives the following benefits: the ability to control the process of formation of biofilms in the pipelines of water distribution networks, reduction in the amount of algae in water, the improvement of the coagulation process (reducing the amount of coagulant used in the water treatment stages), reduction in the amount of chlorine used for water disinfection (Fedorchenko, 2015). Sodium permanganate (CARUSOL) has a liquid form and comes in containers of 1.0 m3 (Figure 5).

Figure 5. Type of container with sodium permanganate CARUSOL.

There are three stable forms of manganese that are important for use in water treatment of drinking water:

- Manganese (II), Mn+2, which is a part of water-soluble compounds that are easily soluble. Therefore, it often appears in water as “dissolved manganese”; it is not possible to see it, and the water thus looks clean.
- Manganese (VII), Mn+7, which is a permanganate ion. This manganese is dissolved in water and it colours the water violet-pink.
- Manganese (IV), Mn+4, manganese dioxide. This is the most stable form of manganese and is the product of most reactions of permanganate known to us. It precipitates in the form of dry flakes with a large area of the surface and a weak negative charge. It is coloured yellow, golden and brown. When MnO2 precipitates itself, the flakes are very small, less than 0.22 microns. They begin to grow when there are positively charged ions in the system. Since the flakes have a negative charge, they adsorb metal ions and organic compounds. A newly precipitated manganese dioxide is also reactive and may be an oxidizing agent. It is a catalyst for some reactions in the transfer of oxygen, which gives it additional victories.

Permanganates are strong oxidizing agents in aqueous solutions.

Potassium or sodium permanganate are most frequently used as oxidizing agents. The solution of sodium permanganate ($NaMnO_4$) in water has a crimson or purple colour (depending on the concentration of the solution). Figure 6. shows the change in the colour of water depending on the concentration of permanganate in it. The first sample corresponds to a concentration of 0.5 mg/dm^3, the second one 1.0 mg/dm^3, the third 5.0 mg/dm^3, the fourth 10.0 mg/dm^3, the fifth 25.0 mg/dm^3, the sixth 50.0 mg/dm^3, the seventh 100.0 mg/dm^3.

Figure 6. Concentration of permanganate solution in water.

The recovery products of $NaMnO_4$ and the oxidation-reducing potential of permanganate-ion in aqueous solutions depend on the nature of the medium. With the increase of the hydrogen exponent of the solution (pH), the oxidizing properties of sodium permanganate weaken.

Reactions of permanganate in water depending on the pH of water occur according to the following schemes:

in a highly acid medium, pH=8.01 and higher
$MnO_4^- + 8H^+ + 5ē = Mn^{+2} + 4H_2O$; Eo ($MnO_4/Mn^{2+}$)=1.51 B

in a faintly acid or neutral medium, pH=6-8
$MnO_4^- + 2H_2O + 3ē = MnO_2 + 4OH$.; Eo($MnO_4/MnO_2$)=0.62 B

in a highly alkaline medium, pH=below 5.99
$MnO_4^- + ē = MnO_4^{-2}$ Eo (MnO_4/MnO_4^{2-})=0.56 B

The CARUSOL reagent has the following chemical and physical properties (Andrijchuk, 2014; Sertyfykat na reagent).
Chemically, sodium permanganate ($NaMnO_4$) is classified as an oxidizing agent, a destroyer of organic compounds, a converter of pollutants into less flavoured, safe by-products.

Visual appearance	dark-violet solution
Formula	$NaMnO_4$
Odour	without odour
Odour threshold	n/a
Ph Indicator	5.0-8.0
Melting/freezing point	-15 °C
Boiling point/range	>101 °C (при 760 мм рт.ст.)
Vaporization level	like water
Ability to ignite (of a solid body, gas)	n/a
Relative density	(at 20 °C) 1.30-1.39 at 20 °C
Water solubility	soluble (is miscible with water in any proportion)

Using the experience of colleagues from "BILOTSERKIVVODA", during 2015-2017, we carried out a series of laboratory experiments on the introduction of CARUSOL reagent into the water treatment technology at the water supply facilities of the Public Utility "Zhytomyrvodokanal" at different temperature conditions. Problems of quality of drinking tap water in Zhytomyr, at which the implementation of the new CARUSOL reagent is directed, are formulated as follows:

- it is necessary to minimize the concentration of dangerous chloroform in drinking water;
- to reduce the oxidative content of permanganate;
- to reduce the concentration of manganese and the amount of phytoplankton.

