ISSN 2229-5518

Utilizing Bulk Nanostructured Materials for Low-Cost Water Treatment: Prospects and Challenges

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***Abstract*—** Delivering hygienic and cheap water to satisfy the basic human demands is an enormous task of the current era. The task of water supply is striving to sustain the rapid Increase in demand; and this is aggravated by water quality deterioration, population development, worldwide climate variation and other factors. The necessity for technological improvement to allow cohesive and affordable method(s) of water treatment for the majority of human populace cannot be overemphasized. Nanotechnology possesses immense potential in improving water treatment effectiveness and also to boost water stock via the use of alternative sources. Thus, in this paper current methods for water treatment using nanotechnologies are reviewed with emphasis on nanofiltration in order to achieve the desired goals at minimal cost. The discussion emphasizes on nanomaterials and procedures that facilitate their usages taking into consideration their advantages and limitations as compared to existing water treatment processes. Case studies of specific products for water management centered on nanotechnology are highlighted in order outline the prospects and limitation.

Keywords*—water treatment; nanotechnology; nanocomposites; nanoporous filter.*

I. Introduction

Clean, portable and affordable water for all purposes – humans and animals, agriculture, industry – is an essential need of life. Nevertheless, only about 1% of the worldwide source of water is accessible and harmless for human drinking [1]. Available data indicates about one billion people have no and/or limited access to hygienic water [2]. The deficiency of a clean water supply not only disturbs human health, but contaminated water from human waste, runoff and chemical pollution is especially harmful, and millions die each year (mostly children) from waterborne diseases contracted from unsafe water sources [1].

Furthermore, it’s not possible to state whether water is medically safe for drinking by only visual inspection, as the contaminants can be very tiny even to be on the micro- and/or nano-scale. Conventionally, the procedures used in cleaning water for drinking/domestic purposes may be by separating solids via several physical processes such as filtration and settling, and alternative chemical methods: coagulation, disinfection etc. [3]. Purification of water involves the elimination of impurities from impure water to yield portable water for fundamental uses. Materials that are removed in the course of water treatment may contain, but not limited to, algae, viruses, fungi, hanging solids, minerals such as iron, sulfur and manganese together with other chemical impurities such as industrial wastes [4].

Nevertheless, the large-scale water treatment plants having integrated water delivery and cleansing set-ups widely used are immensely costly, and are energy consuming with high demands for chemicals and requirement for skilled personnel at various levels. It has also been proven that at some specific conditions and locations, that the integrated water treatment is not even an alternative and is replaced by other options [5]. The alternative options are more convenient in regions excessively poor or isolated to have accessibility to water from integrated treatment(s); in dwellings were an inhabitant are increasing rapidly with wide gap between demand and supply; immediately after calamities when central services are facing problems and/or shut down; or after central water supply is polluted in the course of delivery [5 – 9].

There have been many studies on the potentials of using various modes of nanotechnology to give more inexpensive, operational, well-organized and robust ways of achieving water treatment [10-15]. Specifically, nano-based techniques for water purification will ensure production that is less contaminating compared to conventional techniques and entails less workforce, investment, energy and asset. On the other hand, most of the studies conducted [16 – 21] show challenges in utilizing nanotechnology for water treatment with cost and method been topmost. As a way out, this paper highlights the option(s) for water purification that uses nanotechnology to eliminate viruses, bacteria and other impurities so as to be capable of supplying unpolluted drinking water to poor and/or rural groups at minimal with emphasis on nanofiltration.

II POTENTIALS OF NANOTECHNOLOGY IN WATER TREATMENT

In contrast to other know-hows, nanotechnology covers a widespread collection of science. Basically, nanoscience and nanotechnology encompass probing as well as controlling matter at ultra-small level. It should be noted that a nanometre (nm) represents a billionth fraction of a metre compared to an isolated human hair having a width in range of 50,000 - 80,000 nm [22]. At nanoscale, activities occur with the minutest fragments of matter, atoms and molecules, which we can be manipulated. Thus, nanotechnologies encompasses the design, classification, fabrication, and utilization of structures, mechanisms, and arrangements by manipulating form and dimensions at the nanometer level [12], leading to current and prospective applications in various areas, but not limited to, energy, defense, medical, environment and agriculture, aerospace, chemical refining [1-6].

