Ecologizing of Treatment Methods of Natural Waters Containing Dissolved Organic Substances

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Abstract. Taking into consideration the operating experience of water treatment facilities, we have made an analysis of hazardous consequences of preliminary chlorination for decoloring of natural waters, we have also examined the mechanisms of application of chlorine-containing substances to organic impurities, which are present in an untreated water. It has been determined that there is a necessity of preliminary water treatment before prechlorination as this procedure ensures the required destruction of complex organic compounds. Moreover, we have explained and justified the principles of preliminary treatment of natural waters in biologically active environment, which will allow eradicating the formation of toxic substances and pathogenic microorganisms.

1. Introduction

The world’s practice of treatment of natural waters with high color index for municipal and drinking water supply systems has shown that in recent years even with advancing of technologies it is impossible to achieve total elimination of hazardous impurities in water. One of the reasons of the abovementioned problem is insufficient measurement of transformations of various chemical substances, which are applied in water conditioning and which actively interact with dissolved organic substances (DOS), part of which determine the coloring of water – the color index. However, toxic substances and bacteriological products, which are generated during the process of water treatment, can often be more dangerous then already known natural and anthropogenic pollutants of source waters. Moreover, various studies have proved that it is often not possible to ensure the suppression of metabolic activity, even if preliminary prechlorination of untreated water is organized. Furthermore, the presence of DOS during the process of water conditioning can lead to microbiological contamination of treated water as the result of development of various types of microorganisms, including pathogenic ones.

Thus, it becomes obvious that when traditional water treatment techniques, which are based on application of chemical components, such as chlorine, for initial chlorination (prechlorination), coagulants, flocculants and other agents, are used, the nature of water impurities is not sufficiently considered. The result of interaction can considerably change the properties of water, which can even lead to development of toxic substances. Therefore, it is highly relevant task to ecologize water-conditioning methods by modernization and rational use of technologies, which meet modern requirements and which will ensure providing high quality of treated water with elimination of risks related to forming of hazardous products and with preservation of all vital qualities of environment.
The goal of our work is to justify the strategy of enhancement of technologies for preliminary treatment of water, which contains DOS, in order to exclude the possibility of negative changes in treated water quality due to the presence of toxic substances and hazardous bacteriological products.

2. Justification of enhancement of technologies for natural waters treatment

Until recently, in the world’s practice of water conditioning the treatment of water with high color index, containing dissolved organic substances (DOS) has mostly been fulfilled by using chemical reagent and coagulant methods with preliminary chlorination and with water clearing in settling tanks or clarifiers with a layer of suspended sediment with the application of granular media filtration. However, the experience of application of such techniques demonstrates that, in the majority of cases, the efficiency of purification is not satisfactory [3; 4], which is proved, in particular, by conducted research. It is a well-known fact that sterilization of high color index waters by applying liquid chlorine results in formation of carcinogenic compounds, in such a way chlorine tends to build into organic complexes, which causes oncological illnesses among people. In this regard, the amount of chlorine during preliminary chlorination is limited to 1.5-2.0 mg/l [3; 4]. When decreasing the amount of chlorine agents used during preliminary treatment, they become able to affect only vegetative forms of microorganisms, meanwhile viruses, cysts, spores of protozoa and eggs of helminths are often quite resistant to chlorine exposure and can be present in treated water during the whole cycle of its treatment in water treatment facilities.

Therefore, it is vitally important to take into consideration ecological patterns, which determine direct dependence of presence of specific microbial flora in the environment on its nutritive value. Due to this exact reason, waters, with high color index and with the presence of DOS, always have microbial flora corresponding to the conditions of environment. However, modern techniques of water treatment barely take into account the presence of microorganisms, as it is considered that prechlorination ensures sanitation of the environment and chlorine agents must also eliminate colloidal impurities – DOS. Nevertheless, the practices show the opposite, and, it is also important that there is no possibility nowadays to estimate the content and level of danger of dynamically developing microbiome (complex of microorganisms), which uncontrollably changes its population and species composition adapting (including by means of mutations) to rapidly changing, in the course of water treatment process, conditions.

