Sensors and Biosorption for Better Reuse of Wastewater

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Abstract. Water is an increasingly scarce resource today due to natural and anthropic factors. Therefore, wastewater treatment and reuse is an important parameter of sustainable development. The necessity of reuse wastewater especially for irrigation becomes evident. Innovative wastewater monitoring and treatment methodologies are finding application as technologies improve. The most talented technological advances include: innovative monitoring techniques based on new sensors, computerized telemetry devices, and innovative data analysis tools. Research on sensor and alarming systems is advancing rapidly. Likewise, new methods for wastewater treatment are continually introduced, including the use dead plants biomass for heavy metals removal from wastewater. In this paper, the use of sensors for monitoring and the application of biosorption techniques for wastewater recycling are discussed and evaluated. We propose biosorption for removing heavy metals from wastewater. Sensors are used before and after the biosorption for check the quality of water and the proper functioning of the biosorption process.

Keywords: Wastewater, Sensors, Water quality, Heavy metals, Biosorption.

1 Introduction

Water deficit is one of the greatest problems of nowadays. The exploitation of water resources combined with climate change is precursors of this delicate situation [1]. Four billion people suffer scarcity of water at least one month a year [2]. On the other hand, approximately 65-70% of fresh water is for agricultural purposes [3].

The scarcity of water presents a big problem for the crops in the agriculture, of which the populations of arid and semi-arid zones are supplied. It is in this area where the use of wastewater takes great relevance and can be an alternative of great value to increase agricultural production [4]. Likewise, the quality of water also plays a big role when it comes to using water to irrigate. In most areas, the water quality is enough to be used as irrigation, but in other places, especially in third world countries or in the process of development, water is not suitable for irrigation due to its high content of pollutants. In Europe, a multitude of projects have been carried out for the reuse of wastewater.

Wastewater is treated in such a way that not all harmful agents are eliminated in conventional process. For this reason, many experts propose the application of a tertiary treatment in which to apply biosorption. This process is based on physical and chemical processes by adsorption, where the particles come together and precipitate. Biosorption can be used in all types of sources of pollutants, from non-point sources such as runoff caused by heavy rains through localized focus such as industrial wastewater [5]. Likewise, biosorption is a technique with great aptitude to eliminate the heavy metals of these waters, considering themselves sustainable with the environment and differentiated from the others by their minimum cost of investment [6].

In order to obtain data in real time and in this way to maintain constant monitoring, measurement sensors have started to be used. Wireless Sensor Networking (WSN), is an Intelligent System of sensors, which allow controlling the water quality and, in this way, analyzing the amount of irrigation or the necessary irrigation.

In the current research, we are going to highlight the possibility of using biosorption for water reuse. Different sensor after and before biosorption process are supposed to be used to check its operation and whether we find optimal water.

The rest of this paper is structured as follows: Section 2 presents the goals of our proposed work; Section 3 demonstrates the use of sensors for monitoring water quality; Section 4 presents biosorption techniques and its importance when it comes to eliminating toxic metals from industrial waters; Section 5 discusses the use of sensors, biosorption, and future challenges and in section 6 conclusions and future work are presented.

2 Goals of this paper.

In Mediterranean region especially, the design and operation of competitive and cost effective wastewater treatment systems for irrigation is a real challenge. Within this context an innovative system of wastewater treatment has been proposed that is based on biosorption technology and sensors.

In this section, we explain as the system works, the needs of the sensors, and the mathematical expression of the system.

The biosorption system that we are going to develop could be used for augmenting the reuse of wastewater. It comprises sensors for monitoring water quality in the entry and exit. Sensors in the entry are used for detecting if the water needs treatment. Sensors in the exit are used to assess released water quality and to explore the efficiency of biosorption system. Biosorption technique is used for eliminating wastewater pollutants that are not removed by both primary and secondary wastewater treatment plants. In Fig 1, we show the scheme of the proposed system.

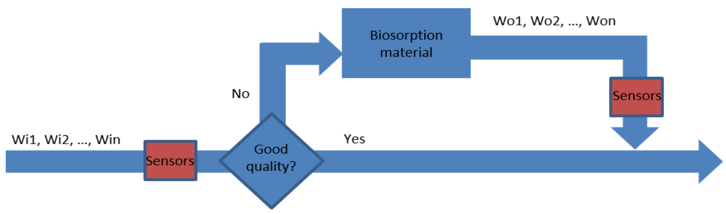

Fig.1. Scheme of the proposed wastewater treatment system

For our proposal, the sensors need to comply with different characteristics: (I) Low cost, because the sensors will be used in many areas especially developing countries. (II) Physical sensors. The use of chemical sensors caused an increase in maintaining cost. (III) Low electrical demand. The sensors are located in the countryside when the supply can be are a problem. (IV) The sensors should be able to detect values in long periods. (V) The sensors should not need a daily calibration.

