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Side Effects of Byproducts from Different Types of Water Purifying Agents on Water Bodies, Their Properties, and Solutions

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Abstract:

Water purifying agents, as materials used to improve water quality and remove impurities and pollutants from water, play a significant role in drinking water safety, environmental protection, modern industrial operations, and water resource supply. However, while improving water quality, these agents may generate some byproducts. A small portion of these byproducts are identified as harmless, but the majority may have side effects on water bodies. For instance, it can cause the proliferation of microorganisms in water bodies, releasing toxic and harmful substances that may directly or indirectly negatively impact human health, such as chronic poisoning ,weakened immunity, and may even lead to cancer and neurological damage .However, its by-products can be eliminated through certain chemical or physical means, thereby reducing the potential side effects they may cause .This article adopts a review approach to explore the hazards, properties, and solutions related to the byproducts of most common water purifying agents.

Keywords: Water purifying agents; water resources; disinfection byproducts (DBPs); sewage purification; industrial water purification.

1. Introduction

Water purifying agents are materials that remove impurities, microorganisms, and pollutants from water through methods such as adsorption, coagulation, and flocculation. They play a crucial role in modern industries, agriculture, daily life, and food and beverage water usage. Unlike water purifiers, water purifying agents are unstructured single mixtures that do not require water to pass through a membrane for purification. They can be broadly dispersed to purify large water bodies. As such, they are widely used for preliminary or rough treatment of water bodies, as well as for sterilizing and removing harmful substances from natural water bodies not intended for drinking.

However, different types of water purifying agents may produce various byproducts during use [1]. These byproducts may possess specific chemical properties and even exhibit certain reactivity. Consequently, they can negatively impact water sources, equipment, and the environment biologically and chemically, such as by promoting microbial growth in water bodies, causing equipment corrosion, and releasing toxic and harmful substances [2]. In the context of healthcare and environmental safety, numerous reports indicate a positive correlation between water purification byproducts and diseases.

Currently, most byproducts of water purifying agents can be neutralized through combined treatment with other agents. The varying properties of water purifying agents lead to differences in the causes and mechanisms of byproduct hazards. Therefore, summarizing the hazards of these byproducts and providing their causes, avoidance strategies, and solutions is valuable for environmental protection and water resource safety. The goal of this article is to classify byproducts based on their hazard mechanisms and produce a report covering the hazards, properties, and solutions for byproducts of most common water purifying agents.

Byproducts are categorized into three types based on their negative impacts and mechanisms: nano-metal residues, metal ion residues, and halogenated organic compounds. Their corresponding hazards include bacterial proliferation, corrosiveness, oxidizability, water hardness, and carcinogenic risks. Solutions include timely maintenance and cleaning; limiting dosage; avoiding use in drinking water purification; and implementing pretreatment and filtration.

2. Nano Zero-Valent Metal Water Purifying Agents

Nano zero-valent metal water purifying agents refer to zero-valent metals with particle sizes ranging from 1 to 100 nanometers, including zero-valent iron, zinc, copper, and aluminum. These materials efficiently remove various pollutants from water through their unique physical and chemical properties. With their large specific surface area and high reactivity, they effectively degrade or remove organic pollutants (e.g., chlorinated organic compounds, dyes, antibiotics, pesticides), inorganic pollutants (e.g., heavy metal ions), and pathogenic microorganisms through mechanisms such as adsorption, reduction, co-precipitation, and catalytic oxidation.For example, nano zero-valent iron exhibits strong reactivity and reducibility, naturally releasing electrons in water to effectively kill microorganisms and decompose organic matter. It is highly effective in transforming halogenated organic compounds, chlorinated hydrocarbons, and dyes [3]. Since the early 1990s, nano zero-valent iron has been used to degrade groundwater pollutants. Compared to larger iron particles, nano zero-valent iron has a larger active surface area, enhancing its reaction with pollutants for degradation.