In areas of utilization such as water filtration, constituents may either be custom-made, and/or improved, to isolate organic contaminants and heavy metals. Substances at the nano-level in most cases have diverse behaviors from similar matter at the micro and/or macro level [16]. For instance, nano TiO_2 have been proven to be more efficient catalyst than at microscale. Utilization of nanotechnology may unravel the procedural task of taking out salt from aqueous TiO_2. This may also be utilized for water management by destroying organic impurities [20]. However, synthetic nanoparticles due to their minute dimensions could cause the substances to have additional toxicity [21].

Nanostructured materials, which consist of all materials purposely fabricated having one or more lengths in nanometer scale, such as nanotubes, nanowires, nanoparticles, super lattices and quantum dots, have drawn significant interest lately which was attributed to their unique behaviors as their particle dimension reduces [20]. Conversely, the widespread application of the aforementioned nanostructured components is currently facing enormous challenges. Relatively, bulk nanostructured materials have apparent benefits when preparing huge amounts, as large configuration is consistent with commercial existing machines/tools. For clarity, nanostructured components denote certain micro/macro substances containing a minimum of one constituent having particle dimensions fewer than 100 nm. The utmost conventional methods for fabricating large nanostructured substances utilize various sintering procedures to produce bulk object materials by fusing powder precursors [23].

III CURRENT NANOTECHNOLOGIES FOR WATER TREATMENT

There is several cost and environmental impacts related to numerous existing water treatment expertise that are basically dependent on the kind of procedure exploited and on the circumstance in which is it utilized. Although there are several functioning know-hows for treating water, lots of them are costly and/or unproductive, and some evolving waste products such as drugs and body treatment goods and endocrine upsetting substances [16] are not basically detached and/or destroyed via conventional methods, signifying the necessity for options. The ability to be used several times as possessed by numerous nanoparticles ensures further potential to reduce energy utilization, boost treatment productivity, and reduce the wasteful by-products generated when using conventional treatment methods.

A. Carbon Nanotubes-Based Technologies

Carbon nanotubes (CNTs) are homogenously arranged to develop films having nanoscale apertures that are able to sieve out waste products. Their nanoscale holes give them a better advantage compared to other existing purification know-hows. Additionally, the CNTs possess widespread surface spaces, extraordinary permeability, together with reliable thermal and mechanical stability. The areas sandwiched between the CNTs may at that point be packed using a suitable ceramic matter to enhance stability to the membrane [24]. Results from some studies conducted showed that CNT films can separate nearly all categories of water impurities, comprising turbidity, viruses, bacteria, and natural impurities [25] at minimal expenses; however the task of building/assembly still exists. Another area where CNTs may utilize is a mesh at nano scale by joining them together and arranged on a flexible, porous substrate [18].

B. Nano-filtration

Nanofiltration is a thin filtration-based procedure utilizing nano-sized pores that are round-shaped. Nano-filtration films have pore sizes ranging from 1-10 nm, those smaller uses other associated techniques such as microfiltration and ultrafiltration, however those slightly bigger than that in reverse osmosis [21]. Films/membranes used are largely polymer-based. Nano-filtration have evolved over years and is commonly applied in steps for cleaning portable water, such as controlling hardening, removal of known harmful agents and tiny/micro pollutant removal. In industrial procedures, nanofiltration is used for the elimination of explicit constituents, such as colouring agents. Nano filtration is a pressure linked method, through which separation occurs, focussed on molecular size(s) of the particles concerned. Films/membranes support and/or regulate the separation. The procedure is mostly utilized for the elimination of organic materials, such as tiny pollutants. Nanofiltration films have adequate holding for specific salts. Additional uses of nano filtration are: elimination of pesticides in groundwater; ejection of heavy metals in wastewater; wastewater reconditioning; treatment of hard water; nitrates elimination etc [25]. Explicit nano-filtration products presently obtainable include Nano-alumina filters (*NanoCeram*) and Nanogravity gadgets [26].

