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Environmental remediation and monitoring of cadmium

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ABSTRACT

The complete remediation of extremely toxic elements, such as cadmium, must be achieved to control the various stages in their life cycles, from mining as virgin ore to using them as consumer and industrial end products, and recycling. Considerable progress has been made in monitoring cadmium ions, but sensors or captors that can simultaneously detect and remove toxic metal ions across a wide range of environments are still greatly needed. This article reviews the tools and the strategies for the environmental remediation of cadmium ions, with special emphasis on state-of-the-art colorimetric sensors. Selective colorimetric sensors based on immobilization of hydrophobic or hydrophilic chromophore molecules into nanosized space cavities have significant advantages because of their dual functionality, namely, early warning “detection” and removal of cadmium ions. This review concludes with a thorough evaluation of emerging challenges and future requirements in monitoring, detecting, and removing cadmium ions from environmental matrices.

Contents

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1. Introduction

Environmental pollution is a real, growing problem that urgently needs to be controlled. A wide range of toxic inorganic and organic chemicals is currently discharged into the environment in the form of industrial waste and causes serious air, soil, and water contamination [1]. Heavy metals are commonly found in wastewaters from chemical manufacturing, paint and coating, mining, extractive metallurgy, nuclear, and other industries. These heavy metals must be removed completely prior to discharge of industrial wastes to the environment. Among the heavy metals, cadmium ions have attracted much attention because of their hazardous nature [2,3].

As one of the transition metals, cadmium is a soft, silver-white or bluish-white metal that is chemically similar to zinc and mercury. The average concentration of cadmium in the Earth's crust is 0.1–0.5 ppm. Cadmium is widely used in pigments, plastics stabilizers, batteries, solar panels, and corrosion-resistant steel plating. Based on the British Geological Survey in 2010, the total world production of cadmium is around 22,300 tons [4]. Cadmium is continually transported between the three main environmental compartments: air, water, and soil.

The Comprehensive Environmental Response, Compensation, and Liability Act in USA has ranked cadmium as seventh in its priority list of top 275 hazardous materials [5]. Tobacco is the most important source of cadmium in air. A cigarette contains about 0.5–2 μg of cadmium, approximately 10% of which is inhaled by the smoker. The occupational exposure standards for cadmium were formerly set at 100–200 $\mu g/m^3$, but, for the past 40 years, the exposure standard was specified at 2–50 $\mu g/m^3$. Human exposure to cadmium induces genomic instability through complex and multifactorial mechanisms, including proteinuria, a decrease in glomerular filtration rate, and an increase in the frequency of kidney-stone formation that causes certain forms of cancer [6–11]. The World Health Organization and the Environmental Protection Agency recommend a 0.003 mg/L standard for Cd(II) in drinking water [12–15].

Several physical and chemical approaches to removal of cadmium ions from different environmental matrices have been reported, including chemical methods (e.g., precipitation and cementation), liquid-liquid extraction, cloud-point extraction and solid-phase extraction based on adsorption or ion exchange, electroanalytical techniques, flame atomic absorption spectrometry and inductively-coupled plasma mass spectrometry (broadly used for its sensitive determination) [16–22]. Among these approaches, the colorimetric solid sensor has the lowest cost and is the easiest to use, most reliable sensor for environmental or biological matrices. This review surveys the various tools and strategies of detecting and removing cadmium ions from biological and environmental samples (Fig. 1).

2. Removal of cadmium ions

2.1. Chemical

Precipitation is the most commonly used method for removal of heavy metal hydroxides, carbonates, or sulfides because of its low cost and simplicity. Cadmium can be precipitated using barium acetate, diisobutyldithiophosphinate, lime, and magnesium [23]. Cadmium can also be cemented using zinc powder [24]. Although precipitation is a simple, low-cost method, its applicability and practicality at low concentrations remain a challenge.

