Advanced treatment of drinking water from chlorine by-products in water transport and stationary facilities

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Abstract. Chlorination is a priority method for drinking water disinfection, since chlorine has strong bactericidal properties. However, a whole set of volatile chlorine derivatives of organic substances dangerous to humans are formed during chlorination, among which it is necessary to mention chloroform, carbon tetrachloride, chlorophenols. To reduce the concentration of organochlorine derivatives, it is necessary to supplement the current water treatment technology with an adsorption stage of advanced treatment at local sorption treatment facilities immediately before water is supplied to the consumer. It is advisable to design a third water treatment stage at water treatment stations, the capacity of which is low, since a huge number of filters will be needed for high-capacity plants, which may significantly reduce the water head when supplied to the city’s water supply networks, and this will entail huge costs associated with the construction of a workshop for the third treatment stage and the cost of the filters themselves. It makes sense to use such sorption plants in cottage estates and water transport. Besides, chlorination remains in the drinking water treatment scheme, which preserves the quality of water during transportation over long distances, and organochlorine substances, including 2-chlorophenol, are removed during sorption.

1. Introduction

Until now, chlorination has been the priority method for drinking water disinfection. This practice is typical of large cities in the world (Moscow, London, Paris, etc.) with a long water supply network. This is due to the strong bactericidal properties of combined chlorine, the long-term effect of which allows the urban water supply network being maintained in an adequate sanitary condition. For the first time in the world, chlorine was used to disinfect water after the cholera epidemic in London in 1870 [1].

At existing Russian water treatment stations, pre-chlorination is often carried out with high doses of chlorine not only to disinfect water, but also to combat plankton, reduce water chromaticity, intensify coagulation processes, maintain the necessary sanitary condition of water treatment facilities, etc. In the process of decontamination, chlorine goes for the oxidation of organic impurities contained in water, therefore, to ensure reliable bactericidal effect in treated water, a certain concentration of
residual chlorine is maintained [2, 3]. During chlorination of drinking water the concentration of residual free chlorine shall be not less than 0.3 and not more than 0.5 mg/l.

2. Problem statement

Water treatment stations mainly use the following reagents for water chlorination: chlorine gas, sodium hypochlorite and chlorine dioxide. The chlorination of drinking water at water intake stations, which yields acceptable results in maintaining the microbiological quality of drinking water during its transportation through water supply networks, has some serious disadvantages. In the process of chlorination (especially primary), a whole set of volatile chlorophenols of organic substances dangerous to humans is formed, among which it is necessary to mention chloroform, carbon tetrachloride, chlorophenols and others [4].

It was later shown how humic and fulvic acids are converted into chlorophenols under the influence of chlorine, which are natural sources of phenolic substances, and chlorophenols arising in this way have indeed been found in tap water [5, 6]. The studies conducted in the USA, Great Britain, Germany, Sweden [7, 8] also confirm the formation of toxic chlorine derivatives in chlorine treatment of natural and waste water containing organic substances of natural (humic and fulvic acids) and industrial (aromatic and aliphatic hydrocarbons, biphenyls, naphthalene, pesticides and others) origin. Thus, at the initiative of WHO, the European countries and the United States of America included chlorophenols as a priority pollutant of drinking water with the already proven development of dioxins in the water supply network [9, 10].

There are three key directions among the main directions to solve the problem of reducing the content of organochlorine compounds in drinking water:

1) measures aimed at preserving and improving the quality of the source water supplied to the water intakes of the city;
2) change or introduction of new treatment technologies that reduce or exclude the formation of organochlorine compounds during water treatment;
3) introduction of additional final stage of drinking water treatment from organochlorine compounds into the existing technologies.

The measures aimed at preserving and improving the quality of the source water entering the city’s water intakes is necessary, but rather difficult [11]. This is due to the fact that the treatment of storm water and deep treatment of industrial wastewater entering the Novosibirsk reservoir, as well as the environmentally justified organization of recreational and water protection zones, requires large investments. In order to change or introduce new treatment technologies at the pumping and filtering stations of Novosibirsk, it is necessary to completely rebuild the entire water treatment process, and invest quite a bit of financial resources.

Hence, it is more reasonable and economically justified to introduce an additional final stage of drinking water treatment from organochlorine compounds into the existing technologies not at Pumping and filtration plants, but immediately before supplying water to the consumer. Organochlorine substances are the most dangerous substances resulting from the water treatment technologies used in modern practice. Among chlorophenol compounds, 2-chlorophenol is the most hazardous pollutant of drinking water in Novosibirsk, recorded in large quantities when water enters the city network. To reduce the content of 2-chlorophenol in drinking water, one of the effective solutions will be sorption advanced treatment of water using activated carbons.

3. Technical solutions for advanced treatment of drinking water

Currently, the most rational methods of using active coals at water treatment stations are the use of active coal in separate sorption filters representing the third stage of water treatment. This method is more reliable from both sanitary and technological point of view. The following grades of granular activated carbons (GAC) may be used as sorbents: AG, AGM, AGOV. Since the drinking water treated at pumping and filtering stations enters coal, coal operates only for its intended purpose as a
sorbent for removing mainly organic contaminants from water. At the same time, depending on the water quality of the water source the coal life may reach 3 years.

