Environment International 80 (2015) 79–88

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Review

Vanadium, recent advancements and research prospects: A review

Muhammad Imtiaz [a], Muhammad Shahid Rizwan [a], Shuanglian Xiong [a], Hailan Li [a], Muhammad Ashraf [c], Sher Muhammad Shahzad [c], Muhammad Shahzad [b], Muhammad Rizwan [a], Shuxin Tu [a,*]

[a] Microelement Research Center, College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, PR China
[b] College of Veterinary Medicine, Huazhong Agricultural University, Wuhan 430070, PR China
[c] Department of Soil and Environmental Sciences, University College of Agriculture, University of Sargodha, University Road, Sargodha, Punjab 40100, Pakistan

A R T I C L E   I N F O

Article history:
Received 4 December 2014
Received in revised form 10 March 2015
Accepted 29 March 2015
Available online xxxx

Keywords:
Vanadium
Environmental fate
Biological function
Toxicity
Research advances
Remediation strategies

A B S T R A C T

Metal pollution is an important issue worldwide, with various documented cases of metal toxicity in mining areas, industries, coal power plants and agriculture sector. Heavy metal polluted soils pose severe problems to plants, water resources, environment and nutrition. Among all non-essential metals, vanadium (V) is becoming a serious matter of discussion for the scientists who deals with heavy metals. Due to its mobility from soil to plants, it causes adverse effects to human beings. This review article illustrates briefly about V, its role and shows the progress about V research so far done globally in the light of the previous work which may assist in inter-disciplinary studies to evaluate the ecological importance of V toxicity.

Contents

* Corresponding author at: College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, China.
E-mail addresses: m.imtiazpk92@hotmail.com (M. Imtiaz), arain_ms@yahoo.com (M.S. Rizwan), xsl@mail.hzau.edu.cn (S. Xiong), lihailan85@sina.com (H. Li), mashraf_1972@yahoo.com (M. Ashraf), smshahzad_uaf@yahoo.com (S.M. Shahzad), m.shahzad@iub.edu.pk (M. Shahzad), m.rizwan112@outlook.com (M. Rizwan), stu@mail.hzau.edu.cn (S. Tu).

http://dx.doi.org/10.1016/j.envint.2015.03.018
0160-4120/

1. Introduction

Vanadium (Z = 23), a transitional element listed in fourth row and Group VB in the periodic table is a hard, steel-gray metal. With two naturally occurring isotopes, ^{50}V is decomposed by electron capturing and β emission with a very long half-life (3.9×10^{17} years), and stable ^{51}V (99.75%). It was discovered for the first time in 1801 and rediscovered by Nils Gabriel Sefstrom (Swedish Chemist) in 1831, and Friedrich Wohler confirmed it (Cintas, 2004; Sefström, 1831). Vanadium can exist in a variety of oxidation states: −1, 0, +2, +3, +4, and +5; however vanadium pentaoxide (V_2O_5) is the most common existing and used form of vanadium. Ammonium metavanadate (NH_4VO_3), sodium metavanadate ($NaVO_3$) and sodium orthovanadate (Na_3VO_4) are also common forms of vanadium. Toxicity of V differs significantly due to compound nature and oxidation state of V; pentavalent vanadium is the most toxic and mobile form (Crans et al., 1998; Llobet and Domingo, 1984; Nechay et al., 1986).

About 80% of the world produced V is being used in steel industry as additive. As one of the important raw materials, it has become an integral part of iron–steel industries and different manufacturing unit such as automobiles, shipyard, fertilizers, etc. Its compounds are useful and have diverse range of applications extending from catalysts to ceramics, pigments, batteries and industries (Fig. 1). Apart from being utilized in nuclear applications, this element is applied for rust resistant, superconductive magnet and high speed steel and iron made tools. Its supplements are also being employed in medicines to control different diseases (Emsley, 2011).

2. Vanadium in soils

The main sources for vanadium contaminated soils are parental rocks (Kabata-Pendias and Pendias, 1993). However, soils can also be polluted by releasing of vanadium from anthropogenic activities (Nriagu and Pirrone, 1998; Taner, 2002) such as mining, industries, burning of fossil fuels, fertilizer and pesticide application and recycling of domestic waste. The primary source of vanadium is titanomagnetite deposits in which vanadium is present as a minor replacement for iron (Evans and White, 1987). Moreover, Fe-oxide compounds, organic fraction and argillaceous minerals also contained V (Kabata-Pendias and Pendias, 1979). Vanadium has a strong attraction for organic matter, and is thus mainly enriched in peats and other organic-rich soils. Mostly, V can be found as a part of residual rock minerals or it can be adsorbed or integrated into clays or Fe oxides minerals due to weathering and sometimes depending on host minerals (Kabata-Pendias and Pendias, 1984). Vanadium is never found unbound in nature and about 65 naturally occurring minerals such as carnotite, roscoelite, vanadinite, patronite, bravoite and davidite (Baroch, 2006; Lide, 2008) contained vanadium however, carbon containing deposits have higher quantity of V than others (Sachin et al., 2011). In lithologies, shales (130 mg V kg^{-1}) contained greater concentrations than sandstones and carbonate rocks (20 mg V kg^{-1}) (Siegel, 1979; Adriano, 1986; Alloway, 1990).