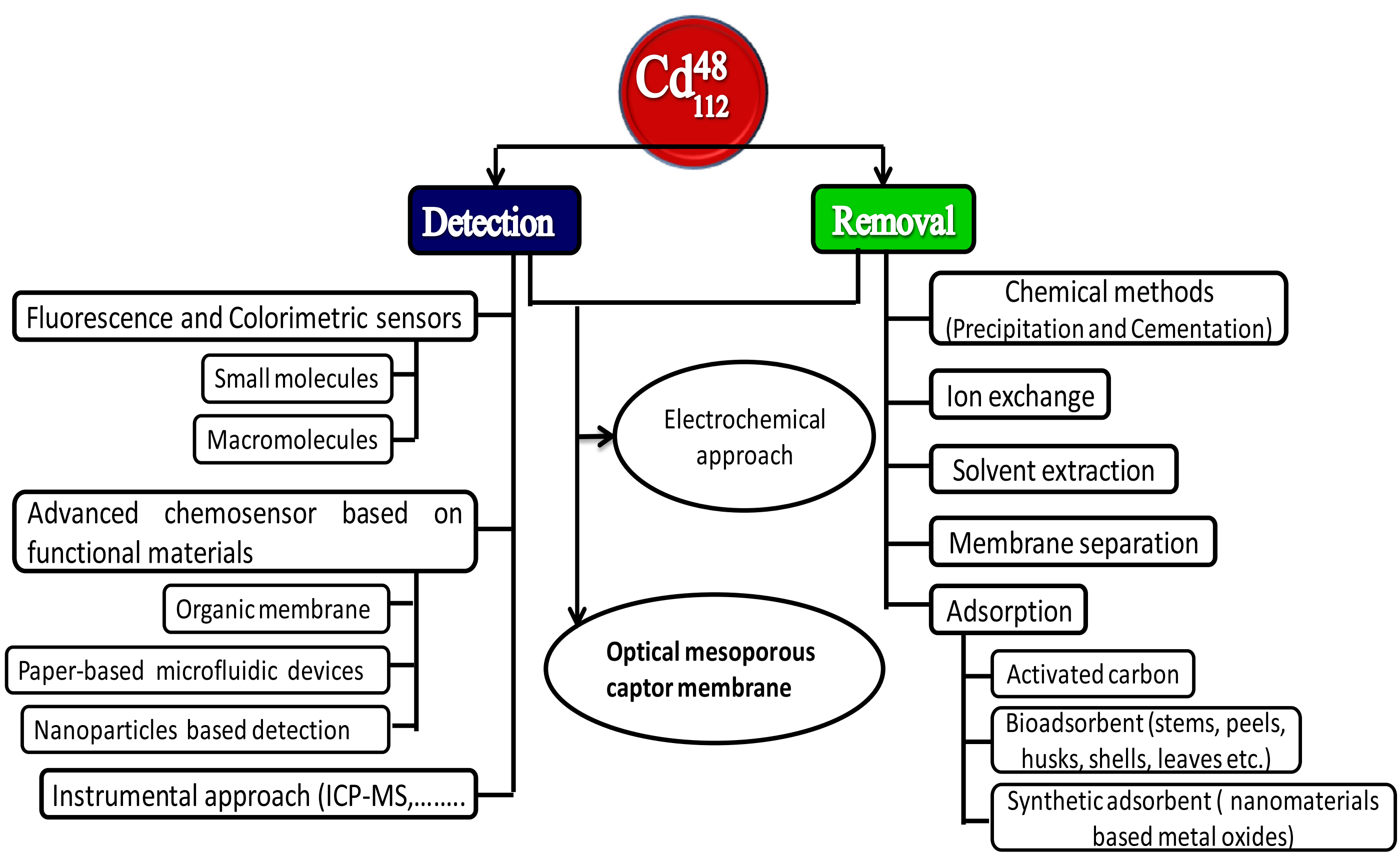

Fig. 1. General approaches to detection and removal of cadmium from the environment.