Declining in quality of treated water is also determined by the fact that microorganisms are immobilized on the metallic elements of treatment facilities, which leads to corrosion. It is believed that products of corrosion are mostly presented by divalent and trivalent compounds of iron, which simply increases its content in treated water. However, in presence of chlorine-organic substances, as well as aggressive ferments, whose qualities are similar to ones of peroxide of hydrogen, iron compounds can easily transform into complex organic substances of various forms, including toxic ones, which is yet to be investigated. It is also difficult to determine whether metabolism products are carcinogenic or toxic and how dangerous enzymes, which are released by various types of microorganisms during the process of elimination of DOS and competitive activity during the process of microbiome formation, are. There is a lack of studies concerning the problems of processing of bacteria breakdown and die-off products, which turn into organic impurities. Without specific microbiological studies it is difficult to determine which amount of these products appears in treated water, and how toxic the substances generated as the result of these processes are. Abovementioned problems are much more serious than the bio-corrosion of metallic elements on its own, together with destruction of these elements, formed iron compounds can also be transformed into dangerous products. It is relatively easy to prevent the destruction of corrosive elements by substitution of materials, however, it does not solve the problem as a whole. Non-corrosive materials exclude the possibility of secondary water contamination with corrosion products, whereas DOS and destructured formations transferred from the solution are present in the process of water treatment, as it can be noticed in the example of examined facilities on the water processing station «Pine Lake» (see. pic. 5).
Bearing in mind the difficulty of finding the solution for the abovementioned issues it is necessary to determine the main directions of development of water treatment techniques, which should exclude the possibilities of forming of carcinogenic chlorine-organic compounds during the process of drinking water processing already at the initial stage of purification. Moreover, they should also prevent the development and activeness of microbiome directly in the treatment facilities, which is possible, as discovered, only by decreasing the nutritive value of water, which is in turn possible by considerable decrease in the amount or total elimination of DOS before delivery of water into a treatment facility at the stage of preliminary treatment.

Earlier it was considered that it was possible to prevent formation of chlorine-organic compounds in drinking water by application of UV-irradiation instead of initial chlorination [4; 8]. Moreover, it was noted that this method was applicable for surface source waters with high content of organic pollution. Such conclusion can only be based on an assumption that a UV-irradiation has a suppressive effect towards a microbiome present in the water containing DOS, and that due to absence of chlorine reagents formation of chlorine-organic compounds does not take place. However, it is necessary to mention that UV-irradiation cannot influence the decreasing of DOS concentration. This effect can be seen only after interaction with simultaneously injected coagulants, which, from our point of view, should not be considered as prevailing during the process of DOS destruction. Presumably, coagulants are quite effective in destruction of highly molecular (with weight of 30-40 kDa) organic substances, which are considered to be relatively weakly stable [8]. So, the destructive influence on complicated stable DOS can only be insured through application of ferments of microorganisms, which under the presence of organic substances must be present in treated water as well. It is also necessary to notice that according to Shelford’s law of tolerance, quantity of microorganisms always equals to the volume of “alimentary products” in the environment. The question is only about how intensive the recovery of microbiome will be after its exposure to ultraviolet irradiation in the environment and how dangerous newly recovered (in quantity) content of microorganisms will be. According to existing assumptions, pathogenic and potentially pathogenic microflora demonstrates the most active recovery, which can be a constraining factor to unconditional application of UV-irradiation in water treatment systems under the presence of DOS in source waters. In addition, it is necessary to keep in mind that the use of UV-sterilization with certain generating capacity can create a risk of forming of toxic and mutagenic products as the result of transformation of various compounds, which are present in treated water [8].