In the wastewater, the main pollutants are: (I) Heavy metals. (II) Nitrogen, (III) Phosphorus, and (IV) microorganisms. Microorganisms are relatively easy to eliminate by means of disinfection processes that usually occur in conventional wastewater treatment plants. In addition, pollutants can be removed in wastewater if the way of operating the plant is changed. Finally, heavy metals are a group of chemical elements. ~~The main~~ They are Mercury, Nickel, Copper, Lead, and Chromium. These pollutants can be eliminated in wastewater treatment plants with chemical precipitation, carbon adsorption, ion exchange, evaporation and membrane processes. However, the typical concentration is low and does not compensate economically. Also, these techniques have certain disadvantages such as incomplete metal removal, high reagent and energy consumption and generation of toxic sludge that require disposal.

Another problem is the high conductivity. This is usually due to marine intrusion and represents a huge cost for its purification. That is why in the presence of high concentrations of salinity is advisable not to use that water for irrigation.

Our system can be defined with equation (1). W_{in} are the concentration of the different pollutants that we measure with our sensors before the biosorption. W_{on} is the same pollutants of W_{in} but after the biosorption. Finally, Ab_{nn} is the % of absortion of the pollutant by the biosorption material. So each output value can be expressed as given by equation (2):

$$\begin{pmatrix} W_{o1} \\ W_{o2} \\ W_{o3} \\ \cdots \\ W_{on} \end{pmatrix} = \begin{bmatrix} Ab_{11} & 0 & 0 & 0 & 0 \\ 0 & Ab_{22} & 0 & 0 & 0 \\ 0 & 0 & Ab_{33} & 0 & 0 \\ . & . & . & . & . \\ 0 & 0 & 0 & 0 & Ab_{nn} \end{bmatrix} * \begin{pmatrix} W_{i1} \\ W_{i2} \\ W_{i3} \\ \cdots \\ W_{in} \end{pmatrix} \quad (1)$$

$$W_{oj} = \sum_1^n Ab_{jj} \cdot W_{ij} \quad (2)$$

3 The use of sensors in assessing water quality

In this section, we analyze the use of sensor for monitoring wastewater quality after and before treatment for irrigation.

For online monitoring, it is necessary to have sensor nodes. These nodes are composed of sensors, a microcontroller, and a system for transmitting the information. Also, it is necessary to have a protocol stack to indicate where the information should be sent.

The main methods for monitoring heavy metals with sensors are spectroscopies methods [7] electrochemical technique [8]. An example of spectroscopy method is presented for Forzani et al. [9]. They developed a sensor based on high-resolution differential surface plasmon resonance. They use light polarized (635nm) that is focused onto a metal film. The metal film has a sensitive area able to trap heavy metals and a reference area. The light ~~are~~ is reflected and detected in four photocells. These reflect have dark lines, corresponding to resonance of surface plasmon. An electrochemical method is presented for Xie et al. [10] used an iridium ultramicroelectrode (chip) arrays for detect trace concentration of Pb and Cd. The chip is manufactured in silicon technology with four working electrode. Each working electrode contains 1012 disc-shaped iridium ultramicroelectrodes.

Other parameter that can be monitoring with sensors is the conductivity. The conductivity sensor is based on a conductivity bridge [11] or with coils [12]. Parra et al. [12] developed a WSN with conductivity sensor based in two coils for monitoring the salinity in estuaries. The system uses a Flyport module with Wi-Fi card. The nodes transmit the information to the server with an infrastructure type ad-hoc connection via Wi-Fi.

4 The use of biosorption for heavy metals removal.

Bioremoval of heavy metals from polluted water has been suggested as a potential alternative to the existing physicochemical technologies for detoxification and recovery of toxic and valuable metals from wastewaters. [13] The natural capacity of microorganisms, fungi, algae and plants to take up heavy metal ions and radionuclides, in some cases, to promote their conversion to less toxic forms ~~has~~ have sparked the interest of microbiologists, biotechnologists and environmental engineers for several decades. Consequently, various concepts for "bio-removal" of metals from waste streams and bioremediations of contaminated environment are being proposed, some of which were brought to pilot or industrial scale [14, 15, 16].

Generally, it has been postulated that there are three routes to follow considering "bio-removal" of metallic species from solutions. The first two rely on properties of living cells and involve active metal uptake- bioaccumulation (i.e., plasma membrane mediated transport of metal ion into cellular compartment) and eventual chemical conversion of mobile metal to immobile forms. The later may occur in the cytoplasm, at the cell surface or in the solution by precipitation of metal ion with metabolites, via redox reactions or by their combination [17].