One of the advantages of using GAC is that it may be reactivated. Recommended facilities with separate coal filters are not widely used at domestic water treatment stations, therefore, the filter operation period between reactivations is not established. The experience of operating foreign water treatment stations confirms that the ozonation of water before it gets to coal filters increases their interreactivation period to several years. The use of ozone and coal leads not to a simple summation of their action, but to the new process consisting in the catalytic oxidation of contaminants and the sorption of decay products, in relation to which coal, as a rule, has a higher absorption capacity.

Thermal method is the most cost-effective for the reactivation of coal. Here, coal is exposed to a temperature of 700-800°C without air access for 15-20 minutes. Coal reactivation directly on the site of water treatment stations may be justified only if considerable volumes of coal are treated at large water treatment facilities. The most promising method is the arrangement of regional coal reactivation nodes (in the region, republic, etc.). Coal losses during thermal reactivation make up 15-25%, while the sorption capacity of coal is restored almost completely.

It is advisable to have a third water treatment stage at water treatment stations with low capacity, since a huge number of filters will be required for high-capacity stations, which may significantly reduce the water head when supplied to the city’s water supply networks, and this will entail huge costs associated with the construction of a workshop for the third treatment stage and the cost of the filters themselves. The use of sorption coal filters requires regular regeneration of granular active coals, which is associated with the organization of the movement of large amounts of loading material, and this is difficult at large treatment facilities and leads to significant operating costs. Since the capacity of the stations in Novosibirsk is quite large (350 and 480 m³/day), it is necessary to consider other options for sorption water treatment.

The most effective solution for the removal of organochlorine compounds will be the use of sorption filters immediately before water is supplied to the consumer, since this will allow water to be purified from the entire amount of organochlorine compounds, even those that could additionally be formed during the residence and movement of water through the distribution networks of the water passage.

It is advisable to use sorption filters before supplying water to several houses, to a cottage estate, to a ship’s galley, i.e. immediately before getting to the consumer. Since water supplied to the filters is pre-treated, this will ensure a uniform distribution of pollutants in the thickness of the filter bed [12]. Stationary water filters provide excellent quality water with minimal installation and assembly costs.

The principle of such filters is based on pressure filtration, i.e. water passing through a precoat. It is advisable to use activated carbon from coconut shell of GAC grade as a filter material, since the conducted experiments proved its high efficiency in removing chlorophenol compounds from water, and it also has a relatively low cost. At concentrations of 2-chlorophenol in water reaching 300 MPC, water purification from them will reach almost 100%.

A schematic diagram of a filtration unit consisting of two filters is proposed for uninterrupted water supply (Figure 1).

The general principle of this unit is as follows. The water is purified at the pumping and filtering station is supplied to parallel operating filters, in which case the activated carbon acts only as a sorbent to remove organochlorine compounds. Water is directed from the bottom up through the holes 10 and 12 to uniformly fill the entire filter section. As it passes the filters, the purified water is supplied to the consumer through the holes 5 and 8 via the conduit 2.

The regeneration of sorbent in filters is carried out alternately by back washing of one of the filters with purified water (without using reagents), at the same time the second filter operates in the normal mode. For example, to wash the right filter, the gate valves 12 and 8 are closed and the gate valves 6, 7 and 11 are opened. Flushing water is supplied from above to the regenerated filter through holes 6 and 7, and after flushing the used water is discharged to the sewage system via water line 4 at open gate valve 11 without additional treatment.
It is necessary to choose a night time to regenerate sorbents, when the consumer uses water less actively. Thus, using this scheme, the purified water is continuously supplied to the consumer.

![Diagram of filtration unit]

Figure 1. Filtration unit. 1 – source water, 2 – purified water, 3 – purified water for sorbent regeneration, 4 – water after sorbent regeneration, 5-12 – gate valves.

The studies of the sorption ability of activated carbon based on coconut shell (GaC) revealed that the sorption of 2-chlorophenol in this case is higher than the sorption on other coals used on an industrial scale (AG-OV-1, AG-3, SKD-515). So, at a concentration of 2-chlorophenol of 2 mg/l, the recovery rate for GaC coal is 98%, while for AG-OV-1, AG-3, SKD-515 it varies from 95.2 to 97.8%. The proposed advanced treatment system has been used in the preparation of drinking water by LLC Analytical Center – Water Treatment since 2013.

4. Conclusion

Thus, to reduce the concentration of organochlorine derivatives, it is necessary to supplement the current water treatment technology with an adsorption stage of advanced treatment at local sorption treatment facilities immediately before water is supplied to the consumer. It is advisable to use such sorption plants in cottage estates and in water transport. At the same time, chlorination remains in the drinking water treatment scheme, which preserves the quality of water during transportation over long distances, and organochlorine substances, including 2-chlorophenol, are removed during sorption.

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