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A review of biological aerated filters for iron and manganese ions removal in water treatment

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A B S T R A C T

Water contains iron (Fe) and manganese (Mn) that can be difficult to remove by singular physico-chemical methods This review paper focuses on the potential of biological aerated filter (BAF) technology for the simultaneous removal of Fe and Mn. It also covers the chemical properties of the respective metals, the causes and effects of high Fe and Mn, and other removal technologies including conventional and advanced treatment methods Surface waters and groundwater aquifers contain concentrations of Fe and Mn above their permitted limits as regulated by the authorities. Thus, the BAF system and its features are believed to have much potential to overcome many of the problems related to Fe and Mn contamination.

1. Introduction

In developing country such Malaysia, many water resources are polluted due to a diminished public awareness regarding environmental health, which leads to the indiscriminate disposal of waste or the discharge of effluent from industrial activity [1]. Approximately 7.4 billion people are estimated to live on the Earth according to the United Nations Department of Economic and Social Affairs, Population Division [2]. As the world population increases, there is an annual decline in the accessibility of clean and safe water, despite it being one of the most basic human necessities. Water is scored as an essential requirement for life second only to oxygen. More than half of a body's weight is composed of water, and it is important for cell growth, use as a body coolant, the protection of tissue from shock and damage, aiding in the digestion and absorption of food, the removal of waste and the maintenance of a healthy weight [3]. The World Health Organization (WHO) estimated that approximately 22% of the population does not have good access to drinking water.

Rapid industrialization over the last few decades around the world, and in Malaysia specifically, has caused serious repercussions including the pollution of groundwater and surface water. The contamination of iron (Fe) and manganese (Mn) ions in groundwater occurs naturally or by anthropogenic sources including industrial effluent, landfill leakage and acid mine drainage. Well casings, pump components, pipes and storage tanks can also contribute to Fe and Mn ions groundwater contamination [4]. Some particular minerals are useful for human and animal health in small doses, such as Zinc (Zn), copper (Cu) and Fe. Certain elements such as Zn, Cu, Mn, sulphur (S), Fe, and boron (B) combined with phosphates, nitrates, urea and potassium are useful in agriculture [5]. However, above the permitted limits and prescribed quantities, the concentration of these chemicals can lead to water pollution. Fe is one of the most abundant metals in the Earth's crust and generally presents together with Mn. Above specific levels, Fe and Mn can pose an unfavourable impact to both the environment and human beings. Both Fe and Mn ions are found in surface and groundwaters at fluctuating concentration levels [6].

The principal goal of water treatment is to minimize the risks from biological, chemical and physical contaminants by reducing them to acceptable levels. This includes ensuring that the water is of high aesthetic quality; that is, the taste, odour, clearness, and colour of the water do not cause offense to consumers. This also means guaranteeing that the water's chemical constituents do not cause operational problems in circulation systems [7]. For that reason, the demand towards cost-effective and environmental friendly technologies for water treatment are substantial and include the need to eliminate heavy metals and other organic constituents from the water supply. Although conventional treatment processes (precipitation, electro-coagulation, filtration and sedimentation) are highly reliable for the removal of Fe and Mn ions and are well-designed and well-tested, they present a number of drawbacks in terms of treatment capacity, efficiency, stability, space requirements, and the generation of large volumes of sludge thus increasing maintenance and operational costs [8].

The use of biological treatment-based biofilm technology offers an alternative to the physicochemical treatment approaches over the last

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twenty years with several advantages. Generally, biological treatment processes rely on the activity of micro-organisms for the oxidation of organic and inorganic matter [9]. Many researchers have reportedly taken the approach of using biological treatments and bacterial decomposition agents for the removal of Fe and Mn ions from wastewater but not for drinking water treatment. According to Dhokpande and Kaware [10], biological methods provide high efficacy with an efficacy of the removal of heavy metals exceeding 90%. This is better than chemical treatment because there is no added chemical composition, and it has a lower operation and maintenance cost [11]. Biological aerated filters (BAFs) have been known to offer advantages in the performance of removing suspended solids, reducing the space requirement for treatment, and generating less sludge [12] and they are generally easy to construct with the ability to treat high organic loads [13]. This review paper focuses on the potential of a BAF system for the simultaneous removal of Fe and Mn ions in drinking water, as well as other treatment technologies. The review covers BAF design, flow configuration, types of supporting media used, the role of effective microbes involved, and the advantages and disadvantages of the BAF system in removing Fe and Mn.

2. Legislation of iron and manganese in drinking water

The Ministry of Health of Malaysia has regulated a standard limit for drinking water quality through a Drinking Water Quality Surveillance Programme (2010) focusing on Fe and Mn. The drinking water guidelines are used as a reference whether water from a particular source is free from Fe and Mn. Table 1 lists the maximum limits for standards of discharges of Fe and Mn in drinking water for many countries in North America, Asia and Europe. In Malaysia, drinking water quality standards are divided into two categories, which are for raw water and treated water.