Some researchers [2-4] believe that the problem of forming of carcinogenic chlorine-organic compounds can be solved by decreasing of organic compounds content in source water during the whole cycle of its treatment in a treatment facility, which can be achieved by preliminary purification of water before application of choline into it. At the same time, this variant of natural water pretreatment for elimination of DOS is supposed to be extremely difficult to implement mainly due to high cost of necessary treatment activities. Even though this method is quite expensive, it is at the same time quite relevant and reasonable, as only in absence of DOS, and consequently, by decreasing of nutritive value of environment, it is possible to stop development of microbiome in treatment facilities and, only in this case, it is possible to tackle the problems, related to formation of toxic substances and pathogenic microorganisms during the process of water treatment. Besides, there are technologically non-demanding methods of preliminary treatment of natural water aimed at elimination of DOS. In particular, a predeveloped method of underground waters treatment aid at elimination of DOS (Patent RF № 2161594), in accordance of which the elimination of such impurities must be done before transfer of water directly into treatment facilities [10, 13]. This method includes pretreatment of water in a bioreactor of not complicated composition without application of any chemical agents.

Exclusion of application of chlorine and chlorine-containing agents during initial chlorination from the scheme of drinking water treatment is considered quite realistic and can show a great potential [2-4]. Nevertheless, it is required to apply other methods, which will guarantee high degree of inactivation of viruses and bacteria with total absence of side toxic products, also, in combination with
other technological elements of purification and secondary sterilization the efficiency of water
treatment should remain high [2, 4].

Over a long period of time, preliminary disinfection by ozonization was vied as quite an
appropriate variant for treatment of natural waters containing DOS. However, as discovered, more
toxic, in comparison with chlorine-organic ones, ozone-organic compounds are generated as the result
of application of this method, and the absence of active forms of microorganisms is not guaranteed.
Thus, it is impossible to exclude the possibility of bio-corrosion of metallic structures and formation of
carcinogenic compounds based on DOS. Mechanism of ozone interaction with existing in water
organic compounds triggers the process of their transformation, which leads to formation of
carcinogenic substances, which can make a negative impact on human health [4; 9]. As the result of
ozonization in water-supply service pipelines, it is also possible to notice the effect of intensification
of development of disease-inducing microorganisms, the source of which is biodegradable organic
compounds [7, 12, 13]. Besides, it is known that ozone itself is more dangerous and toxic ingredient,
than chlorine, as it intensifies the corrosion processes, can be explosive, it demands special security
and safety measures to be taken and only qualified maintenance staff can work with it properly [4, 9].

3. Basic requirements to preliminary treatment of natural waters
Taking all the above mentioned into consideration, we must state that preliminary treatment of natural
waters, the task of which is to eliminate DOS from natural not yet treated water, remains the most
preferable variant of creation of water treatment system as a whole. Technique of preliminary DOS
elimination must include effective destructive treatment activities, which are capable to affect complex
organic substances and ensure their elimination. At the same time, this technique must be simple and
cost-effective. Thus, destructive influence on DOS, with the goal of their extraction, must be made
before water delivery into a treatment facility at the stage of preliminary treatment. During the whole
process of treatment, the following basic requirements must be met:
- preliminary processing of water containing DOS must be organized before delivery of water into
  main treatment facilities using the methods, which must ensure effective destruction of DOS with the
  highest possible level of their elimination from water;
- the technique of preliminary water treatment must be simple and cost-effective and must be
  implemented with the use of efficient decomposers, which must ensure elimination of complex
  molecules of colloid systems;
- the technique of preliminary water treatment must facilitate the regulation of species composition
  of microbiome with the aim of decreasing the risk of development of pathogenic and potentially
  pathogenic microbial flora;
- the technique of preliminary water treatment must be implemented without application of
  chemical agents, which increase the possibility of toxic products formation;
- preliminary chlorination must be done on a mandatory basis, but only after significant decrease in
  concentration or sufficiently high level of elimination of DOS from water, the contact time of chlorine
  and water must not be less than 20-30 minutes.

Mentioned above requirements to the technique of preliminary treatment of water can be
considered strict and they can make it hard to develop a system of activities that would totally meet
these requirements.