C. Nanoporous Membranes

Nanoporous films/membranes are described by holes having diameters in the scope of nm and sub nm with the ability to separate liquid and/or gaseous mixtures. The separation of the solutions is based on difference in sizes of the constituents (mole sieving), dissimilar adsorption (adsorption selectivity) and dampening or steric hindrance. Ceramic nanoporous films/membranes are characterized by elevated mechanical, thermal and stability [18]. Examples of nanoporous membranes include: Ceramic Bio-Media, Ceramic Membrane Filter, Self-Assembled Monolayers, adsorbent resin, Polypyrrole-Carbon Nanotube Nanocomposite and others [6]. The ceramic may also be fused by means of nano-based reactants to remove biological impurities, phosphates, heavy metals for instance arsenic and lead including other waste products. Porous Ceramic films/membranes possesses about hundred times more prevailing surface area compared to other similar bio-based means. The material that is ceramic may also be handled to back inorganic films as a replacement to reverse osmosis, where in most cases organic films are utilized [25]. Filters made from ceramic materials are anticipated to become economic replacement for oil-based expensive plastics used in organic and related filters.

D. Zeolites

Zeolites are materials having adsorption property and possessing pattern arrangements that improve apertures and obtainable from geological mines or synthesized in laboratories. Synthetic zeolites are usually made from Si-Al combinations or fly ash from coal, and are utilized as sorbents in column or cartridge filters [25]. Zeolites are typically employed for the removal of metal pollutants. Natural zeolites from Hungary and Mexico indicates reduction in arsenic concentration in portable water wells to amounts acceptable by WHO [26]. Zeolites prepared via coal fly ash have the ability of adsorbing different heavy metals such as Pb, Cu, Zn, Cd, Ni and Ag present in wastewater. In certain circumstances, zeolites with fly ash is capable of also adsorbing arsenic, mercury and chromium. The quantity of water treatable by zeolites is determined by source of the material and the medium/device used. For films made of fly ash zeolites, the carbon volume considerably effects surface area and, accordingly, the adsorptive ability [27].

E. Magnetic nanoparticles

Nanoparticle materials that are magnetic possesses greater surface areas compared to their volume and have the ability to effortlessly fasten/bind with chemicals. In water treatment applications, magnetic nanoparticles removes impurities such as oil or arsenic by attracting them as does by a magnet. Some establishments are implementing such expertise and investigators are regularly disseminating new findings in this field. Magnetic nanoparticles are generally investigated as nanocatalysts and adsorbents intended for water management/treatment. Magnetic nanoparticle may ease forward osmosis, a possibly energy competent alternative to reverse osmosis [26]. Magnetic nanoparticles are engaged to produce the pressure necessary to move water through a filtration membrane/film, contrasting to reverse osmosis that is utilizing energy-input to create osmotic pressure. These films/membranes can be used for salt removal, while additional impurities may as well be separated, depending on the category of film that is active. Relevant data about cost of magnetic nanoparticles for water management/treatment is not easily obtainable, however reviews indicates that the life span in addition to recycling of the material renders it to be more cost effective in comparison to reverse osmosis [27].

IV EXAMPLES OF DEVELOPED NANO-BASED WATER TREATMENT PRODUCTS

There are many possible nanotech-enhanced water treatments such as *Lifesaver bottle* (ultrafiltration membrane), *Seldon Technologies Water Stick and Water Box* **(**Nanomesh filter), *Electrochemical Carbon Nanotube Filter* and others [25] have been developed and marketed. Despite their advantages, they are relatively expensive when compared to financial capacity of millions in developing countries. As a way out, some cheaper products for nano-based water treatment are enumerated below:

A. Ceramic filter(MadiDrop)

This is a tablet made from ceramic material for water purification and is simple as created at University of Virginia mainly from impregnated Ag or Cu nanoparticles. It has been used to repetitively purify water for up to six months basically by laying in a container/vessel where water is dispensed. It was built for use in populations in South Africa having minimal or not at all contact to hygienic water. A filter is be able to service a family of comprising of 5-6 members for a period of 2-5 years. The ceramic filters are prepared using available indigenous clay, sawdust together with water. The layout permits a user to transfer water from an impure source, such as a well and/or a river, into the pot and permitting it to filter through into a 5-gallon container below. The pot is having a flow rate of 1-3 liters per hour, which is enough for cooking and drinking for an average family. The cleaned water is retrieved through a plug in the container [28].