Meanwhile, public drinking water standards established by the Environmental Policy Act (EPA) are grouped into two categories, which are primary and secondary standards. Primary standards refer to health considerations that are designed to protect human health and are enforceable, while secondary standards are recommended but are not enforceable. The latter are based on aesthetic factors such as odour, taste and colour, which may consequently affect suitability for drinking water use [14]. In the United States (US), Fe and Mn are classified under Secondary Maximum Contaminant Level (SMCL) standards, indicating that they are recommended for limitation but are not enforced by either Federal or State Drinking Water Acts [14].

Table 1
Standard of Fe and Mn in water for different countries.

Continent	Country	Fe (mg/L)	Mn (mg/L)	Reference
South America	Canada	0.3	0.05	[44]
	United States	0.3	0.05	[45]
Asia	India	0.3	0.1	[46]
	Japan	0.3	0.04	[47]
	Korea	0.3	–	[48]
	Malaysia	0.3	0.1	[49]
Europe	France	0.2	0.05	[50]
	Germany	0.2	0.05	
	Ireland	0.2	0.05	
	Italy	0.2	0.05	
	Denmark	0.2	0.05	
	Spain	0.2	0.05	
	Netherlands	0.2	0.05	
	Finland	0.2	0.05	
	United Kingdom	0.2	0.05	

3. Iron and manganese

3.1. Chemical properties of iron and manganese

Fe exists in two forms, which are soluble ferrous iron [Fe(II)] and insoluble ferric particulate iron [Fe(III)]. Fe in water is generally present in the ferrous state. It is a lustrous, ductile, malleable, silver-grey metal (group VIII of the periodic table). It is known to have boiling and melting points of 1535 and 2750 °C, respectively, and a specific gravity of 7.87 with a molecular mass of 55.845g/mol [15]. The most common valence states of Fe are +2, +3, +4 and +6. Fe is soluble in cold water, hot water and diethyl ether [16]. The presence of Fe ions in natural water may be attributed to the dissolution of rocks and minerals, acid mine drainage, landfill leachate sewage or engineering industrial effluent.

Mn is a pinkish-grey and chemically active element. It is known to have boiling and melting points of 2095 and 1244 °C, respectively, and a specific gravity of 7.44 with a molecular mass of 54.94g/mol [17]. It is a hard and very brittle metal that is hard to melt but is easily oxidized. Mn is soluble in both hot and cold water. It is reactive when pure, and as a powder, it will burn in oxygen; it also reacts with water and dissolves in dilute acids [18]. It is non-corrosive in the presence of glass. The most common oxidation states of Mn are +2, +3, +4, +6 and +7, although all possible oxidation states from −3 to +7 have been observed. Bi-valent manganese (Mn^{2+}) compounds are usually soluble in water, while manganese with high valence states are generally not soluble in water [19]. The most stable oxidation state for manganese is +2, which presents with a pale pink colour, such as manganese (II) sulphate ($MnSO_4$) and manganese (II) chloride ($MnCl_2$) [20].

3.2. Case study of iron and manganese contamination

Most of the general sources of Fe and Mn ions in water resources are produced from industrial wastewater, including sources from mining, pesticides, organic chemicals, rubber and plastics, lumber and wood products, metal processing, tanneries and pharmaceuticals [21]. However, the major river pollutants are from domestic sewage, waste from livestock and farms, runoffs from farms and towns, silt from earthworks, leachate from rubbish dumps, litter from riverside squatters and mining waste [1]. Since groundwater moves through rocks and subsurface soil, it has numerous opportunities to dissolve substances as it disseminates through the subsurface [22]. In a natural aquifer system, water percolating through soil and rocks can dissolve minerals containing Fe and Mn and store them in solution [22]. When exposed to air, groundwater containing dissolved Fe and Mn becomes insoluble, and the remaining water is left with a brown-red colour that is problematic for consumption [23].

The presence of Fe ions in groundwater is generally attributed to the dissolution of Fe-bearing rocks and minerals, which are primarily oxides (hematite, magnetite, and limonite), sulphides, carbonates and silicates under anaerobic conditions in the presence of reducing agents such as organic matter and hydrogen sulphide [24]. Mn is used principally in the manufacture of iron and steel alloys, as an oxidant for cleaning, bleaching, and disinfection as potassium permanganate, and as an ingredient in various products. Fe and Mn are present in water in combination with carbonates, sulphates, humic compounds, chlorides and sometimes phosphates. The reaction of Mn and Fe with air will form dark precipitates, following which water will become dull and darkly coloured [24].

Fig. 1 illustrates some of the point sources that contribute to contamination with Fe and Mn ions. The concentration of Fe ions is 0.023–0.035, 0.14 and 0.08 mg/L, while the concentration of Mn ions is 0.068–0.199, 0.01 and 0.06 mg/L as recorded, respectively, in the effluent of textile and dyeing, pulp and paper mill, and fertilizer industrial wastewater [25–27]. Gurgel et al. [28] discovered that river water in northeastern Brazil contained concentrations of 0.780 mg/L Fe