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Article in Polish Journal of Environmental Studies · April 2022

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Original Research

The Feasibility of Heavy Metals Removal from Drinking Water Sources Containing Sulfide Ions by Pillared White Sand of Different Grains Size

Omar Asad Ahmad*

Department of Civil Engineering, Engineering Faculty, Amman Arab University,
P.O Box. 2234, Amman 11953, Jordan

Received: 24 July 2021

Accepted: 7 January 2022

Abstract

In Jordan, groundwater is the predominant reservoir utilized for human consumption since surface water makes a barely discernible contribution to supply. The investigation of inexpensive and readily accessible adsorbents for heavy metal extraction forms the topic of this research. The aim of this study was to assess the efficacy of a filtration method for the subtraction of heavy metals, i.e. (Fe, Cu, Co, Ni, Zn and Cr), which employed white sand and chlorine as a large filter and oxidizing agent, respectively, and represented a simulation of the clarification procedure. The experiments were performed using pillared sand of varying grain dimensions to explore the impact of particulate size on the adsorption and retention of the heavy metals under examination. Sulfide ions employed as a catalyst.

The data revealed that the extraction of Zn, Ni, Cu, Cr, Co and Fe was 75%, 95%, 99%, 65%, 89% and 94%, respectively. Adsorption was conducted using a sand particle dimension of between 50 and 60 μm . Chlorination and sulfide facilitated oxidation, generating fixed oxide compounds. Owing to the notable part performed by the micro-sand particles, the heavy metal fixation was considered a result of hydrogen bonding, electrostatic interaction and ion exchange. This study offers a novel perspective on drinking water clarification using white micro-sand, thus offering a relatively innovative strategy for the efficacious extraction of a number of heavy metals, which is apposite for application to drinking water resources.

Keywords: pillared sand, grain size, adsorption, drinking water, heavy metals

Introduction

Heavy metals are a class of trace metallic elements that encompass aluminium (Al), arsenic (As), cadmium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese, mercury, nickel (Ni), tin and zinc (Zn). Their concentration is relatively high, i.e. $>4 \times 10^6$ mg/L. It is well established that these metal ions are present as pollutants in the soil, air and water reservoirs; they are toxic even in minute quantities [1, 2]. A number of issues relating to the environment have been recently identified owing to water pollution by both organic and inorganic compounds, which are distinguished by their failure to clear, poisonous properties and ability to bioaccumulate. These require complete eradication prior to being emptied into a receiver medium [3, 4].

Heavy metals are the most frequently arising environmental aquatic contaminants and may be a possible cause of malignancy in humans [5, 6]. In contrast to organic pollutants, heavy metals are noted for their unrelenting presence long-term and their lack of biodegradability [7, 8]. Thus, the efficacious eradication of both organic and inorganic contaminants has evolved to be a pressing contemporary concern [9].

The pollution of water bodies is a grave environmental matter and thus the design of an effective and apposite method of eradicating heavy metal contaminants from solutions of water is required. A number of techniques have been utilized to clear heavy metals from polluted water, e.g. chemical precipitation [10], ion exchange [11], adsorption [12], membrane filtration [13, 14], reverse osmosis [15], solvent extraction [16] and electrochemical treatment [17]. The majority of these processes are expensive both to establish and to maintain.

Adsorption appears to be one of the most optimal modalities as it is highly efficacious, relatively cheap and straightforward to perform. A diverse range of adsorbents has been utilized in order to clear heavy metal contamination from water; examples include carbon foam [18], activated carbon [19], zeolite [20], clay minerals [21], organic polymers [22] and biochar [23]. Numerous waste products have also been employed, e.g. fly ash [24], recycled sanding wastes [25], biomass [26] and water treatment residuals [27, 28]. There are a plethora of advantages to the deployment of inexpensive items as adsorbents, encompassing lowering the cost of heavy metal extraction and optimizing the volume of any residues which are accreted within the environment.

