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Aloe vera waste biomass-based adsorbents for the removal of aquatic pollutants: A review

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ABSTRACT

Aloe vera has been cultivated for many centuries for its beneficial properties, finding application in a wide range of medical and health products. Nowadays, the research has also focused on an alternative use of *Aloe vera* which is related to environmental applications such as clean water technology/wastewater treatment process. In recent years, biosorption has been shown to be a cost-effective and efficient alternative method for removing various pollutants from wastewater and water. This work provides a comprehensive review on using *Aloe vera* waste biomass-based sorbents, as well as modified counterparts, for the removal of heavy metals, dyes and other pollutants from aqueous media. The discussed biosorbents have been grouped in five categories based on the treatment of the *Aloe vera* leaves. Adsorption mechanisms, in addition to the significant factors influencing sorption capability like physical and chemical properties of the adsorbent, initial concentration, initial pH and temperature of the solution, dosage and contact time, have been discussed in detail. Furthermore, the applied equilibrium and kinetic models have been also summarized. The history, taxonomy, botany, and applications of *Aloe vera* are also presented in brief.

1. Introduction

Aloe vera has been recognized as one of the most prominent medicinal plants with various applications (Baruah et al., 2016). Because *Aloe vera* leaves contain numerous bioactive compounds, its usage has been associated with several health benefits since ancient times. Some of the reported properties include wound healing, anticancer, antioxidant, immunomodulatory and laxative (Reynolds and Dweck, 1999), amongst others. Nevertheless, it must be pointed out that the biological activity of these compounds is attributed to their synergist effect and not to a sole action of an individual substance (Avijgan et al., 2014; Hamman, 2008). Besides medicine and pharmaceutics, *Aloe vera* is being valorized by the food industry, cosmetology and nanotechnology (Kumar and Yadav, 2009; Soltanizadeh and Ghiasi-Esfahani, 2015; Yapar, 2017). Recently, *Aloe vera* and its by-products have attracted attention for employment in environmental applications.

Water is considered as an important and scarce commodity in all countries around the world. This substance is the source of life and is of the basic survival needs for human (Enoh and Christopher, 2015). A global issue is the quality of water which is deteriorating day by day mainly due to the anthropogenic activities, population growth, unplanned urbanization, rapid industrialization and unskilled utilization of natural water (De Gisi et al., 2016; Enoh and Christopher, 2015).

Intense industrial and agricultural activities result in the contamination of wastewater with various pollutants such as dyes, pesticides, toxic heavy metals, organic compounds, phenols, dyes, and other persistent organic pollutants (Anastopoulos and Kyzas, 2015a). These types of pollutants enter the food chain and are taxed with causing toxic

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effects, cancer, and diseases, thus affecting the aquatic biota and human health (Anastopoulos and Kyzas, 2015a). Moreover, wastewaters derived from municipalities and from various industries, which are highly loaded with various pollutants, have become of serious global environmental issues in the last decades (Anastopoulos et al., 2013). Therefore the removal of emerging contaminants of concern is now as ever important in the production of safe drinking water and the environmentally responsible release of wastewater (Grassi et al., 2012).

Compared to other purification technologies such as chemical precipitation, carbon adsorption, ion exchange, evaporation, and membrane filtration (Rajasulochana and Preethy, 2016), biosorption appears as a promising process because of its advantages in terms of low-cost operation, easiness of handling, avoidance of generating secondary pollutants (e.g. toxic sludge), and high efficiency over a wide range of pollutants (Anastopoulos and Kyzas, 2014; Javanbakht et al., 2014; Rao and Prabhakar, 2011).

There are many biosorbents exhibiting high adsorption efficacy for aquatic pollutants such as algae (Anastopoulos and Kyzas, 2015b; Bilal et al., 2018; Jayakumar and Govindaradjane, 2017), fungi (Dhankhar and Hooda, 2011), bacteria (Hansda and Kumar, 2015; Vijayaraghavan and Yun, 2008), plants waste such as maize, barley husk, jute, cotton stalks, rice husk, food crop straw (Saba et al., 2016), composts (Anastopoulos and Kyzas, 2015a; Anastopoulos et al., 2013), agricultural peels (Anastopoulos and Kyzas, 2014; Bhatnagar et al., 2015; Dadwal and Mishra, 2017; Salmani et al., 2017), olive oil industry waste (Anastopoulos et al., 2015; Bhatnagar et al., 2014), coffee residues (Anastopoulos et al., 2017b), barks (Şen et al., 2015), banana waste (Ahmad and Danish, 2018) wood waste (Saeed et al., 2005; Shin et al., 2007), and sugar industry waste (Anastopoulos et al., 2017a).

For the first time, the present review article summarizes and discusses the synthesis of *Aloe vera* waste biomass-based sorbents (raw, treated, ash, activated carbons) and their performance in the removal of different aquatic pollutants. Isotherm, kinetic, and equilibrium modelling have been discussed in details. Moreover, parameters which affect the biosorption process, such as the solution's pH, contact time, temperature and biosorbent's dose, have been also evaluated.

