

Magnetic Nanoparticle Based Filter Prototype to Cater Drinking Water Needs in Remote Areas

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ABSTRACT: An economic, energy efficient, portable filter prototype based on surface modified super paramagnetic iron oxide nanoparticles is designed, which could cater drinking water needs. The nanoparticles demonstrate high surface area to volume ratio, ability of magnetic immobilisation and generation of oxidative stress in microbial contaminants thereby leading to heavy metal adsorption and anti-microbial activity. The filtration efficiency can be improved by specifically coating the nanoparticles with anti-microbial agents like plant extracts and metals. The body of the filter is made up of light, cylindrical (height: 25 cm, diameter: 6 cm) biodegradable plastic. It is suggested to have five main components which can be easily assembled and disassembled. The filter specifically targets people working in remote areas where availability of safe water is a challenge. Simultaneously it can also be scaled up and used as an attractive nanotechnology based sustainable and cheap household treatment filter.

KEYWORDS: Portable, Prototype, Superparamagnetic, Nanoparticles, Sustainable

I. INTRODUCTION

Water is one of the major components of human body comprising of about 70% of the body weight. It is the most vital nutrient which acts as the medium for different cellular reactions to take place. An individual needs an average of about 3 litres of water as his daily requirement. Scarcity of drinking water has intensified concerns in the academia in the recent years. The increased urbanisation, industrialisation and over exploitation of the available water resources is the main reason behind it. All these human activities has led to alarming concentrations of dissolved chemicals and unwanted biological microorganisms in water making it unsafe for human consumption. Consumption of unsafe and polluted water makes the people prone to many water borne diseases and heavy metal poisoning [1]. In this regard access to safe water as defined by the water safety guidelines by WHO becomes a challenge [2]. Especially people from economically weaker sections are deprived of pure water, also people who work in remote areas such as defence personals, mountaineers, archaeologists, wild life enthusiasts and adventurers often find it difficult to avail safe water. In such conditions of unavailability of treated or packaged drinking water and poor economic conditions to procure high end household water filters, people have to depend upon the natural water resources to cater their drinking needs. Here low cost and economic point-of-use technologies which can reduce the microbial and heavy metal contamination in drinking water at the point of use may be typically useful [3]. Many strategies have been developed for point-of-use filters, the most common ones being ceramic filters and membrane based filters. Recently nanotechnology based strategies have attracted a lot of attention for water treatment. Nanoparticles owing to their small size and large surface area display unique properties like adsorption of heavy metals and anti-microbial property. Different mechanisms behind demonstration of anti-microbial activity are reactive oxygen species generation, hampering the cell envelope, inhibition of enzyme activity and inhibition of DNA synthesis [4]. Commonly used water treatment methods using nanotechnology employ nano fibres or nanoparticles based on silver, gold, TiO₂, ZnO, carbon nanotubes, fullerenes, chitosan and magnetic iron oxide [4,5]. These nanoparticles provide additional advantage of immobilisation and

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reusability which make them a better candidate for point-of-use water purification. This study deals with design of an economic, light weight and magnetic iron oxide based portable filter which can satisfy safe water needs in remote areas. Further it may be scaled up and used as an efficient household water treatment option.

II. MAGNETIC ASSISTANCE AND SAFE WATER

Safe drinking water is one of the basic requirements of life. People depend on two types of natural resources: surface water and ground water. Though some inorganic contaminants are present naturally in the water bodies, increased human interference have raised their values to critical levels. Major contaminants found in water bodies are sediment, inorganic ions (Ca, Mg, Cu, Fe, Mn, Hg, Cd, As, Pb, Zn, Cr, chlorides, sulphates, nitrates, fluorides), complex organic compounds and microbial contaminants (Escherichia coli, Giardia, Salmonella typhi). Other important parameters for safe water are colour, turbidity, pH, total hardness, odour and taste [6].

Nanotechnology has recently been exploited as a potential water treatment alternate. Magnetic iron oxide nanoparticles in the size range of 1- 100 nm display unique property of being influenced by external magnetic field. Common examples of these nanoparticles include magnetite and hematite. They are typically super paramagnetic in nature and display zero remanence and coercivity. Due to their nano scale size they exhibit higher surface area to volume ratio thereby helping them to adsorb heavy metals and organic contaminants. These nanoparticles can be magnetically removed by employing external magnets after the remediation is effectively complete. Alternatively they can be immobilised on magnetic arrays and can assist in water purification. As the particles can be removed magnetically, the risk of nano-toxicity is avoided efficiently. Also these particles exhibit anti-microbial activity on pathogenic and biofilm generating microbes. The origin of this anti-microbial activity is the oxidative stress caused by the ROS (Reactive oxygen species) formed by the nanoparticles which leads to damage the membrane, DNA and cellular organelles thereby leading to the microbial death [7]. These particles can specifically be surface modified or coated with anti-microbial agents like plant extracts (garlic tulsii, neem) or metal coatings (silver, gold, zinc oxide) to enhance the overall activity. These have also been successful in displaying better biofilm penetration aided with external magnet thereby controlling the biofilms more effectively.