The effectiveness of the process will depend on the (bio) chemistry of particular metal and on metabolic activity of eligible organism, which is in turn affected by the presence of metal ions. To this point, the use of metallo-tolerant species or physical separations of the production of metal-precipitating metabolite from metal precipitation in contaminated solution produce viable methods for treatment of industrial effluents [18]. Several of them are to various extents dependent on or involve the metabolism-independent metal uptake event at the cell wall by polysaccharides, associated molecules, and functional groups. This metal sequestration capacity is commonly known as biosorption, which itself represents the third potent way of "bio-removal" of metals from solution [19]. The biosorption process is a non-polluting efficient process that can be highly selective; it operates easily with low cost for the treatment of large waste water systems [20]. It uses divergent biomass such as seaweed, microalgae, bacteria, and various other plant materials [13]. However, it is affected by many factors such as: pH, metal ions concentration, contact time, temperature as well as biosorbents dosage (20). Biosorption process was proved to be affected by several factors: biomass type, pH, ionic strength contact time, temperature and biosorbents dosage [21, 22, 23, 24, 25]

A considerable number of bacteria, fungi, algae and yeasts, and different wastes and by-products of the agriculture and food industry have been investigated for their biosorbents metal properties (Das et al., 2008)

Bacterial surface display has been proved a viable approach for a wide range of medical, industrial and environmental applications. Metal binding by biomolecules of structural components or excreted polymers of bacteria is generally fortuitous and relative efficiencies depend on attributes of the metal ion as well as on reactivity of provided ligands [19].

Shi et al. [26] investigated the efficiency of *Pannonibacter phragmitetus* on the reduction of Cr (VI) from aqueous solution was investigated. The maximum rate of Cr removal was found to be 562.8 mg L-1 h-1. Miranda et al. [27] have been isolated two species of cyanobacteria, *Oscillatoria laetevirens* and *Oscillatoria trichoides* from a polluted environment and studied for their Cr (VI) removal efficiency from aqueous solutions, the highest removal through biosorption for living biomass was achieved between pH 5 and 5.9 and for dead biomass at pH 2. Of the two species, living cells of *O.trichoides* were most effective for which removal was 38.7mg g^{-1} and reached 51.6% of the total Cr (VI) at 30 mg L^{-1} at pH 5–5.9.

Biosorption of hexavalent chromium using biofilm of Escherichia coli ASU 7 supported on granulated activated carbon (GAC), lyophilized cells of Escherichia coli ASU 7 and granulated activated carbon has been investigated [28] .the maximum adsorption removal (qmax) of hexavalent chromium calculated from Langmuir equation for biosorption by biofilm, GAC and bacteria are 97.7, 90.7, 64.36 mg/g, respectively. The results demonstrate that biofilm supported on GAC, which prepared by impregnation method could be used as promising biosorbents for the removal of Cr (VI) ions from aqueous solutions.

Common filamentous fungi can also sorb heavy metals from aqueous solutions. Fungal biosorption largely depends on parameters such as pH, metal ion and biomass concentration, physical or chemical pretreatment of biomass, presence of various ligands in solution, and to a limited extent on temperature. The cell-wall fraction of biomass plays an important role in the sorption of heavy metals.

The biosorption of chromium (VI) from saline solutions on dried *Rhizopus arrhizus* was investigated [29]. Results showed that the maximum chromium (VI) sorption capacity was for 78.0 mg/g of sorbent. Also, the biosorption efficiency of tropical white-rot basidiomycete on chromium (VI) removal from aqueous solutions has been studied [30] .It was found that the Pre-treatment of fungal biomass with acid resulted in100% metal adsorption compared to only 26.64% adsorption without any pre-treatment.

The biomass of *Mucor rouxii* and *Absidia coerulea* along with chitosan and walnut shell media were used for the removal of oil from water [31]. Results demonstrated that nonviable *M.rouxii* biomass was more effective than *A.coerulea* biomass in removing oil from water. The adsorption capacities for standard mineral oil, vegetable oil and cutting oil were 77.2, 92.5, and 84 mg/g of biomass, respectively. However, these capacities using *M.rouxii* biomass were less than those obtained with chitosan and walnut shell media.

Biosorption onto plants and raw agricultural waste is a low-cost treatment technique for the removal of contaminants, including heavy metals, from water and wastewater.

The biosorption efficiency of some agricultural wastes as maize husk on the removal of Cd(II), Pb (II) and Zn(II) ions from aqueous solutions was investigated [32]. It was found that the modification of the biosorbent by EDTA enhanced the biosorption capacity. Jain et al. [33] studied the biosorption efficiency of sunflower *Helianthus annuus* waste for Cr (VI) removal from waste water under different experimental conditions and biosorbent's treatments, either in boiling water or in formaldehyde. Obtained efficiencies were 81.7 and 76.5% for boiled and formaldehyde treated biosorbents, respectively and (4.0 g/L) biosorbent's dose.