2. History, taxonomy and botany

The etymology of *Aloe vera* comes from a combination of Arabic and Latin words. "Alloeh" means "shining bitter substance" in Arabic and "vera" means "true" in Latin (Basmatker et al., 2011). The first recorded pharmaceutical use of *Aloe vera* has been depicted in a Mesopotamian clay tablet (1750 B.C.E.). Egyptians used it for skin infections (550 B.C.E) and, in 74 C.E., Pedanius Dioscorides, a Greek physician in the Roman army, reported that *Aloe vera* could heal wounds, hemorrhoids, infections and be used as a treatment for hair loss, in his book *De Materia Medica* (Shelton, 1991). Intensive cultivation started in the 1920s and in the 1960s Dr. Bill C. Coates extracted *Aloe vera* gel without losing the healing properties. Nowadays, Mexico is the leading country among the *Aloe vera* producers worldwide (Pal et al., 2013).

The taxonomy of *Aloe vera* is presented in Fig. 1. Its botanical family includes also other plants with established chemical properties. Based on the International Rules of Botanical Nomenclature, the official scientific name is *Aloe barbadensis* Mill. with *Aloe vera* (L.) Burm. F. as a synonym (Sánchez-Machado et al., 2017).

The *Aloe vera* plant is a perennial xerophyte, with thick, fleshy, sharp leaves that form a rosette at the stem. The green, triangle leaves (12–16 per plant) are up to 0.5 m long and can weight up to 1.5 kg when mature. They contain gel, with 98% water and 0.66% total solids, that arises from the parenchyma cells (Baruah et al., 2016; Maan et al., 2018; Shelton, 1991). Red, yellow, purple or pale stripped flowers bloom from October to January and fruits develop during spring. The plant usually does not suffer from diseases, except the presence of black fungal spots or a soft bacterial rotting that may occur occasionally. It lasts long drought periods and cannot survive at low temperatures. *Aloe vera* is native to Northern Africa and can also be found in the Mediterranean region, India, South America and South Africa along the Nile (Ahlawat and Khatkar, 2011; Maan et al., 2018).

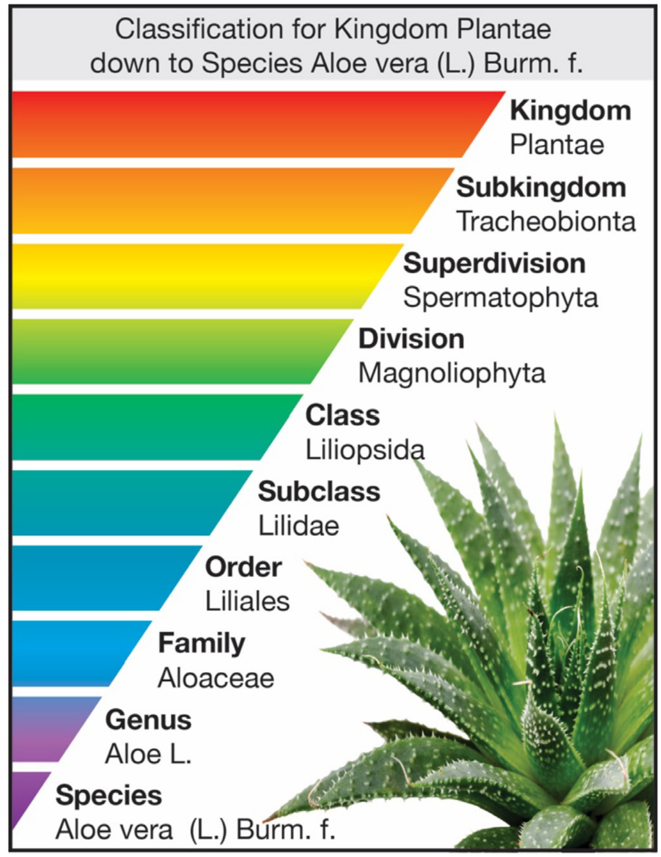

Fig. 1. The taxonomy of *Aloe vera.*

3. *Aloe vera* applications

The content of *Aloe vera* is characterized by its abundance in compounds with biological activity, namely mono-, di- and polysaccharides, phenolic compounds, minerals, water- and lipid soluble vitamins, organic acids and lipids (Minjares-Fuentes and Femenia, 2017; Sánchez-Machado et al., 2017). Their beneficial effects and applications are summarized below with an emphasis on recent advances.

3.1. Food industry

According to Food and Drug Administration (FDA) *Aloe vera* can be safely consumed as "dietary supplement" in the U.S. In Europe, it is listed among "flavoring compounds" in accordance with European Commission Annex I of Regulation No. 1831/2003 (Javed and Atta-Ur, 2014).

The antimicrobial properties of *Aloe vera* have been valorized by the food industry for the production of herbal edible coatings. In addition to their activity against microorganisms, such coatings enhance shelf life of products since they prevent moisture loss (Hassan et al., 2017). *Aloe vera* gel coatings have been used for post-harvest protection of peaches, papaya, sapota, melon and other fruits (Hazrati et al., 2017; Kuwar et al., 2015; Padmaja et al., 2015; Riaie et al., 2017). Recently, Chin et al. investigated the potential of combining fish gelatin and various concentrations of *Aloe* gel, for the production of composite films (Chin et al., 2017). The composite films showed improved physical and functional properties and concentration-dependent antioxidative activity which makes active packaging with these films feasible.

The water retention property of *Aloe vera* improved the final quality