It is quite possible to ensure effective destruction of DOS with the highest possible level of their
elimination from untreated water by using the mechanisms of natural self-purification of water bodies,
the main role in these mechanisms is played by microorganisms immobilized on particles of
suspended substances present in water. Intensification of destruction of DOS is possible by creating
artificial optimal conditions for immobilization of microorganisms in specially built units –
bioreactors, where specific microbiome is formed. However, it is necessary to pay attention to the fact
that quantitative and qualitative content of microorganisms will always be formed and transformed in
accordance with changing conditions of environment, which, in our case, is water containing DOS.
Bioreactors can be placed directly in water storage reservoir or in the units on the territory of water treatment facilities. An essential requirement to proper operation of bioreactor is creating optimal conditions for immobilized microbiome, the conditions are determined by chemostat regime. Such a regime is characterized by the fact that constant supply of nutritious substrate – treated water – is maintained in the operational zone of bioreactor, this water contains organic substances in the form of complex organic compounds presented by colloidal formations, under this process constant extraction of metabolism products of microorganisms, excesses of biomass, must be maintained as well. If a flow of treated water evenly and proportionately passed through a nozzle – carrier, where the microorganisms are placed, as the result of their metabolism the processes of biotransformation of organic compounds take place, in particular their destruction and mineralization.

Optimal conditions for metabolic activity of immobilized microorganisms in bioreactors can be created by application of net carriers with an extended surface, the structure of such an equipment has been developed by Far Eastern Scientific Research Institute of Hydrotechnics and Land Development. In these biocatalysts equal flowage is maintained in the operational zone of nutritious substrate – treated water containing organic substances, automatic discharge of excesses of biomass and simplified regeneration of nozzle are also properly maintained.

The mechanism of complex organic compounds decomposition with involvement of microorganisms is quite complicated and, in particular, it can be explained by the fact that certain microorganisms use organic part of the molecule or energy from transformation reaction of such compounds in order to support their life activity. This is proved by the research, which has been made in recent years, and what is quite important to mention is that iron-deposing bacteria, which are quite widely spread in natural waters, have been discovered to belong to the group of heterotrophic organisms, even though they are mistakenly referred to as autotrophs. During the metabolism process, such organisms use the organic part of complex compounds for support of their life activity, at the same time, some metabolism products are used for destruction of molecules of these compounds, and for instance, it is possible to use hydrogen peroxide, which allows significant “saving” of energy for facilitation of this process.

It is possible to organize the regulation of microbiome species composition in bioreactors with the aim decreasing the risk of development of pathogenic and potentially pathogenic microflora by means of administration of microbiological agents, which include strains of only non-pathogenic types, such as, for instance, “AQUA-EM-1”, produced in Primorskiy Region, into treated water. Alongside with this, it is necessary to establish their numerical advantage, which will allow suppressing the competitive species, including pathogenic and potentially pathogenic microorganisms. It is vital to notice that biotransformation of DOS with microorganisms’ involvement takes place on the molecular level and, as considered, the speed of reaction of such processes is significantly (at a far quicker rate) higher in comparison to physical and chemical methods of destruction.

Preliminary water treatment in storage reservoir [6] has certain advantages as generated sedimentation stays in the reservoir and does not enter water treatment facilities. Such a method of water treatment is possible by means of administration of biological agent directly into water body with their equal distribution across water surface or under water flowing though bioreactors, which can be placed, for instance, in an entry of a river with drinking water. In free volume after administration of microbiological agent, the process of DOS destruction becomes significantly slow, which is especially noticeable with low level of water turbidity, and which is proved by the results of the research conducted at a full-scale body.