This paper presents a series of several laboratory experiments conducted in November-December 2015.
Source water was the river water from the water receiving chamber of the "Vidsichne" reservoir. CARUSOL A was applied as a chlorine substitute at the first lift.
The sequence of introduction of reagents in this experiment corresponds to the sequence of introduction of reagents in the existing water treatment technology at the water supply facilities of the Public Utility "Zhytomyrvodokanal": CARUSOL A (1 lift), in 2 hours sodium hypochlorite related to chlorine (2 lift), in 30 seconds coagulant, in 30 seconds flocculant, mixing 5 minutes and precipitation time 30 minutes. In experiments, the dose of sodium hypochlorite related to chlorine is chosen to correspond to the dose of chlorine of this period of the year.
In the experimental studies, the following reagents were used: anionic flocculant based on polyacrylamide-EXTRAFLOCK P-70 and coagulant-24.11.17-01.12.2015-hydrochloride aluminum Polvac-40 (weight part of Al2O3 16%) in town Polohy, 02.12.2017-07.12.2015-coagulant based on aluminum KZhA Make A (weight part of Al2O3-13.4%) in city Dnipro. The results of laboratory experiments on the introduction of a reagent, an oxidizing agent of sodium permanganate CARUSOL A are presented in Table 1.

Table 1. Results of laboratory experiments on the use of the reagent-sodium permanganate (CARUSOL A) in the water treatment technology.

Reagent	**Dose of coagulant, mg/dm^3**	**Dose of CARUSOL A mg/dm^3**	**Dose of chlorinem g/dm^3**	**Turbidity, mg/dm^3**	**Colored-ness, degrees**	**Permanganate oxidation, mg/dm^3**	**Manganese, mg/dm^3**	**Chloroform, mg/dm^3**
1	2	3	4	5	6	7	8	9
24.11.2015								
The "Vidsichne" reservoir				6.8	26	8.96	0.205	n/a
NaClO	50	n/a	8	1.4	4	7.2	0.014	0.032
CARUSOL A+NaClO (Sample 1)	50	0.16	4	1.1	6	8.96	0.023	0.009

CARUSOL A+NaClO (Sample 2)	50	0.2	4	1.8	8	9.28	0.043	0.009
CARUSOL A+NaClO (Sample 3)	50	0.26	4	1.4	8	7.2	0.012	0.007
30.11.2015								
The “Vidsichne” reservoir				7.2	32	11.04	0.202	n/a
NaClO	50	n/a	8	1.7	4	8.32	0.016	0.026
CARUSOL A+NaClO (Sample 1)	50	0.2	4	0.7	6	9.6	0.027	0.006
CARUSOL A+NaClO (Sample 2)	50	0.26	4	0.7	8	7.04	0.016	0.006
CARUSOL A+NaClO (Sample 3)	40	0.2	4	0.9	8	7.68	0.009	0.009
01.12.2015								
The “Vidsichne” reservoir				7.2	32	11.04	0.202	n/a
NaClO	40	n/a	8	1.9	6	7.84	0.01	0.029
CARUSOL A+NaClO (Sample 1)	40	0.2	4	0.7	9	8.32	0.053	0.008
CARUSOL A+NaClO (Sample 2)	40	0.26	4	0.9	9	6.56	0.05	0.006
CARUSOL A+NaClO (Sample 3)	50	0.2	4	0.4	8	6.56	0.024	0.007
02.12.2015								
The “Vidsichne” reservoir				7.2	28	10.4	0.14	n/a
NaClO	40	n/a	8	0.9	4	7.68	0.019	0.055
CARUSOL A+NaClO (Sample 1)	40	0.16	4	1.1	4	6.08	0.021	0.025
CARUSOL A+NaClO (Sample 2)	40	0.2	4	1.1	5	6.08	0.022	0.024
CARUSOL A+NaClO (Sample 3)	40	0.26	4	1.1	5	5.28	0.027	0.023
1	2	3	4	5	6	7	8	9
07.12.2015								
The “Vidsichne” reservoir				6.7	26	11.68	0.22	n/a
NaClO	50	n/a	8	0.4	4	9.6	0.006	0.028
CARUSOL A+NaClO (Sample 1)	30	0.2	4	1.5	5	8	0.049	0.015
CARUSOL A+NaClO (Sample 2)	40	0.2	4	1	4	6.88	0.025	0.015
CARUSOL A+NaClO (Sample 3)	50	0.2	4	0.4	4	7.72	0.018	0.014