III. FILTER DESIGN

The design of the filter is suggested to be made up of light biodegradable plastic. The suggested filter is comprised of five parts. Each of these parts can be detached and assembled when needed. It is cylindrical in shape having a height of 25 cm and diameter of 6 cm. The parts of the water filter are: water inlet (A), grit pre-filter (B), magnetic filter unit (C), activated carbon layer (D) and water outlet (E) as depicted in "Fig. 1". The three dimensional view demonstrating the components in details and the overall cross sectional view is presented in "Fig. 2" and "Fig. 3" respectively. The water inlet is 5 cm in dimension, slightly angled and is provided with a top transparent cap. Water from the natural source can be filled through the inlet. The inlet is followed by about 2 cm long grit pre-filter. In this part three to four layers of cloth is packed to effectively remove any suspended and particulate impurities present in the water. Third part of the filter acts as the main filtering unit is magnetic unit of 5 cm length. It consists of a magnetic mesh to which are attached magnetic iron oxide nanoparticles. The particles used for this purpose are surface modified super paramagnetic iron oxide nanoparticles. Typically anti-microbial coating materials will be used for the purpose such as plant extract based (garlic, neem, tulsii) or metal based (silver, gold, zinc oxide). Particles can be conveniently prepared using co-precipitation technique employing Fe^{2+}/Fe^{3+} in 1:2 molar ratio at a pH of about 8-10 [28]. Being super-paramagnetic in nature the particles can be easily attached to the magnetic mesh. Iron oxide nanoparticles possess high surface area to volume ratio and hence can adsorb harmful heavy metals present in the water sample. Also the anti-microbial coating helps in controlling the microbial flora by producing reactive oxygen species. The total surface area for filtration is increased by the combined presence of magnetic mesh and magnetic nanoparticles. The magnetic filter unit is effectively separated from the fourth component of the filter that is a sieve which checks any chance of escape of the nanoparticles from the mesh. Fourth part is a layer of activated charcoal which is made about 5 cm thick and is sandwiched tightly between two sieves on its either side. Activated carbon provides additional adsorption of any

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contaminants that were left over by the magnetic nanoparticles. This charcoal layer not only removes colour and odour from the water, but also adds taste to the water. The fifth and the last part of the filter is 8 cm long and is chiefly the clean water collector and water storage region. This has two parts: (i) Water collector which is made only 2 cm long and is angled at 45 degrees. It is attached with a magnetic ring (2 cm diameter) which can check the escape of any nanoparticle from the filter thereby eliminating any chances of Nano-toxicity in the drinking water. The magnetic ring leads to a layer of cloth leading to the storage space which is about 6 cm in length. Storage space is transparent in shape, attached with an outlet tap and can provide about 150 ml of potable water. Previously magnetite based water purification was described by Xu and co-workers [29]. A filter prototype based on magnetic iron oxide nanoparticles was described by Helen D’Couto [30]. The suggested water filter is a portable filter prototype based on magnetite nanoparticles with antimicrobial activity coated plant extracts. The extra precaution of removal of colour and complex organic molecules by adsorption on activated charcoal makes the water ultrapure and tasty. The parts are dismantled at ease and can be fixed back when required.