Currently, the development of novel and financially expedient interventions for water treatment and the recycling of wastewater using de novo substances and methods has acquired considerable urgency [29]. One new and efficacious process is white micro-sand filtration. Several publications have described the deployment of various forms of sand enriched with iron oxide, e.g. sand treated with iron oxide altered by sulfate [30], iron-zirconium oxide-coated sand [31], zirconium

oxide-coated marine sand [32] and iron oxide-activated red mud [33].

Of these methods, filtration utilizing white micro-sand could represent a new way of decontaminating water containing poisonous compounds. It is a straightforward inexpensive method and requires minimal energy which means that sand filtration is the most prevalent pretreatment employed in contemporary sizable installations [34]. The process is efficacious and suitable for the treatment of water. It has two functions: (i) heavy metal adsorption and biomass fixation, which can be instigated in relation to the sand grains; and (ii) organic material biodegradation [35, 36].

In the current research, sand filtration and the adsorption technique were utilized to eradicate heavy metals, i.e. Fe, Cu, Co, Ni, Zn and Cr, by deploying a novel form of unadulterated micro-sand, additionally referred to as white sand. This sand is found in areas situated in proximity to the Qa'ar Ed Disi region, which lies 280 km from the capital, Amman. The sand originates from physical decomposition of the sandstone rocks that are derived from the Disi Sandstone Formation, which dates back to the early Ordovician era. The impact of crucial variables and the fixation process were explored in order to evaluate the two arms of the technique.

Material and Methods

Sampling

Specimens of sand were gathered from the surface stratum of the sand location and transported to the laboratory where they were washed, dried and filtered through pores with a diameter of 40-80 μm and then reserved for subsequent examination. Aqueous samples were made up using non-ionized water treated with ready-made heavy metal solutions, i.e. Zn, Fe, Cu, Ni, Cr and Co, comprising 0.5, 1 and 2 mg/L concentrations of each metal, respectively.

In order to delineate a potential function of chlorine, the aqueous samples were treated on two occasions using sodium hypochlorite (SH) as a way of delivering NaClO with a molar mass of 74.44 g/mol in two concentrations, i.e. 0.2 and 0.6 mg/L. The specimens were additionally admixed with three sulfate solutions, i.e. 0.1, 0.2 and 0.3 mg/L in order to generate sulfide water; the impact of these varied concentrations on the clearance of heavy metals was observed. In addition, an experiment contrasting the subtraction of the different heavy metals was conducted.

The efficacy of heavy metal eradication via the white sand filtration technique was investigated. Filtration was performed on the treated specimens using Whatman filter paper prior to heavy metal assays. In order to circumvent precipitation of the metals, several drops of concentrated nitric acid were incorporated into the solutions to give rise to a pH of 2 [37].

The samples were then kept in glass containers at a temperature of 4°C. Analysis was performed by deploying AA-7000 graphite furnace atomic absorption spectrometry.

Working Methods

The study objective was to examine the impact of the dimensions of the sand grains on the heavy metals under examination in aqueous solution, and so three pillared sand columns were established containing varied sand grain sizes:

Fine micro-sand (FMS): 40 µm - < 50 µm

Medium micro-sand (MMS): 50 µm - < 60 µm

Coarse micro-sand (CMS): 60 µm - ≤ 80 µm

The Pilot-Scale Micro Sand Filter

The pilot scale filter illustrated in Fig. 1. It comprises a column 1.5 m tall with a diameter of 25 cm. Each of the three columns utilized for the current work contained sand of a single particle dimension as specified above. The active white micro-sand layer was 1.5 m in depth. A 20 cm tier of identical gravel was deposited inferior to the sand so as to circumvent sand loss. A perforated plate was present at the superior end of the column in order to enable the passage of the aqueous solutions.

