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Enhancing lead removal from water by complex-assisted filtration with acacia gum

Yehia Manawi[a,b], Gordon McKay[b,*], Norafiqah Ismail[c], Ahmad Kayvani Fard[a,b], Viktor Kochkodan[a,b], Muataz Ali Atieh[a,b,*]

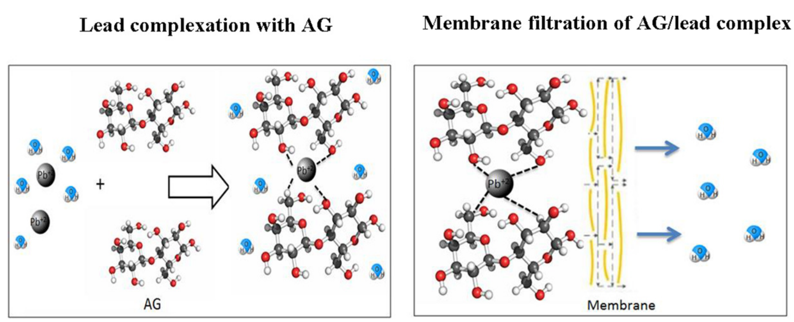
[a] Qatar Environment and Energy Research Institute (QEERI), Hamad Bin Khalifa University (HBKU), Qatar Foundation, Doha, Qatar
[b] College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, PO Box 5825, Doha, Qatar
[c] Advanced Membrane Technology Research Centre (AMTEC), Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

HIGHLIGHTS

- Acacia gum (AG) was used as novel & cheap agent for lead removal from water.
- Effect of AG dosage, pH, and contact time on lead removal was studied.
- Lead removal of 99.9% achieved with AG followed by membrane filtration.
- The possible mechanism of lead chelating with AG was discussed.

GRAPHICAL ABSTRACT

Graphical abstract demonstrating the complexation of acacia gum with lead in water and the removal of the complexed AG/lead by membrane filtration.



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ABSTRACT

In this work, for the first time, the use of AG as a natural, widely available and cheap material to enhance the removal of lead from contaminated water using polymer-enhanced membrane filtration (PEMF) has been carried out. In this technique, heavy metal ions are chelated with high molecular weight water-soluble polymers with following rejection of the formed polymer-metal complexes with the wide-porous and high flux polymer membranes. Acacia gum (AG) is a natural gum, which is collected from the hardened sap of some species of the acacia tree. The surface area particle sizes, zeta potential and elemental composition of AG were evaluated using BET, FE-SEM, zeta potential analyzer, EDS and XPS methods. The effect of AG dosage, lead concentration, feed pH, and contact time on lead-AG complex formation has been studied. The highest binding capacity of AG was about 12.2 mg/g when 1000 ppm AG was added to 35 ppm lead solution at pH 7. It was found that, with a dosage of 1000 mg/L of AG at pH 7, successful lead removal efficiencies of 97.5%, 98.3% and 99.9% were achieved using microfiltration polytetrafluoroethylene (PTFE), 30 kDa and 3 kDa molecular weight cut-off ultrafiltration cellulose membranes, respectively. The possible mechanism of lead removal with AG has been discussed. The obtained data have shown that AG can be used as a safe and cheap chelating agent for lead removal from water.

* Corresponding authors at: Qatar Environment and Energy Research Institute (QEERI), Hamad Bin Khalifa University (HBKU), Qatar Foundation, Doha, Qatar (M.A. Atieh).
E-mail addresses: vkochkodan@hbku.edu.qa (V. Kochkodan), mhussien@hbku.edu.qa (M.A. Atieh).

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Nomenclature

A	arabinosyl
AG	acacia gum
Ara	arabinose
ATR-FTIR	attenuated total reflectance Fourier transform infrared spectroscopy
BET	Brunauer–Emmett–Teller
C_i	initial lead concentrations in the aqueous solutions (mg/L)
C_f	permeate lead concentration in the aqueous solutions (mg/L)
EPA	environmental protection agency
DI water	deionized water
Gal	galactose
GlcA	glucuronic acid
m_{AG}	mass of AG (grams)
MWCO	molecular weight cut-off
PEMF	polymer enhanced membrane filtration
PETE	polytetrafluoroethylene
Rha	rhamnose
TOC	total organic content

1. Introduction

Lead is one of the more toxic elements found naturally in water bodies and agricultural soils. It is termed as persistent, bio-accumulative and toxic metal and has adverse neurodevelopmental effects (such as decreased cognitive function, inattention and impulsivity) on children at blood lead levels of 10 μg/dL [1]. Lanphear [2] have reported a strong evidence of nonlinear relationship between reduced intelligence quotient and blood lead levels [1]. Lead can also lead to death at high exposure concentration. The permissible level of lead in potable water is 10 ppb and the EPA action level is 15 ppb [3]; however, globally, lead is still found at levels much higher than that in water bodies such as surface waters and groundwater [4].