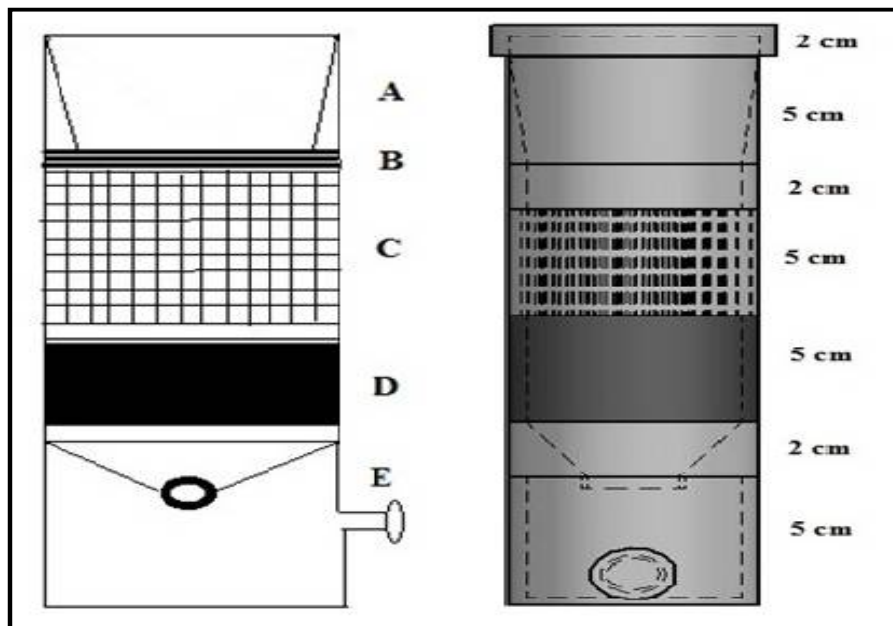


Fig. 1. Two Dimensional View of the Filter Prototype Depicting the Five Major Components and Filter Dimensions

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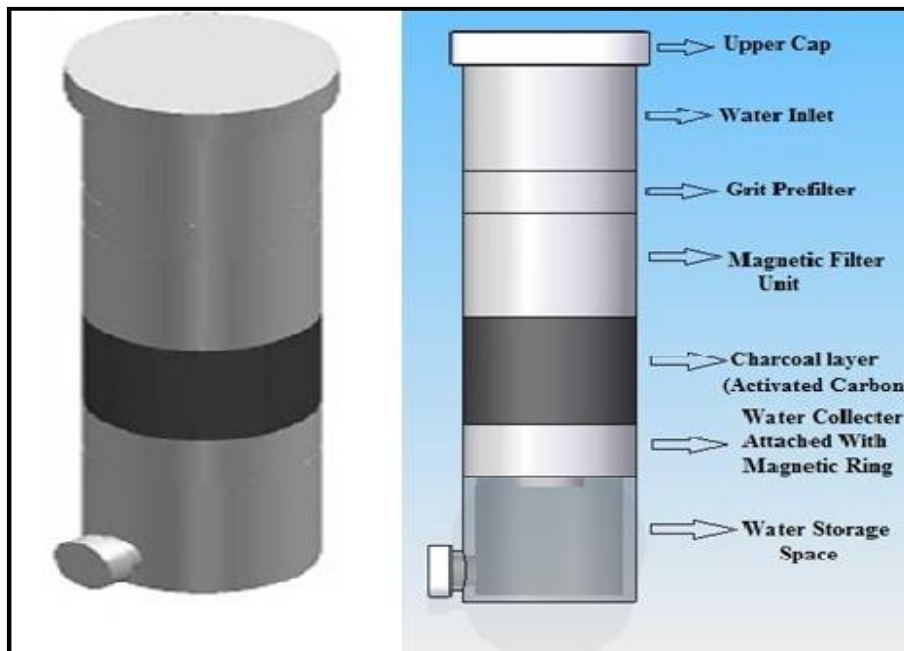