Biomass of *Garcinia mangostana* shell was investigated for the removal of Pb(II), Cd(II) and Co(II) [34]. The sorption capacity of Pb(II), Cd(II) and Co(II) reached 3.56 mg/g, 3.15 mg/g and 0.34 mg/g, respectively.

The biosorption efficiency of tea waste on the removal and the recovery of U (VI) from the aqueous solution were investigated [35]. The removal and recovery percentages were up to 86 % and 80 %, respectively. Moreover, it was found that the biosorption of U (VI) by tea waste is a physical multilayer adsorption.

Gossypium barbadense waste was proved to be an efficient biosorbent for the removal of Cd(II) ion from aqueous solutions [25]. Based on the regression model (R2 0.873), the optimum experimental factors were pH 7.61, biosorbent dosage 24.74 g/L, particle size 0.125–0.25 mm, and adsorption time 109.77 min, achieving Cd2+ removal of almost 100% at concentration 50 mg/L

Fawzy et al [36] used *Potamogeton pectinatus* biomass for Ni(II)-ions biosorption from aqueous solutions . Results showed that Ni(II)-ions were successfully loaded on the biomaterial surface due to the ion exchange mechanism by different cations, mainly K+. Ni(II)-ions (4.25 ± 1.26 mg/L) . Results also showed that Ni(II)-ions was totally removed from real industrial wastewater within 30 minutes, and the net cost of the adsorption system was 3.4 $USD/m3.

According to gathered information using plant biomass, as biosorbents, are proved to be more safe, ecofriendly and economically feasible. As such in our system we will use plant biomass for wastewater treatment.

5 Discussion and future challenges

Water sacristy is deeply linked to food security. As such , reuse of water is one of the more important challenges of the humanity as In this paper we propose an innovative wastewater monitoring and treatment methodology by using sensors for monitoring wastewater before and after of biosorption process.

The main pollutants of wastewater are microbiota, nutrients, and heavy metals. Usually the wastewater plants have a disinfectant process based on chlorination or in UV irradiation. These systems are very effective. Therefore, they will hardly cause problems in the crops. The principal nutrients are phosphorus and nitrogen; these can be eliminated in wastewater treatment plant if the process is adapted. On the other hand, heavy metals are the pollutants that deter reuse of wastewater. Generally, these pollutants are not removed in conventional wastewater plants. Low cost and relatively higher efficiency of heavy metal removal from diluted solutions are among the leading advantages of biosorption. Besides, regeneration of biosorbents and possibility of metal recovery On the other hand, biosorption is mainly used to treat wastewater where more than one type of metal ions would be present; the removal of one metal ion may be influenced by the presence of other metal ions.

We have appointed different works about the use of different biomasses to perform biosorption. As it, is intended to eliminate different pollutants.

Wastewater quality assessment studies should be done first to explore type and species of contaminants present in the water where we want to install our system. According to the collected data, it will be decided to choose one plant species or another as biosorbents. Also, biomass of mixed plant species could be used.

Increased levels of electric conductivity in irrigation water can have an adverse effect on crop production. For measuring the conductivity there are two methods. The inductive methods are better than Conductivity Bridge, because the inductive methods do not need to be in contact with water. This allows a reduction of the water corrosion in the sensor part, increasing the life of the sensor. The turbidity does not have a direct negative effect on agriculture. The presence of solids can cause an obstruction in the irrigation systems. In addition, the turbidity can cause a negative acceptation of the water by the agriculturist.

6 Conclusion and future works

In this paper, we study the application of technology for augmenting the reuse of wastewater. We propose the use of biosorption technology for removing pollutants from wastewater and sensors for monitoring the water irrigation.

The main pollutants in wastewater are pathogens, nutrients, and inorganic pollutants, salts and heavy metals. Pathogens and nutrients can be easily eliminated in wastewater treatment plants with changes in the process. In contrary, the concentration of heavy metals is low and usually is not removed in these treatment plants. Another pollutant is the conductivity that affects the production of crops. Water with high levels of conductivity should be rejected for use in irrigation. The use of sensors allows monitoring the water. We can use electrochemical or spectroscopic methods for detecting the heavy metals. We will need to test in real conditions for select the best option. Finally, for measuring the conductivity we use inductive sensors. The efficiency of biosorption technique and biosorbents used will be determined by the competence in the removal of heavy metals, the water conditions and the place where it is installed. In future work, we will develop our proposal and test it in real conditions to verify the optimum function of it.

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