B. Nanofiltration Device

During research at an Institute in Indian, a nanoparticle water filtration system worth equivalent of $16 was built capable of producing clean water for low income earners locally and in other countries living at similar economic level. Though inexpensive filtration set ups have been built earlier, this design is the pioneer one to merge high capacity killing of microbes together with the capability to eliminate chemical pollutants such as arsenic and lead. Since the filters for chemicals and microbes are distinct parts, the set-up is capable of been adapted to purge water of chemical pollutants , microbial contaminants, and/or both, subject to needs of the end users [29]

C. Nanoporous filter

Water filters made from ceramics have been built for processing of drinkable water in both rural and urban populations. These filters utilizes ceramics with pores that have micro- and nano-sizes within the range of microbes (bacteria, fungi, algae, protozoa) from biologically contaminated water. Novel approaches are also being explored for the removal of viruses and chemical contaminants (fluoride) from water. Recent work at a University in Nigeria has studied the flow through these ceramic water filters. Banks of water filters have also been assembled to produce sufficient potable water for rural/urban communities. These are being tested in ongoing studies [30].

D. Customized Water Filter

Notwithstanding the nearness of Tanzania's to three main lakes, nearly half of its people do not have access to clean water. Well water is repeatedly the alternate, but the source is not constantly uncontaminated. Wastes from mining sites/deposits and contaminated drainage set-ups may outflow into fresh well/ground water, making the water contaminated. The *Nanofilter* has been developed to soak up contaminants available in a particular pool of water – whether it is minerals like Cu and others – to biological impurities like bacteria or contaminants such as insecticides. The built *Nanofilter* has earned the African innovation prize from the UK's Royal Academy of Engineering for "……. it is customized. The filter can be tailored for specific individual, household and communal use" [31]

V. LIMITATIONS ON THE USE OF NANOMATERIALS/NANOTECHNOLOGY FOR WATER TREATMENT

1) To be useful, technology transfer need to be together with technology adaptation and adoption to suit the technical expertise, organization and market potential of the emerging/developing country that desires the knowledge and/or skill. Distinctive approaches may be desired for each developing nation having independent arrangements of socioeconomic way of life. Conversely, access to drinkable water is a worldwide predicament that entails a determined striving from all stakeholders. This requires resources, expertise (nano and others) and operational adaptation and adoption policies that are intensely built on knowledge/skill sharing in addition to indigenous capacity growth.

2) Right from inception, the extreme high cost of nano-based filters has been counted as a foremost obstacle to water treatment usages [32]. Currently, for instance the value of carbon-based nanomaterials such as nanotubes has been significantly lowered, nevertheless it is still worth thousands of dollars/kg [11], which is still comparatively too expensive in relation to other low-priced materials used as adsorbents, such as activated carbon.

3) Several studies conducted to quantify the toxicity associated with carbon-based nanomaterials indicates challenging effects on human and related animal cells [14]. As detected in the studies, nanomaterial size, form, dosage, and contact time played significant task on the human and environmental consequences of these nanomaterials. Although several of the outcomes are encouraging, much demanding exertion need to be done so as to regulate the uses of identified nanomaterials for water management/treatment.

4) There are several restrictions on the analytic tests to be conducted on various aspects of nanomaterials in relation to water management/treatment. Whereas methodology for finding of CNT has gathered substantial consideration, inadequate investigation have not been much conducted and/or available specifying procedures for revealing of latest materials.

VI. CONCLUSION

Nanotechnology for water treatment has widespread potential and is securing impetus internationally. The exclusive features of nanomaterials and their incorporation with current water treatment know-hows offer ample potentials. Notwithstanding some of the nanotechnologies highlighted in this review are still in the initial research phase, some have already reached pilot testing or even commercialization stage. Amongst them, three classes point toward widespread usage due to current achievements at various levels: nanophotocatalysts, nanoadsorbents, and nano-enabled membranes. All aforementioned categories have developed commercial outcomes, but not at enormous and/or extensive range water treatment. The difficulties faced when using water treatment nanotechnologies are substantial, but some of these challenges may be regarded as short-term, such as technical difficulties, excessive cost, and possible ecological and human risk. In order to overcome these impediments, collaboration amongst research institutions, industry, government, and other relevant stakeholders is crucial. Accordingly this may imply that enhancing nanotechnology by practical targeting affordable products/systems and significant population at the same time avoiding unplanned after-effects may continuously offer dynamic resolutions to prevailing water treatment impediments, both original and incremental.

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