The crystalline configuration of the specimens was determined utilizing X-ray fluorescence (Table 1). The most prevalent compound was silicon oxide (SiO₂), which exhibited a weight spectrum of 97.88-99.07%. Additional oxides, i.e. of iron (Fe₂O₃), aluminum

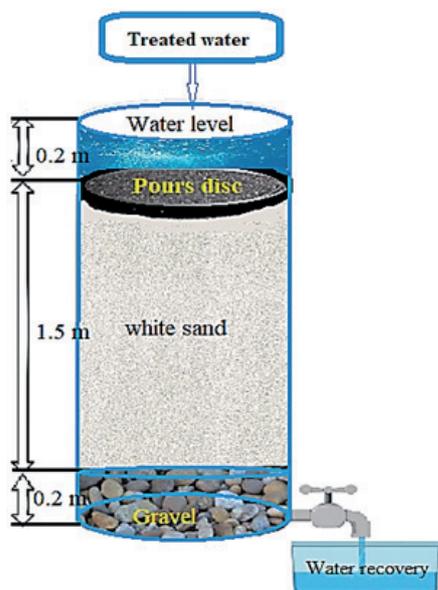


Fig. 1. Pilot-scale micro sand filter.

Table 1. Composition of sand samples (analysis by XRF).

Compound	FMS (Weight %)	MMS (Weight %)	CMS (Weight %)
SiO ₂	99.07	98.78	97.88
Fe ₂ O ₃	0.019	0.32	0.76
Al ₂ O ₃	0.56	0.83	0.94
TiO ₂	0.03	0.08	0.12
ZrO ₂	0.02	0.09	0.11
CaO	0.03	0.13	0.21

Table 2. Specific gravity and the specific surface area of micro sand fraction.

Sand fraction	Surface area (m ² g ⁻¹)	Specific gravity
FMS	1.011	2.68
MMS	0.893	2.66
CMS	0.765	2.57

(Al₂O₃), titanium (TiO₂), zinc (ZnO₂) and calcium (CaO) were present in quantities of roughly 1% in total. The micro-sand particles had an even veneer. The diversely configured oxide particles on the micro-sand's surface were responsible for its appearance and enhanced the porosity of the substance. These characteristics meant that the micro-sand is a beneficial amorphous entity, which can be deployed to eradicate heavy metals from water destined for human consumption.

The specific gravity and surface areas of the three respective sand fractions are presented in Table 2. The surface areas were as follows: CMS, 0.765 m² g⁻¹; MMS, 0.893 m² g⁻¹; and FMS, 1.011 m² g⁻¹. The specific gravity was between 2.57 and 2.68, dependent on the sand type.

Results and Discussion

The micro-sand performs a number of essential and important functions during metal clearance. It works as a ballasting mediator for solution separation, owing to the large specific surface area: volume proportions of the micro-sand particulates, which act as a kernel for material production. The micro-sand also encourages the capture of substances in suspension, which gives rise to the generation of a sizeable, structurally robust floc. The micro-sand's have a relatively large specific gravity, i.e. approximately 2.65, acts as a ballast for the synthesis of high-density floc, which leads to alterations in the empirical quantity of the aqueous solution. Given that the sand is chemically inactive, it does not engage in any reactions with the water and thus can be easy to recycle. All these properties make this a technique

that is effective for the treatment of ‘challenging’ solutions, structurally sound with alterations in the inherent water quality and straightforward to work and to improve.

Generally, the employment of micro-sand leads to the generation of chemical floc that is dense and robust. Such flocs demonstrate greater speeds of settling than traditional ones and thus enable markedly raised clarifier overflow rates, which frequently give rise to favorable financial considerations when contrasted with more typically used techniques.

The data from the developed micro-sand filters utilized for the aqueous heavy metal solutions, i.e. 0.5, 1.0 and 2.0 mg documented and analyzed. Fig. 2 show data from the sand filters that were individually treated with 0.2 mg Cl⁻ and 0.1, 0.2 and 0.3 mg/L of sulfate, respectively. Fig. 3 present data from the sand filters that were individually treated with 0.6 mg Cl⁻ and 0.1, 0.2 and 0.3 mg/L of sulfate, respectively.