The studies aiming at decreasing of DOS with the help of the agent “AQUA-EM-1” took place at the pond, artificially constructed for recreational purposes, in one of the residential areas of a town Luchegorsk (Primorskiy Region) [5, 13]. The pond has a form of a low flow water body with depth of up to 1.5 m and total volume of up to 3.2 thousand m³. For a long period of time during warm seasons water in the pond demonstrated an excessive color index around 50-60 degrees Pt/Co, which signified about the presence of dissolved organic substances in water, also there was an odor up to 4-6 points. The agent “AGUA-EM-1” with total volume of up to 200 liters was administered on one-off basis
with relatively equal sprinkling over the surface of the pond. Simultaneously with the agent, the clay balls were dispersedly placed into water, the clay balls are widely used in world’s ecological practices for deodorization and in order to decrease the color index of water. As a part of conducted experiment 230 clay balls were placed into the pond (approximately 1 ball for every 10 m²), which is about 20 times less than the standard amount set by practice. Clay ball, or EM-mudballs, are made of clay mixed with microbiological matter with addition of molasses (nutritious product), non-pathogenic microorganisms, contained in “AQUA-EM-1”, intensively develop inside the balls. After placement of clay balls into aquatic environment, they become a long-lasting source of microorganisms capable of ensuring proper destruction of DOS.

In the course of the experiment low concentration of colloidal matters (up to 24 mg/l), low amount of microbiological agent (up to 8,2·10⁻⁴ %) for total volume of water in the pond and low number of clay balls were administered into water. It was expected that intensity of discoloration, or destructive influence on DOS, which determine the coloring of water, must be quite low. Measurement of color index of water after administration of the agent demonstrated that only after 30-60 days the color index decreased to 10-20 degrees Pt/Co (fig. 8). For comparison, there is a graphic of color index of the same season (July-August) of 2017, when the agent was not administered and the color index remained relatively high during the whole warm period of the year.

The results of the experiment have proved that with proper justification of rules and regulation, as well as dosing of microbiological agent, it is quite possible to implement preliminary treatment of water directly in a water storage reservoir. In this regard, it is possible to facilitate biotransformation of organic compounds and decrease the risk of development of pathogenic and potentially pathogenic microflora. It is necessary to mention that even though the concentration of the agent “AQUA-EM-1” was rather low, it was possible to notice quite high effectiveness in decreasing number of DOS, even if to judge solely by number of substances that are involved in coloring of water. It also essential to mention the effect of deodorization of water in the pond, which was determined by the fact that after 20-30 days the level of odors turned out to be twice lower and had fallen from 4-5 to 2 points.

Interaction of microorganisms with DOS within the limits of the storage reservoir capability (in free volume) ensures the emission and accumulation of sediments in its near-bottom part. Species composition of microbiome of bottom sediment also has special significance as it influences greatly on the processes of destruction of DOS, which are present in water. With this in mind, it is important to say that possibility of pathogenic bacteria and viruses entering the waters must be excluded. If a bottom sediment in a water body has a high content of microorganisms and concentration of DOS, more available nutritive substances, in water is higher than in the sediment, it can turn into “supplier” of these microorganisms into aquatic environment.

![Figure 1. Changing of color index of water in the pond in the town of Luchegorsk after the administration of microbiological agent “AQUA-EM-1”](image-url)
It is possible to influence the content of bottom sediment microbiome and form a non-pathogenic microflora in it, for instance, by placing clay balls, made with addition of agent “AQUA-EM-1” (EM-mudballs), into water. By doing this the quantity and microbiological species composition of bottom silt can be regulated, and the risk of bacteriological contamination of water with pathogenic species can be decreased. Moreover, as the results of the experimental studies showed, in the number of water bodies of Primorskiy Region bottom sediment starts to self-tighten mainly as the result of release of attached water, which in turn happens as the result of destructive influence of microorganisms. The thickness of silt layer can decrease and become 4-6 times weaker.

It is highly important to define the way of characterization of DOS transformation regime. If organized in bioreactors and in water storage reservoirs it can be characterized as nonstationary, as some of the parameters change in a course of time. Application of this regime can be followed by certain difficulties in calculation of main operational characteristics. These characteristics may include the necessary quantity of non-pathogenic microorganisms present in bio agent, which is administered at the stage of preliminary treatment of water containing DOS and various forms of bacteria, including pathogenic ones. As it was mentioned before, the relevance of this activity is dictated by the fact that it is vitally important to regulate the species composition of microbiome and to eliminate the risk of development of pathogenic microbial flora in water, which is going to be delivered into treatment facilities. Other essential characteristics are permissible speed of treated water flow and contact time of microorganisms from the agent and treated water.