Discussion

According to the data of laboratory experiments, the most effective for water purification and economically feasible is the CARUSOL dose of 0.2 mg/dm^3 and coagulant (with a mass fraction of Al2O3 not less than 13%)-50 mg/dm^3. With such a ratio of reagents doses, the most optimal indicators of drinking water quality are obtained, namely:

On 01.12.2015

- the colorness of the river water was 32 degrees (visually on the chrome-cobalt scale), after the adding of reagents-8 degrees, which is 24 degrees less or cleared by 75%;
- the water quality index of permanganate oxidation (PO) at "Vidsichne" was 11.04 mg/dm^3, after purification with reagents-6.56 mg/dm^3, that is, there was a decrease by 4.48 mg/dm^3 or by 40.6%;
- the concentration of manganese was at the level of 0.202 mg/dm^3, after purification with reagents-0.024 mg/dm^3, there was a decrease by 0.178 mg/dm^3 or by 88.1%;
- there was no chloroform in "Vidsichne". When adding sodium hypochlorite only, without Carusol, the concentration of chloroform has increased up to 0.029 mg/dm^3. After cleaning with reagents, chloroform was 0.007 mg/dm^3, which is 0.022 mg/dm^3 less than when using sodium hypochlorite only.

On 07.12.2015

- the colorness of the river water was 26 degrees (visually on the chrome-cobalt scale), after the adding of reagents-4 degrees, which is 22 degrees less or cleared by 84.6%;
- the water quality index of PO at "Vidsichne" was 11.68 mg/dm^3, after purification with reagents-7.72 mg/dm^3, that is, there was a decrease by 3.96 mg/dm^3 or by 33.9%;
- the concentration of manganese was at the level of 0.22 mg/dm^3, after purification with reagents-0.018 mg/dm^3, there was a decrease by 0.202 mg/dm^3 or by 91.8%;
- there was no chloroform in "Vidsichne". When adding sodium hypochlorite only, without Carusol, the concentration of chloroform has increased up to 0.028 mg/dm^3. After cleaning with reagents, chloroform was 0.014 mg/dm^3, which is 0.014 mg/dm^3 less than when using sodium hypochlorite only.
- Graphically, the dynamics of changes in experimental parameters of drinking water quality when changing the dose of Carusol added is presented in Figures 7-9.