The results demonstrate that perspicuous beyond reasonable doubt alterations in heavy metal eradication arise following low-concentration pretreatment with sulfide, i.e. 0.1 mg/L. A sulfide concentration of 0.2 mg/L led to a marked rise in the clearance of Zn and Cu. The most efficacious elimination (100%) occurred at a sulfide concentration of 0.3 mg/L, where baseline Zn and Ni concentrations were 0.5 to 1.0 mg/L. However, at this sulfide level, greater clearance efficacy for Cu, Zn and Ni for concentrations of 0.5 to 1.0 mg/L were noted.

The effectiveness of Zn clearance where the level was less than 1-2 mg/L was notably higher by the greater concentration of sulfide throughout the entire adsorption process, with a rise of 100% and 65%, respectively, in the peak Zn clearance when judged against the remaining heavy metals in the specimen. These results demonstrated that sulfide pretreatment potentiated the eradication of Zn, especially in the

more concentrated form. A comparable phenomenon was noted for Ni, with respective adsorption elevations of 57% and 100% as shown in Fig. 2. Chen et al [38] published equivalent data in relation to heavy metal degradation utilizing NaHS. The more alkaline pH is a further potential reason for the greater Zn and Ni clearance, i.e. the generation of Zn and Ni precipitant ions.

Pretreatment stages with highly concentrated sulfide solutions, i.e. 0.3 mg, provoked a transparent dose-dependent efficacy decrease in complete Ni, Cu and Zn clearance, which dipped to an imperceptible degree in all the pre-treated cohorts. The data imposed that Ni, Cu and Zn elimination is associated with sulfide concentration; greater baseline concentrations were included to preserve improved distribution and structural integrity whereas oxidative dissolution and nanoparticle precipitation were facilitated at lower sulfide concentrations. Furthermore, distinguishable quantities of a reduction in total Cr, Co and Fe extraction efficacy were also heightened by higher concentrations of sulfide throughout the adsorption process, with a rise of 40% for Cr, 60% for Co and 85% for Fe in the peak clearance effectiveness compared to the remaining metals in the identical samples. A potential reason for this is that these metals may be immediately transformed into nanoparticle or bigger aggregates via a solid-fluid sulfidation reaction in the presence of more concentrated sulfide, giving rise to a greater entrapment of these ions within the sand column.

It can be anticipated that different heavy metals with varying adsorption loci and metal-binding energies within a range of micro-sand columns may exhibit dissimilar levels of clearance. The discernible extraction efficacy suggested sulfide may have more robust binding affinities for Ni, Cu and Zn than for Cr, Co and Fe. Together with the data shown in Fig. 2 and Fig.3, demonstrate the eradication of heavy metals

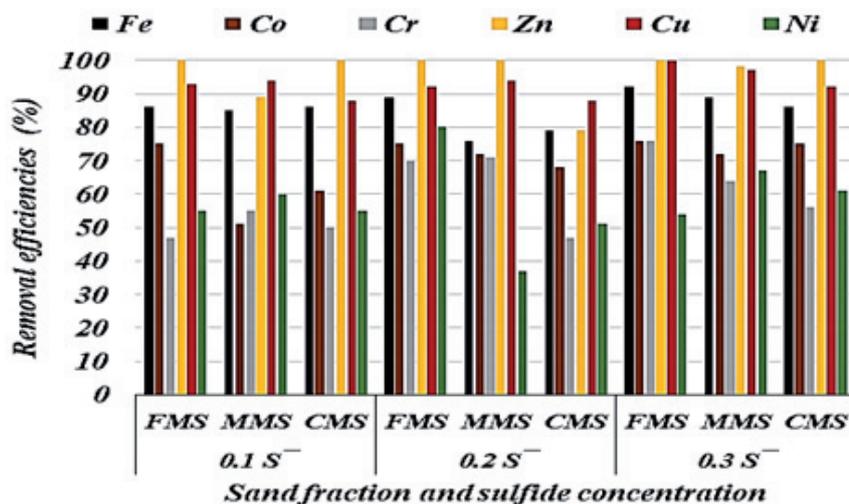


Fig. 2. Average removal efficiency for different sand fractions, sulfide concentrations, and 0.2 mg/L SH.