Species composition of microbiome and the number of microorganisms ($C_M$), for instance, biomass, per unit volume of apparatus (bioreactor or water storage reservoir) depend on wide variety of factors. Mainly they depend on nutritive value of substrate – on concentration of DOS in water ($C_{DOS}$) and on form of these substances ($A_{DOS}$), on the temperature ($t$), concentration of hydrogen ions ($pH$), scale of water muddiness ($M$), on speed of the flow ($V$), duration of interaction – time of contact ($T$) of DOS with microbiologically active environment. It is also necessary to take into consideration the significance of reactors’ volume ($W_p$) and their geometrical parameters as they determine the intensity of blending of products and impurities, direction of the flows and displacement conditions, moreover, some other minor characteristics of bioreactors have a significant value as well. Significance of the above-mentioned factors may vary depending on the type of bioreactors and conditions of their placement, the mechanism of reaction may be demonstrated by the functional dependence presented in the following way:

$$C_M = f \cdot (C_{DOS}, A_{DOS}, t, pH, M, V, T, W_p). \quad (1)$$

In theory of reactors the mechanism of reaction is usually considered as identified, therefore the formal kinetics is applied, so despite of the fact that in our case the process of biotransformation of DOS can not be considered sufficiently studied we will have to examine this process based on models with taking into account macro-kinetic assumptions about biochemical reactions. Also, we will have to keep in mind a range of factors, which are usually not paid attention to in the kinetics, but which are related to a reaction behavior in the volume of reactor, in particular, versatile interactions of competitive antagonistic microorganisms. The conducted experiment enables us to determine that in water storage reservoir (or in the pond) the processes mainly take place in free volume, and after placement of clay balls on the bottom non-pathogenic microorganisms constantly find their way into the water body, which works as a bioreactor with fitful regime of operation. Functional dependence (1) and analyses of the results of the experiment allows making only preliminary conclusions that selected approach to solving the problem of DOS destruction and managing of qualitative composition of microbiome is quite relevant in the practices of water processing and preliminary water treatment.

In particular, it is necessary to define main estimated characteristics and optimal dozes of microbiological agent necessary for destruction of DOS and moderation of species composition of microbiome in reactors and water storage reservoirs. It is known that non-linear nature of these systems is the main reason of choosing numerical techniques as a preferable solution. Widely
applicable in quantitative microbiology mathematical modeling, with regard to variable concentration of DOS in substrate (source water), and proper analysis combined with use of systems of differential equation will allow us to justify all main conditions of application of proposed preliminary water treatment technique.

4. Conclusions
Analysis of the results of conducted studies allows us to conclude that for the proper organization of treatment of natural waters containing DOS it is necessary to consider important features related to danger of preliminary chlorination. This danger appears due to two main reasons. Firstly, it is determined by the fact that chlorine agents form complex organic compounds, which are resistant to destruction. Secondly, building into the structure of complex molecules of DOS chlorine agents lose their disinfecting capacity and their antiseptic potential decreases dramatically. Developed during water treatment process toxic and carcinogenic substances, as well as bacteriological products, can often be more dangerous than familiar natural pollutants of water bodies.

In this situation, chlorine-organic compounds can be present in treated water during the whole process of water treatment in colloidal state. Moreover, they appear to be toxic substances and chlorine agents almost do not demonstrate any capability of destruction of colloids with low molecular weight. Thus, after preliminary chlorination, the conditions for water discoloration deteriorate significantly and new problems, which are related to presence of toxic and hazardous for human health compounds in water, appear.

If water contains DOS, which possesses nutritive value for microorganisms, we can notice an active populating of this environment by various species of bacteria, and, as the result, competitive battle between these species and mutagenic qualities of microflora lead to formation of microbiota with unpredictable content and degree of danger in water. Therefore, it is unacceptable to allow the presence of DOS during water purification already at the stage of sedimentological treatment, it means that it is crucial to enhance the technique of water treatment itself and to organize preliminary water treatment procedure before prechlorination with the highest possible level of DOS elimination.