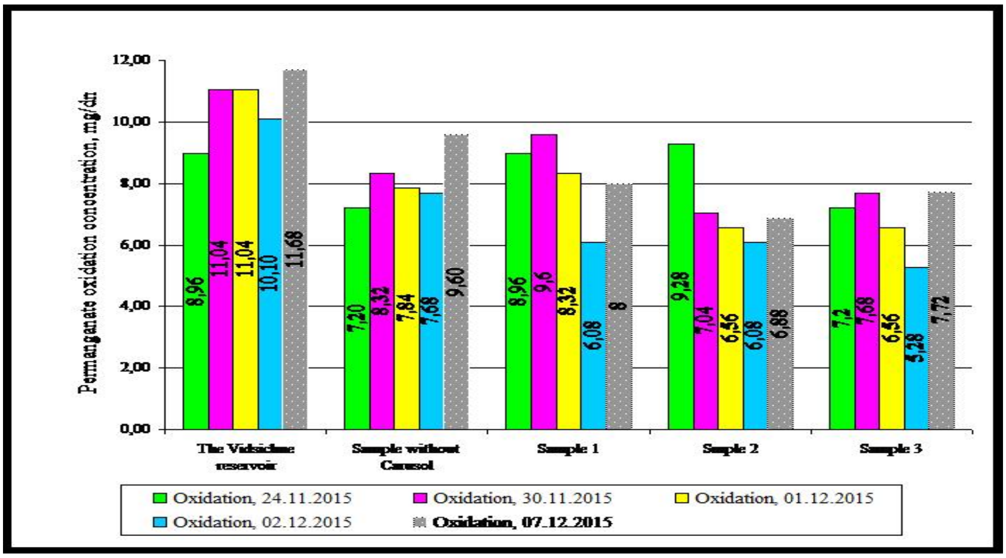

Figure 7. Dynamics of water quality change by the indicator of permanganate oxidation when changing the dose of Carusol added.

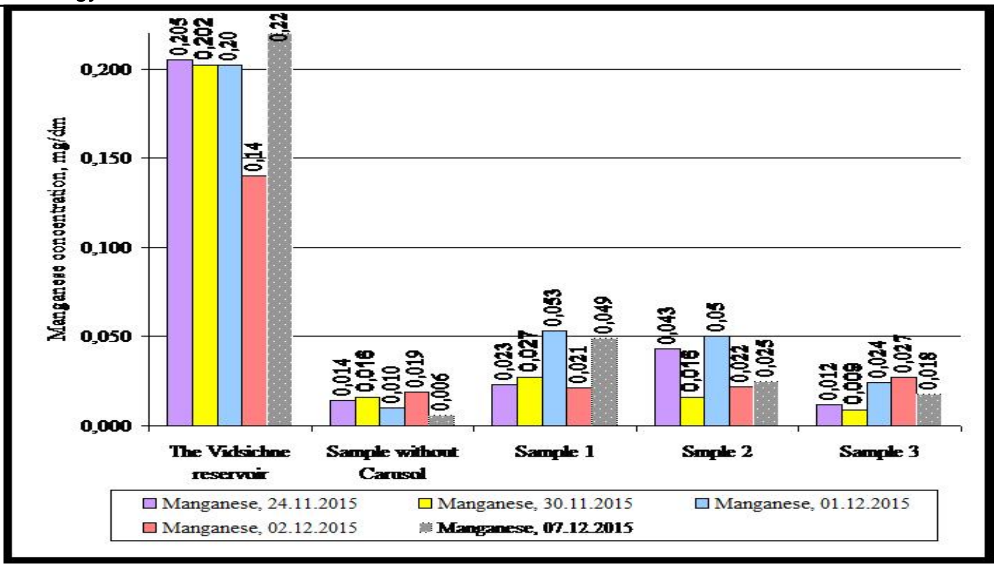

Figure 8. Dynamics of water quality change by the concentration of manganese when changing the dose of Carusol added.