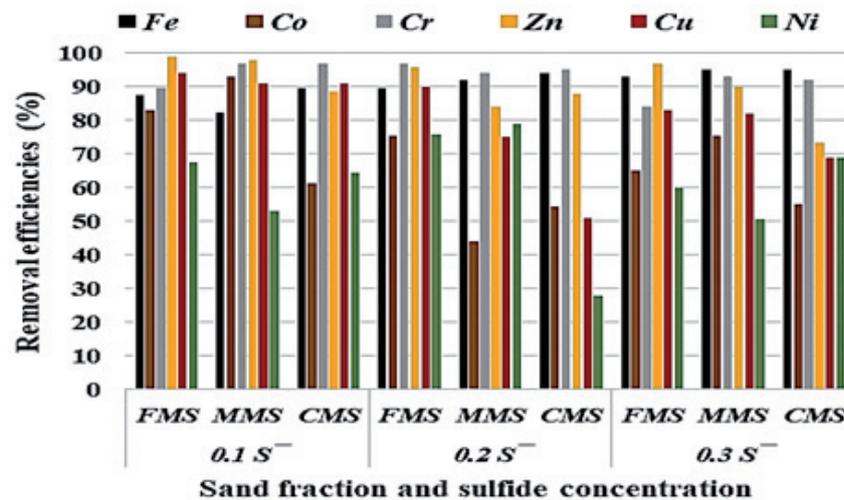


Fig. 3. Average removal efficiency for different sand fractions, sulfide concentrations, and 0.6 mg/L SH.

was associated with the 40-50 μm and 50-60 μm sand fractions, respectively.

The sulfidation event is equivalent to metal hydroxide precipitation. Sulfide is admixed so as to precipitate metals from solution; the precipitate can then be collected by methods such as deposition or gravity filtration [39].

Moreover, a number of studies have proposed that low-dose hydrogen sulfide has a beneficial consequence for growth, development and abiotic/biotic stress resilience in animals, plants and microorganisms [40, 41]. For instance, NaHS administration to plants can augment their ability to withstand poisonous heavy metals, e.g. Pb, Cd, Cu, Cr, Zn, Al and As, and diminish heavy metal accretion, thus mitigating the toxic impact [42, 43]. In contrast, in the current research, the use of sulfide was shown to potentiate the extraction effectiveness of a number of heavy metals, i.e. Zn, Ni, Cu, Fe, Co and Cr.

An initial consideration is that it is imperative that the concentration of sodium hypochlorite is appropriate, i.e. typically between 0.5 and 1.0%, for drinking water purification. If it were too low, too great a volume will be required which would be unrealistic. If it is at the opposite end of the spectrum, it is challenging to judge the quantity required, thus increasing the likelihood of too large an aliquot being added, which is unpleasant to taste, or too little, which may be insufficient to clean the solution. A further issue is that the solution's pH should be at least 11 in order to prolong the solution's longevity, hence why in this work, concentrations of 0.2 mg/L and 0.6 mg/L were selected for the experiment.

Chlorine is a highly reactive element. As soon as sodium hypochlorite is administered to the solution, the chlorine concentration drops owing to its reaction with inorganic material and volatile loss into the atmosphere. This process underpins the breakdown of free and total chlorine titers over a period in a sealed unit and

additionally, the reason why the hypochlorite solution's pH should be maintained >11 to prolong the solution's serviceable duration prior to usage.

A high chloride concentration leads to the configuration of soluble chloride complexes in association with heavy metals. This highly efficacious process is frequently utilized to subtract heavy metals from residues, i.e. brine leaching [44]. The extreme solubility of heavy metals in concentrated saline solutions, whilst beneficial for brine leaching, is a disadvantage, however, in wastewater purification [45, 46].