Fig. 2. Detailed Three Dimensional View of Filter Prototype

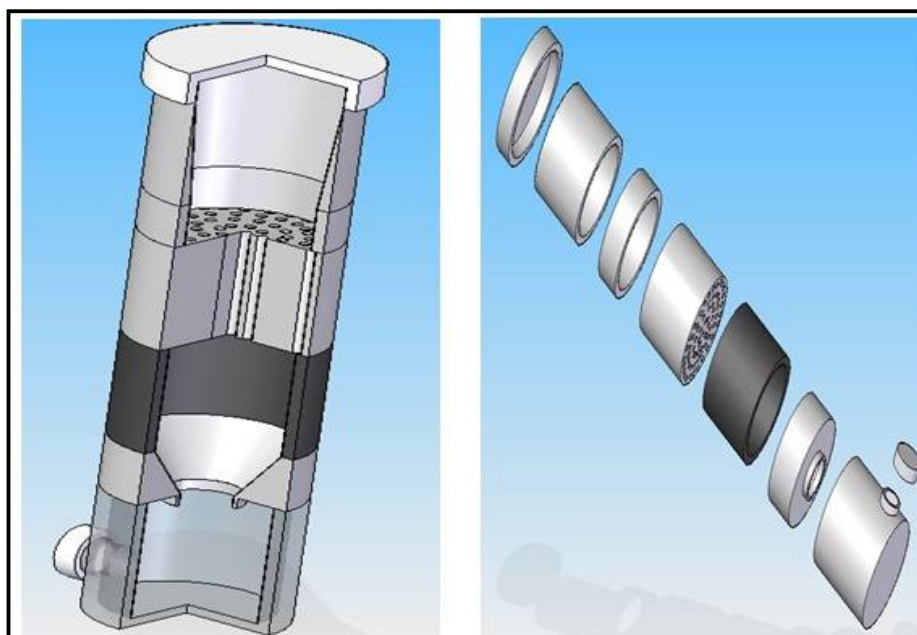


Fig. 3. Cross Sectional View and Demonstration of the Filter Components

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IV. RESULT AND DISCUSSION

The adsorption of heavy metals and anti-microbial activity of the magnetic iron oxide nanoparticles is displayed in “Tables 1 and 2” respectively. The current study details an attractive point-to-use portable water filter for getting clean and pure drinking water based on magnetic iron oxide nanoparticles. Light body, easily detachable components and convenient dimensions (25 cm height, 6 cm diameter) make it very user friendly. Main filter components such as magnetic iron oxide nanoparticles and activated carbon layer can be easily synthesised using cheap resources making the filter very economic. The immobilised magnetic nanoparticles can be reused many times. This typically works without any external energy source and hence can be used effectively in remote locations. Further in conditions where people have no access to treated water can avail safe water by scaling up this filter prototype. The filter components can be generated locally with minimal skill development training and cheap resources.

Table 1.
Anti-microbial Activity of Magnetic Iron oxide Nanoparticles

Sl. No	Particle type	Anti-microbial activity	Reference
1	Bare SPIONs CES- grafted SPIONs APTES-grafted SPIONs	Gentamicin-resistant Staphylococci	[8]
2	PQA coated Fe ₃ O ₄	Escherichia coli	[9]
3	Ag coated SPIONs	Biofilm causing bacteria	[10]
4	Fe ₃ O ₄ and γ -Fe ₂ O ₃	Staphylococcus aureus	[11]
5	Fe ₃ O ₄ /oleic acid:CHCl ₃	C. albicans and C. tropicalis	[12]
6	Zn-Fe nano composite	Staphylococcus aureus and Escherichia coli	[13]
7	FePt	Enterococci	[14]
8	PVP-CCDP coated IONPs/Ag0	Staphylococcus aureus and Escherichia coli	[15]
9	Glycol chitosan (GC-coated IONPs)	Escherichia coli, Salmonella enteritidis, Staphylococcus aureus,	[16]
10	Silver-conjugated SPION.	Methicillin-resistant Staphylococcus aureus	[17]

Table 2
Heavy Metal Adsorption by Magnetic Iron oxide Nanoparticles

Sl.No	Type of NP	Metals adsorbed	Reference
1	Chitosan-bound Fe ₃ O ₄	Cu(II) ions	[18]
2	Fe ₃ O ₄ @APS@AA-co-CA MNP	Cd ²⁺ , Zn ²⁺ , Pb ²⁺ , Cu ²⁺	[19]
3	Fe ₃ O ₄ /SiO ₂ nanoparticles	Hg ²⁺	[20]
4	Fe ₃ O ₄ nanoparticles with gum Arabic	Copper ions	[21]
5	Maghemite nanoparticles	Cr(VI)	[22]

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6	Amine-functionalized Fe ₃ O ₄ nanoparticles	Pb(II), Cd(II), Cu(II)	[23]
7	MNP-OPP (Orange peel powder modified into a novel magnetic nano-adsorbent)	Cadmium	[24]
8	Fe ₃ O ₄ -TW: Fe ₃ O ₄ - tea waste	Ni(II)	[25]
9	Magnetic γ -Fe ₂ O ₃ nanoparticles coated with poly-L-cysteine	As(III), Cu(II), Cd(II), Ni(II), Pb(II), Zn(II)	[26]
10	Ascorbic acid-coated Fe ₃ O ₄ NP	Arsenic	[27]

V. CONCLUSION

Given the low cost and effective model for water purification, this model can be a non-energy intensive and sustainable alternate to cater house hold water treatment in economically deprived regions. The efficiency can be further improved by the usage of novel engineered or composite nanoparticles. Large scale systems can be supplied with heating facility aided by renewable solar energy. This nanotechnology based filter prototype will add to new dimensions in point-to-use water filter technology, thereby strengthening water security in remote and rural areas.

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