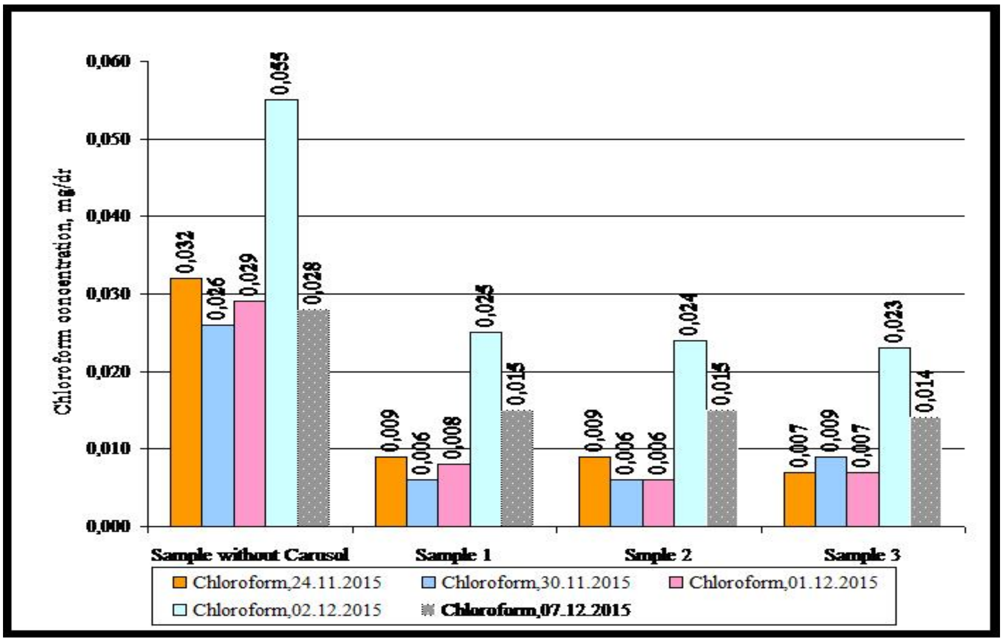

Figure 9. Dynamics of water quality change by the concentration of chloroform when changing the dose of Carusol added.

I would like to note that in the experiments, when adding on the first lift the doses of chlorine only, without permanganate sodium, there is a better oxidation of manganese:
24.11. from 0.205 mg/dm^3 to 0.014 mg/dm^3,
30.11. from 0.202 mg/dm^3 to 0.016 mg/dm^3,
01.12. from 0.202 mg/dm^3 to 0.010 mg/dm^3,
02.12. from 0.140 mg/dm^3 to 0.019 mg/dm^3,
07.12. from 0.220 mg/dm^3 to 0.006 mg/dm^3),
but the result is a higher concentration of chloroform in the drinking water as output:
24.11. 0.032 mg/dm^3 compared to 0.009 mg/dm^3,
30.11. 0.026 mg/dm^3 compared to 0.006 mg/dm^3,
01.12. 0.029 mg/dm^3 compared to 0.008 mg/dm^3,
02.12. 0.055 mg/dm^3 compared to 0.025 mg/dm^3,
07.12. 0,028 mg/dm^3 compared to 0.015 mg/dm^3).
If we compare the experimental data obtained with the norms established in the State Sanitary Rules and Norms 2.2.4-171-10, then the results obtained for manganese and chloroform correspond to the established norms. As for permanganate oxidation, the picture is slightly different. As the laboratory data obtained did not meet the established norms, however, as a result of the experiments, the permanganate oxidation index was sufficiently reduced by 4.48 mg/dm^3 and 3.96 mg/dm^3. This is a pretty good result.
It is also worth noting that at water supply plants-lighters and quick filters, which are loaded with filtering material with zeolite and quartz sand, there is an additional final purification of drinking water. Part of the residual concentrations of pollutants after oxidation is kept by the filters with zeolite and sand of water treatment facilities.
In general, analyzing the experimental data, we obtain the percentage of purification of drinking water, which corresponds by

the permanganous oxidation to 13-49.2%, by manganese-73.4-95.6%. The presence of chloroform concentrations in drinking water in all samples after the experiments corresponded to the established norm, and compared with water samples without adding CARUSOL the difference in chloroform concentrations is from 0.013 mg/dm^3 to 0.032 mg/dm^3. That is, the addition of CARUSOL reagent to river water before adding of chlorine (the pre-oxidation stage) reduces the formation of chloroform by 46.4-58.2%.

If we compare the experimental data obtained with the data of the laboratory control of the drinking water quality in the water treatment facilities in the days when the experiments were carried out (presented in Table 2), we obtain information confirming that the purification of drinking water with the help of a sodium permanganate reagent is sufficiently effective, in comparison with the existing water purification technology, as there is a strong oxidation of manganese and less concentration of chloroform and permanganate oxidation.