2.1 Potential Danger

Potential byproducts include unreacted nano zero-valent metals and metal ions. Unreacted nano zero-valent metals may enter surface water through groundwater discharge, coming into contact with aquatic organisms and causing harm [4]. Nano zero-valent iron may cause neurotoxicity in neurons of rodents (Phenrat et al., 2009). Its antibacterial activity and cytotoxicity may lead to cell membrane damage, lipid peroxidation, and DNA damage (Stohs and Bagchi, 1995; Valko et al., 2005). Chen et al. investigated the effects of nano zero-valent iron on medaka fish. The results showed that the solution had significant toxic effects on medaka larvae, including increased acute mortality and sublethal toxic effects such as disrupted oxidative balance, intestinal damage, and inhibition of antioxidant enzymes (e.g., catalase). Lethality occurred at concentrations exceeding 100 mg/L. Keller et al. studied its effects on Daphnia, revealing that zero-valent iron had extremely negative impacts on Daphnia upon direct contact.

2.2 Solution

Potential byproducts include unreacted nano zero-valent metals and metal ions. Unreacted nano zero-valent metals may enter surface water through groundwater discharge, coming into contact with aquatic organisms and causing harm [5]. Nano zero-valent iron may cause neurotoxicity in neurons of rodents (Phenrat et al., 2009). Its antibacterial activity and cytotoxicity may lead to cell membrane damage, lipid peroxidation, and DNA damage (Stohs and Bagchi, 1995; Valko et al., 2005).Chen et al. investigated the effects of nano zero-valent iron on medaka fish. The results showed that the solution had significant toxic effects on medaka larvae, including increased acute mortality and sublethal toxic effects such as disrupted oxidative balance, intestinal damage, and inhibition of antioxidant enzymes (e.g., catalase). Lethality occurred at concentrations exceeding 100 mg/L. Keller et al. studied its effects on Daphnia, revealing that zero-valent iron had extremely negative impacts on Daphnia upon direct contact.

3. Salt-Based Coagulation/Flocculation Water Purifying Agents

These agents work by generating charged colloids after hydrolysis, such as positively charged aluminum hydroxide colloids, which neutralize negatively charged suspended particles or other colloids in water, destabilizing and

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aggregating them. Examples include aluminum sulfate, alum (potassium aluminum sulfate), ferric chloride, and ferrous sulfate.As simple-to-prepare and versatile water purifying agents, they hold significant importance in areas where modern water treatment technologies are unavailable, such as remote regions, and were crucial before the advent of modern water treatment plants. They greatly reduce the risk of waterborne diseases (e.g., cholera, typhoid, dysentery) and are used as portable water purification methods by military forces. In summary, they have played a vital role in public health history.

3.1 Potential danger

The primary byproducts of these agents are metal ions (e.g., aluminum ions, iron ions), as they rely on the charge of metal salt colloids for adsorption. The main threats include potential disruption of ecological balance, water discoloration, and proliferation of iron bacteria. Additionally, ingestion of aluminum ions may interfere with calcium-phosphorus metabolism, affect bone health, or cause anemia and neurological decline. Regular aluminum intake can lead to elevated aluminum levels in urine, serum, and bones. For example, workers in the aluminum industry may exhibit adverse neurological symptoms. Epidemiological studies have reported associations between occupational aluminum exposure and neurological disorders, though these studies are limited due to complex exposure scenarios and confounding factors.Aluminum can act as a pro-oxidant under certain conditions, leading to lipid peroxidation and reduced antioxidant enzyme activity. It inhibits sodium-potassium ATPase, generates reactive oxygen species, and causes damage to liver cells, mitochondria, and DNA. In the brain, it can lead to neurodegeneration through various mechanisms, and in bone marrow, it may cause osteomalacia and anemia. It also affects gene transcription, iron homeostasis, and can induce apoptosis in cortical neurons. Aluminum exposure in drinking water has been linked to neurological disorders, though evidence for causality is inconclusive [6-8]. Iron ions have fewer negative effects on the human body compared to aluminum ions but can still cause issues such as water discoloration. If ferrous ions (Fe^{2+}) are present, they may promote the growth of iron bacteria, contaminating the water [9].

3.2 Solution

Solutions include limiting dosage, avoiding use in drinking water purification, enhancing filtration, and monitoring metal residues. Adjusting water acidity and adding corresponding ions to form low-solubility precipitates can also help. Studies show that nanofiltration or ultrafiltration combined with coagulation can effectively remove metal ions from drinking water.