Different methods have been reported in literature to remove lead from drinking water such as: electrochemical separation, solvent extraction, precipitation, distillation, reverse osmosis, ion exchange, adsorption, coagulation and bio-sorption [5,6]. While some of these techniques are expensive and difficult to operate (such as reverse osmosis, electrochemical separation, solvent extraction, etc.), the others are energy intensive processes (such as distillation). Numerous research papers have been published reporting the use of conventional adsorbents to remove heavy metals such as zeolite, activated alumina clay and activated carbon; however, such conventional adsorbents were reported to exhibit low adsorption capacity towards heavy metal ions [6,7].

Recently, nanomaterials have been introduced to the field of adsorption as it demonstrates relatively higher adsorption capacity due to its large surface area. Numerous research articles have been published in the field of heavy metals removal from water using different nanomaterials such as: graphene oxide, carbon nanotubes, etc.[6,8–12]. However, these materials are still expensive [13] and difficult to prepare, reuse and dispose of safely [14]. Moreover, some of nanomaterials are toxic and pose a threat on human life as these can leach to drinking water being treated and create a serious health hazard.

Therefore, a search for novel methods of lead removal from water is still very important. Polymer-enhanced membrane filtration (PEMF) is one of the promising techniques suggested to treat contaminated water with heavy metals due to several advantages such as: high bonding selectivity, fast reaction kinetics, low energy requirement, etc. [15]. In this technique, heavy metal ions are chelated with high molecular weight water-soluble polymers which have strong affinity to bind to the dissolved trace metals in contaminated water. The formed polymer-metal complexes of high molecular weight can be rejected with the wide-porous and high flux polymer membranes. The advantages of this process are high removal efficiency and low energy consumption as well as the capacity to separate the metal ions from very dilute solutions. Different macro-ligands have been studied for PEMF. For instance, Barakat [16] reported the removal of Cu(II), Ni(II), and Cr(III) from wastewater using carboxy methyl cellulose combined with ultrafiltration (PES membranes with 10,000 Daltons cut-off). The optimum conditions corresponding to the highest metal rejection was achieved at pH ≥ 7 with increasing complexation agent concentration. Gao et al. [17] have treated wastewater containing nickel by PEMF using sodium polyacrylate as complexation agent and rotating disk membrane modules to separate the complexed ions from the wastewater. About 98.26% Ni^{2+} rejection was achieved at n < 848 rpm, pH = 7.0 and P/Ni = 13 (mass ratio). Desai et al. [18] reported the removal of silver from aqueous solutions by PEMF using the complexation agent: anionic polyacrylamide (average molecular weight > 50 kDa) and polyethersulfone ultrafiltration membrane (molecular weight cut-off: 10 kDa) to filter out the silver from the water. a maximum rejection of silver ions of about 100% was achieved at the optimum operating parameters. Khosa et al. [19] conducted a study to remove heavy metal ions (such as: Zn^{2+}, Pb^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, etc.) from aqueous solutions using water soluble bio-macromolecule complexation agent (sericin biopolymer). Sericin has been proved to possess potential to exhibit chemical interaction with metal ions as a result of its rich content of protein units which subsequently have lots of amino acids. The presence of functional groups such as: carboxylic acid (−COOH), amine ($-NH_2$) and disulfide linkage (S-S) inside sericin facilitates its job to act as a poly-dentate ligand. The presence of negatively charged surface which contain lone pair of electrons assists the complexation of metal ions with sericin due to the availability of d-electron deficient metal ions [19]. Chen et al. [20] tested the removal of heavy metals from water using poly(sodium 4-styrenesulfonate) as complexation agent followed by ultrafiltration. The selectivity of the poly(sodium 4-styrenesulfonate) towards the metals was evaluated and reported as following: ($Ba^{2+} > Pb^{2+} > Sr^{2+} > Ca^{2+} > Cu^{2+} > Co^{2+} > Ni^{2+} > Mg^{2+} > H^{+} > K^{+} > Na^{+} > Li^{+}$).

Despite the potential advantages of PEMF; however, it has not been practically used as a way to produce potable water from contaminated water. The safety aspect concerning the use of PEMF is still one of the crucial aspects as trace amounts of chelating polymers might pass through the membranes and possess a serious health risk. For this reason the need to use a natural, green, safe, and cheap chelating material to remove heavy metals from contaminated water is of vital importance in areas where there are no other alternative ways to get potable water.

Acacia gum (AG) or gum Arabic is a natural gum which is collected from the hardened sap of some species of the acacia tree [21]. In food industry, AG is widely used as an approved edible food additive acting as a surfactant, emulsifier and stabilizer (E414). It is highly soluble in water (1 g of AG in 2 ml of water can be dissolved) [22]. AG consists of about 97% polysaccharides and 3% proteionuos fraction [23]. According to Renard [24], the composition of the key monosaccharides present in AG are: 44% for galactose (Gal), 27% for arabinose (Ara), 13% for rhamnose (Rha) and 16% for glucuronic acid (GlcA) [25]. The main amino acids in AG are: arginine, alanine, histidine, glycine and glutamic [23]. Fig. 1, which was adapted from Cui [26] and Gashua [25], depicts a schematic representation of the molecular structure of AG where 1,3-linked β-D-galactopyranosyl units constitute the polysaccharide backbone of the AG, while two to five 1,3-linked β-D-galactopyranosyl units constitute the side chains, which are connected to the backbone by 1,6-linkages. The amphiphilic nature of the AG has