Table 2. Data of the laboratory control of the drinking tap water quality after water treatment facilities.

No	Date of sample	Turbidity, mg/dm^3	Colourness, degrees	Permanganate oxidation, mg/dm^3	Manganese, mg/dm^3	Chloroform, mg/dm^3
1	24.11.2015	0.8	4	7.66	0.052	0.045
2	30.11.2015	1	4	7.66	0.014	0.038
3	01.12.2015	1.1	4	7.68	0.016	0.059
4	07.12.2015	1	4	7.84	0.018	0.059

Thus, the scheme presented in Figure 10 is proposed for introducing into the existing water treatment technology a phase of pre-oxidation of river water with a solution of sodium permanganate (CARUSOL) at the first rise with subsequent disinfection by sodium hypochlorite at the second rise and coagulation and filtration at the water treatment plants of Zhytomyr. Disinfection and disinfection of drinking water with sodium hypochlorite should be conducted in several stages, namely, primary decontamination-the point of adding of sodium hypochlorite when the river water flows through the water supply from the first to the second rise, secondary decontamination-in the water supply facilities, the final decontamination-before the release of drinking water from reservoirs to the water supply network to consumers.

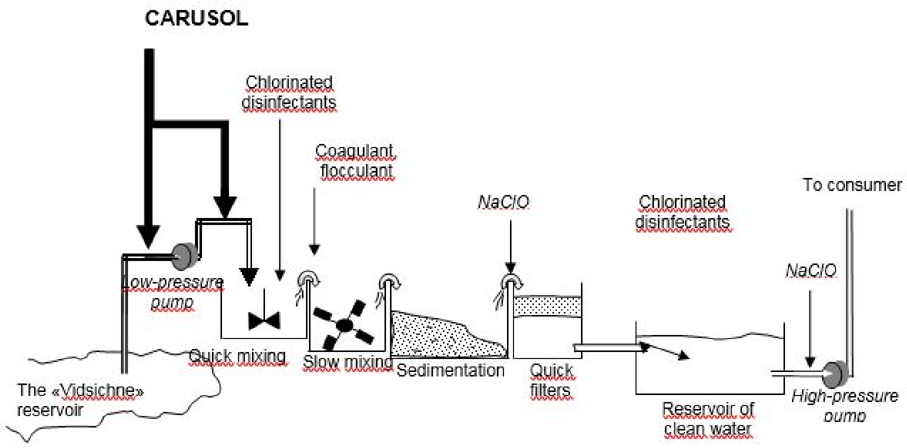

Figure 10. Scheme of adding the reagent-oxidizer Carusol in the technology of water treatment in water supply facilities of Communal enterprise "Zhytomyrvodokanal".

Conclusions

As the quality of surface water in the "Vidsichne" Reservoir is characterized by the average and high level (especially in the summer months) of organic contamination, by a large amount of phytoplankton in the surface water and by high concentrations of manganese, the disinfection of river water with the chlorine-based reagent-chlorine, in accordance with the existing technology of water treatment, leads to the formation of high concentrations of chloroform in drinking water. A series of laboratory experimental studies was conducted with the introduction of the process of pre-oxidation with the reagent-the oxidant of sodium permanganate Carusol instead of chlorine with the introduction of water-treatment technology-to the expediency and efficiency of purifying drinking water from manganese, permanganate oxidation and chloroform.

The use of the Carusol reagent reduces the amount of coagulant used for water purification, significantly reduces the concentration of trihalomethanes in the drinking water and leads to the saving of the amount of chlorine, as the previous pre-oxidation phase is eliminated at the first rise.

In the following articles there will be presented the results of research of several series of laboratory experiments with the introduction of the reagent-the oxidizer of sodium permanganate Carusol into the technology of water treatment in different periods of the year with different temperature regimes and water quality in the water supply source at the "Vidsichne" reservoir during 2016-2017.

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