

1. Introduction

Water is one of the most essential companions of life on earth. During the phases of creation, evolution and continuity of life on earth, water remained as its most vital component. The molecular as well as macromolecular functions of making life possible are carried out using water. The earliest form of life appeared in sea water about 3.5 billion years ago and was transferred to land only 380 million years ago. Despite this transfer to land, an ocean, in terms of fluidic composition, continues to exist within us. Similarly, keeping a very high proportion of living organisms body weight as water (~70%), nature has iterated the vitality of water for life. It is very appropriate to state that existence of life on earth is largely owed to the presence of water. Water is vital to us, both as a universal solvent as well as being an important component of metabolic processes within the body. Clean and fresh water is essential for the existence of life as quoted by William Beloe (London, 1830). The evolution of civilization has always revolved around water signs of prosperity, health, serenity, beauty, artistry, purity and many other attributes.

1.1. Waste water treatment

Although disinfection methods currently used in drinking water treatment can effectively control microbial pathogens, research in the past few decades have revealed a dilemma between effective disinfection and formation of harmful disinfection by-products (DBPs). Chemical disinfectants commonly used by the water industry such as free chlorine, chloramines and ozone can react with various constituents in natural water to form DBPs, many of which are carcinogens. More than 600 DBPs have been reported in the literature. Considering the mechanisms of DBP formation, it has been predicted that DBPs will be formed any time chemical oxidants are used in water treatment. Furthermore, the resistance of some pathogens, such as *Cryptosporidium* and *Giardia*, to conventional chemical disinfectants requires

extremely high disinfectant dosage, leading to aggravated DBP formation [1]. Therefore, there is an urgent need to re-evaluate conventional disinfection methods and to consider innovative approaches that enhance the reliability and robustness of disinfection while avoiding DBP formation.

Contemporary advances in nanotechnology offer enormous opportunities to develop next-generation water supply systems. Our current water treatment, distribution, and discharge practices, which heavily rely on conveyance and centralized systems, are no longer sustainable. The highly efficient, modular, and multifunctional processes enabled by nanotechnology are envisaged to provide high performance, affordable water and wastewater treatment solutions that less rely on large infrastructures. Nanotechnology-enabled water and wastewater treatment promises to not only overcome major challenges faced by existing treatment technologies, but also to provide new treatment capabilities that could allow economic utilization of unconventional water sources to expand the water supply. The rapid growth in nanotechnology has spurred significant interest in the environmental applications of nanomaterials. In particular, its potential to revolutionize century-old conventional water treatment processes has been enunciated recently.

Nanomaterials are excellent adsorbents, catalysts, and sensors due to their large specific surface area and high reactivity. More recently, several natural and engineered nanomaterials have also been shown to have strong antimicrobial properties, including chitosan, silver nanoparticles (nAg), photocatalytic TiO₂, fullerol, aqueous fullerene nanoparticles (nC60), and carbon nanotubes (CNT). Unlike conventional chemical disinfectants, these antimicrobial nanomaterials are not strong oxidants and are relatively inert in water. Therefore, they are not expected to produce harmful DBPs. If properly incorporated into treatment processes, they have the potential to replace or enhance conventional disinfection methods [2].

Another potential application of antimicrobial nanomaterials is their use in decentralized or point-of-use water treatment and reuse systems. The concept of decentralized or distributed water treatment systems has attracted much attention in recent years due to concerns on water loss and quality deterioration associated with aging distribution networks and the increasing energy cost to transport water, as well as the increasing need for alternative water sources and wastewater reuse for areas with water shortage problems and national security issues [3]. It is envisioned that functional nanomaterials, including those with antimicrobial properties, can be used to build high-performance, small-scale or point-of-use systems to increase the robustness of water supply networks, for water systems not connected to a central network, and for emergency response following catastrophic events.

The origin of chemical reactivity for metals is related to their standard reduction potentials. Metals are usually electropositive and have a tendency to lose electrons depending on the corresponding ionization energy. Reduction potential is thus correlated with the electro positive nature of the metals i.e. a metal with high electropositive nature is likely to exist as an ion in the solution phase and thus is a strong reducing agent. Nanomaterials are typically defined as materials smaller than 100 nm in at least one dimension. At this scale, materials often possess novel size dependent properties different from their large counterparts, many of which have been explored for applications in water and wastewater treatment. Some of these applications utilize the smoothly scalable size-dependent properties of nanomaterials which relate to the high specific surface area, such as fast dissolution, high reactivity, and strong sorption. Others take advantage of their discontinuous properties, such as super paramagnetism, localized surface plasmon resonance, and quantum confinement effect. These applications are discussed below based on nanomaterial functions in unit operation processes. Most applications discussed below are still in the stage of laboratory research.