It is possible to ensure the destruction of DOS and moderation of species composition of microbiome in bioreactors at the stage of preliminary water treatment with the aim of elimination and mineralization of organic substances by administration of microbiological agents, which include strains of only non-pathogenic types, into water. It will also allow decreasing of risk concerning development of pathogenic and potentially pathogenic microflora in aquatic environment.

Application of biocatalysts with immobilized microorganisms for treatment of natural, in particular, high color index waters containing DOS, at the first stage of their treatment will allow achieving significant economic benefit due to decrease in operating expenditures. Such a method of preliminary water treatment, which includes the capacity to mineralize organic compounds, will ensure lowering of coagulant doses used for sedimentation and discoloration and will improve the work of filters or clarifiers as the result of increase of sorption effect of mineralized pollutants. It will also extend the life duration of water supply and distribution systems by decrease of intensity or by total elimination of bio-corrosion in pipelines, and well as will facilitate the improvement of organoleptic properties of water due to absence of toxic chlorine-organic compounds and other ingredients related to application of excessive doses of coagulant.

5. References
[1] Voitov E L 2012 Purification of low turbidity natural waters with high content of organic compounds for drinking water supply: Extended abstract of the thesis Doctor of Engineering Sciences (Novosibirsk)
[2] Voitov E L 2004 Purification of low turbidity river waters with high water color index Water supply and waste water disposal: quality and efficiency: Proceedings of VII International Research-to-Practice Conference (Kemerovo) p 42
[3] Voitov E L, Skolubovich Y L 2013 Improvement of purification efficiency of river waters with high content of organic compounds Bulletin of higher education institutions. Building and Construction 6 pp 64-75

[4] Volkov S V, Kostuychenko S V, Kudryavtsev N N, Gilbukh A Y, Smirnov A D 1996 Prevention of formation of chlorine-organic compounds in drinking water Plumbing and Water supply 12 0321-4044 pp 11-12

[5] Golovin V L, Popova T Y, Medved P V, Tkach N S 2017 Opportunities to use microbiological methods for decoloration of natural waters The problems of land development and water management in the Russian Far East: Collection of studies of the Far Eastern Scientific Research Institute of Hydrotechnics and Land Development (Vladivostok: Dalnauka) Edition 19 pp 89 – 103

[6] Koryaikina A V, Selivamov A S 2009 Biological methods of pretreatment of natural waters from surface sources with the aim of drinking supply under conditions of the North-West of Russia Natural and engineering sciences 1(39) pp 361-370

[7] Koryaikina A V 2010 Biological methods of drinking water treatment under the conditions of the North-West of the Russian Federation (at the example of Karelia) Extended abstract of the thesis of Doctor of Engineering Sciences (Saint-Petersburg)

[8] Kudryavtsev N N, Kosyuchenko S V, Zaytsev S G, Tulakin A V, Tsypalanova G V 2009 Estimation of possibility of side products development as the result of ultra-violet sterilization of drinking water Plumbing and Water supply 6 pp 41-46

[9] Nikitin A M, Kurbatov P V 1999 Certain aspects of purification of low turbidity waters with high water color index Plumbing and Water supply 3

[10] Golovin V L, Marchenko A Y Method of purification of underground waters from persistent forms of iron Patent RF № 2161594; IPC 7 с 02 f 1/64, 3/34 № 99102891/12 applied 15.02.99 published 10.01.2001 1

[11] Husmann S 1966 Versuch einer ökologischen Gliederung des interstitiellen Grundwassers im Lebensbereich eigener Prägung Archiv für Hydrobiol 62 H

[12] Boon J, Vigo C, Boon T et al 2019 Per and polyfluoroalkyl substances in source and treated drinking waters of The United States Science of the Total Environment v. 653 pp 359-369

[13] Popova T, Golovin V, Medved P 2020 Microbiological Treatment of High-Coloring Natural Waters International science and technology conference "FarEastCon-2019" IOP Conf. Series: Materials Science and Engineering 753 052042