Chloride exhibited minimal influence on the heavy metal solutions in the current research, and the results were demonstrated in Fig. 3 and Fig. 4. The failure to associate chloride concentrations with any change in the heavy metal titres is potentially owing to the higher affinity of the metals for particulates rather than chloride. Since several of these elements generate inner-sphere complexes with particle veneers, it is improbable that chloride could provoke any metal desorption [47]. The inner-sphere complexation has a higher chance of being impacted by alterations in pH; the latter have been demonstrated to degrade these associations. If chloride were a major actor in heavy metal desorption from particle surfaces, the metals would have exhibited a marked relationship with the two respective chloride concentrations as a result of chloride complex formation.

Fe, Co, Cr, Zn, Cu and Ni desorption into a solution have been demonstrated to arise with an elevated concentration of chloride, i.e. 0.6 mg/L. Metal chloride complexation is a process through which desorption and trace metal partitioning into the aqueous phase may alter in surface aquatic bodies. Nevertheless, in the course of metal hydroxide precipitation, significant quantities of precipitate are generated. Since metal hydroxides are amphoteric in nature, the precipitated metal can return to solution.

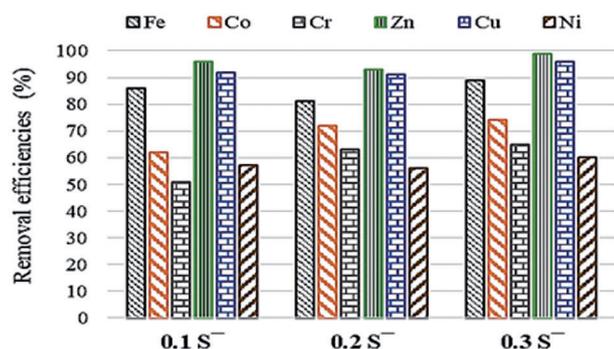


Fig. 4. Average removal efficiency for different sulfide concentrations and 0.2 mg/L SH.

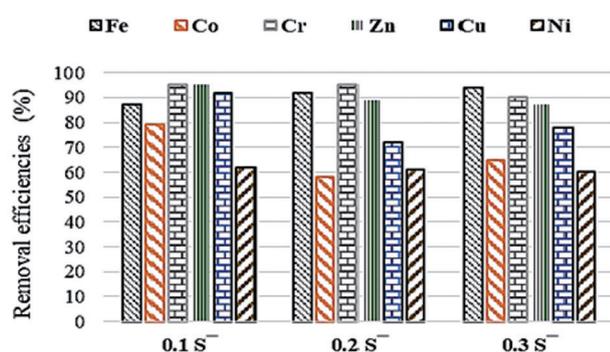


Fig. 5. Average removal efficiency for different sulfide concentrations and 0.6 mg/L SH.

Conclusion

The objectives of this study were to investigate inexpensive and accessible adsorbents for heavy metal removal. The aim was to assess the efficacy of a filtration method for heavy metal clearance utilizing white micro-sand and chlorine as a large filter and oxidizing agent, respectively, thus simulating a water cleaning technique in specimens comprised of varied sulfide concentrations.

Filtration with micro-sand could be employed as a pretreatment in drinking water installations. Two principal working advantages of the micro-sand filtration system include its structural soundness and its adaptability. It has therefore been demonstrated to be an outstanding cleansing technique for a range of challenging and taxing water treatments. The method is straightforward and inexpensive.

The addition of sulfide notably enhanced the subtraction of the heavy metals under examination; sulfide-facilitated peroxidation and oxidative stress produced by heavy metals was mitigated by an increase in sulfide dosage. Benefits of utilizing sulfides encompass a greater level of metal clearance related to the lesser solubility of metal complexes as sulfides as opposed to metal hydroxides in the presence of a broad spectrum of pH.

There was minimal influence from chloride on the heavy metal solutions. The absence of a relationship between the heavy metal and chloride concentrations may be owing to the higher affinity of these elements for particulates.

The results from this study offer proof of the possible utility of micro-sand filters and sulfide in the purification process of drinking water and have notable import for improving the comprehension of the adsorption-retention mechanism and the reactions relating to the presence of sulfide.

Acknowledgments

It would not have been possible to undertake this experimental work at the Engineering Faculty without the support of Amman Arab University.

Conflict of Interest

The authors declare no conflict of interest.

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