Vanadium, as a plentiful element is widely spread and distributed with an average amount of 159 g/t and 0.14 mg kg^{-1} in earth crust. The average abundance of 135 mg/kg in soil ranks this element 5th among all transitional metals and 22nd among all discovered elements in the earth crust (ATSDR, 2012; Amorim et al., 2007; Baroch, 2006; Anke, 2004; Moskalyk and Alfanti, 2003; Adriano, 1986; Mason and Moore, 1982). It is also a common element in the lithosphere and part of alkaline and argillaceous rocks (Fig. 2).

Commonly, the soils around the combustion sites (oil refineries, fuel plants and automobile units) showed the highest level of vanadium than natural abundance (Khan et al., 2011; Teng et al., 2011a). Teng et al. (2011b) conducted research about occurrence of vanadium in soil in China and the results showed that the bioavailability of vanadium in soils from mining, smelting area, in agricultural and urban park were 18.0–83.6 mg kg^{-1}, 41.7–132.1 mg kg^{-1}, 9.8–26.4 mg kg^{-1} and 9.9–25.2 mg kg^{-1}, respectively.

The geochemical characteristics of vanadium are strongly dependent on two major factors; oxidation state and pH. In reducing conditions the relatively immobile V (III) is dominant; the higher oxidation states are much more soluble. Average concentration of vanadium in different soils varies from 10 to 220 mg kg^{-1} dry mass according to the soil types and chemical characteristics (Połedniok and Buhl, 2003; Małuszynski, 2007). The soils which are directly under the use of human beings contain much higher amount of vanadium (1510 to 3600 mg kg^{-1}) and the mining areas contain vanadium up to 738 mg kg^{-1} and 3505 mg kg^{-1} (Panichev et al., 2006; Teng et al., 2006). Previous research revealed that lime stone soils contained higher level of vanadium than peat soils, soils near the industrial units have more vanadium because of human activities (Kabata-Pendias and Pendias, 1993; Połedniok and Buhl, 2003; Ovari et al., 2001).

The soil community such as soil in-vertebrates, plants and micro-organisms is the major source to find the hazardous effects of vanadium in soil. Therefore, many countries have made criteria through which toxicity of vanadium can be measured via community responses. Canadian scientists developed guidelines about soil-quality for vanadium toxicity, to protect the environment. According to that 130 mg kg^{-1} is the optimum range of vanadium in soil for vascular plants and soil in-vertebrates (CCME, 1999). Moreover, these guidelines are not applicable to assess the potential risk of vanadium for native non-crop plants because these guidelines were made using crop species like cabbage, radish and lettuce (CCME, 1999), Netherlands (42 mg kg^{-1}), Czech Republic (180 mg kg^{-1}) and Slovenia (120 mg kg^{-1}) also

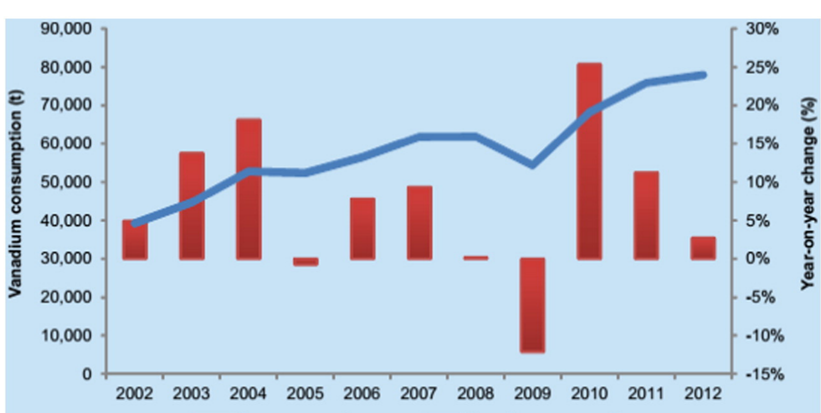

Fig. 1. World: Estimated consumption of vanadium (Vanadium: Global industry, 2013).