4. Oxidizing and Halogen-Containing Water Purifying Agents

These agents work by: Oxidizing agents: Decomposing organic matter (e.g., pesticides, humic substances), killing microorganisms (bacteria, viruses), or transforming toxic substances (e.g., oxidizing arsenic and manganese from low to high valence states for easy precipitation). Halogen-containing agents: Generating halogen acids (e.g., hypochlorous acid (HOCl), hypobromous acid (HOBr)) or oxidizing halogens (e.g., chlorine dioxide) upon dissolution. These active components penetrate the cell membranes of microorganisms, oxidizing and destroying their enzyme systems, proteins, or nucleic acids, thereby inactivating them [10].

4.1 Potential Danger

The main threat is the generation of halogenated organic compounds directly or indirectly through oxidation, such as trihalomethanes (THMs) and haloacetic acids (HAAs) [11]. This is particularly common when disinfectants are not used in excess.For example, THMs primarily enter the human body through drinking, inhalation, and skin contact. Long-term exposure may lead to various health issues [12]. Prolonged consumption of drinking water with high THM concentrations may increase cancer risk, particularly bladder, rectal, and colon cancer. For instance, chloroform may form highly reactive intermediates—phosgene—in the human body. Phosgene is a strong acylating agent that can covalently bind to macromolecules such as proteins and DNA, causing cell damage and mutation, leading to carcinogenesis. Thus, chloroform is classified as a Group 2B carcinogen [13]. Exposure to high THM concentrations during pregnancy may lead to adverse outcomes, such as spontaneous abortion and fetal malformations. Danielle N. Medgyesi's study in U.S. communities showed a positive correlation between halogenated methane levels in domestic water and cases of kidney function defects, indicating that long-term THM exposure may impair kidney function [14]. The mechanism involves high doses of THMs (especially chloroform) causing liver cell necrosis, fatty degeneration, and abnormal liver function. Similar to carcinogenic mechanisms, reactive intermediates (e.g., phosgene) can break liver cell membrane structure and function. Additionally, akin to the neurotoxicity of many volatile organic solvents, acute high-concentration inhalation of THMs can depress the central nervous system, causing symptoms such as dizziness, drowsiness, and coma.Haloacetic acids, for example, exhibit cytotoxicity, genotoxicity, mutagenicity, and teratogenicity. Studies show that haloacetic acids inhibit the activity of glyceraldehyde-3-phosphate dehydrogenase (GAPDH), interfering with cell metabolism and energy homeostasis. Long-term exposure to haloacetic acids may increase cancer risk [15].

4.2 Solution

Numerous solutions exist, such as simple boiling, as some halogenated organic compounds (e.g., THMs) have low boiling points and can separate from water upon boiling. Some halogenated organic compounds are volatile; air can be bubbled through water to transfer them from water to air, followed by exhaust gas treatment. Similarly, other water purifying agents can be used for pretreatment to reduce organic matter content, thereby minimizing the generation of halogenated organic compounds. For example, coagulants can remove macromolecular organic matter like humic and fulvic acids; granular activated carbon filters can adsorb organic matter; and ultrafiltration or nanofiltration membranes can keep organic matter. Ultraviolet light combined with hydrogen peroxide or other oxidizers can also break down these compounds into harmless small molecules through highly oxidative hydroxyl radicals.

5. Conclusion

While water purifying agents serve as essential materials for water treatment, they generate byproducts that may pose various environmental and health risks. This article categorizes common byproducts into three types based on their negative impacts and mechanisms: nano-metal residues, metal ion residues, and halogenated organic compounds. Their corresponding hazards include biological toxicity (nano-metal residues), water hardness and long-term consumption leading to diseases (metal ion residues), and health risks such as carcinogenicity (halogenated organic compounds).

Solutions involve using other water purifying agents in combination, limiting dosage, avoiding use in drinking water purification, enhancing filtration and metal residue monitoring, and implementing pretreatment methods such as permanganate pretreatment, biological (microbial) pretreatment, enhanced coagulation and sedimentation, granular activated carbon filtration, biological activated carbon, membrane filtration, and ultraviolet light combined with hydrogen peroxide or other oxidizers.

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