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A new application of anaerobic rotating biological contactor reactor for heavy metal removal under sulfate reducing condition

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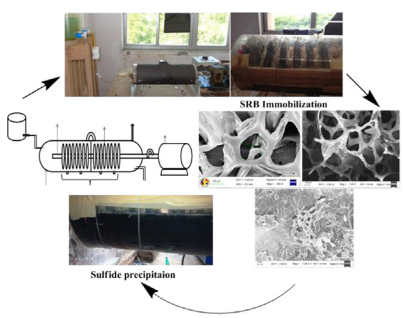
HIGHLIGHTS

- Continuous metal removal was evaluated in an anaerobic rotating biological contactor reactor.
- Very high removal was achieved for a low inlet metal concentration.
- Cu(II) removal was the best among all the metals studied at all loading rates.
- Metal removal mechanism is due to sulfate reduction to sulfide precipitation.
- High metal loading rate is detrimental to the performance of the An-RBC reactor.

GRAPHICAL ABSTRACT



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ABSTRACT

This study evaluated the performance of a continuously operated laboratory scale anaerobic rotating biological contactor (An-RBC) reactor at 24 h and 48 h residence time (RT) for heavy metal removal from synthetic wastewater under sulfate reducing condition. A maximum removal of Cu(II) (97%) followed by Cd(II) (90%) and more than 77% removal in case of the other metals, *viz* Pb(II), Fe(III), Zn(II) and Ni (II) were obtained for a maximum inlet metal concentration in the range 50–175 mg/L at 48 h RT. Metal loading rates greater than 3.64 mg/L·h in case of Cu(II) and 1.87 mg/L·h, in case of Fe(III), Pb(II), Ni(II), Zn(II) and Cd(II) are toxic and inhibitory to SRB activity and are therefore, detrimental to the performance of the An-RBC reactor. The metal removal values were slightly reduced at 24 h RT and the heavy metal removal was in the order: Cu > Cd > Pb > Fe > Zn > Ni at both the RTs. Sulfate removal results further confirmed that the heavy metal removal is due to sulfide generation in the reactor system. Field emission scanning electron microscopy (FESEM) images clearly revealed the immobilized sulfate reducing bacteria (SRB) onto the support material. Hence, this study demonstrated an excellent potential of the An-RBC reactor for treating metal containing wastewater even at high inlet concentration.

1. Introduction

Heavy metals find an essential and extensive role in several applications, and as a consequence of which these metals are discharged into the environment from different industries, such as metallurgy, leather industries, mining, nuclear and electronic industries, electroplating plants, etc. [1,2]. Metals such as Cd, Cu, Ni, Fe, Hg, Mn, Pb and Zn are of particular interest, discharged from several industrial wastewater and acid mine drainage (AMD) [3]. These metals are often toxic at high concentration and, therefore, pose a serious risk to both human health and the environment. Along with the heavy metals, sulfate is abundantly found in

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wastewater, such as AMD and effluent from several other industrial processes. Therefore, elimination of metals and sulfate from wastewater before their discharge into the environment is mandatory [2].

In view of the strict environmental legislations governing wastewater discharge standards, biological processes seem to be more attractive than the already existing technologies for treating wastewater containing heavy metals and sulfate. Biogenic sulfide precipitation of metals, one of the biological processes, is proven to be an efficient and successful method for treating wastewater containing both metals and sulfate. This method depends on the capability of sulfate reducing bacteria (SRB) to mediate the elimination of metals *via* their sulfide precipitation [4].

Compared with the conventional chemical techniques applied for metal removal, heavy metal removal by sulfide precipitation entails several merits; for example, this process produces low residual sludge amount which is more insoluble than the sludge produced by chemical treatment systems [5]. Besides the elimination of metal toxicity from wastewater, this method also aids in recovering the metals as their sulfide salts [6]. Hence, it is recognized as a resourceful method to both remove and recover metals from contaminated wastewater [4]. However, for a successful application of this method, the choice of a suitable reactor system is essential. Among the several bioreactor systems to treat wastewater, rotating biological contactor (RBC) reactor is well known for treating various types of effluents [7–9] as it offers a high interfacial area on its rotating discs for biomass growth and attachment, which enables sufficient contact between the microorganisms and contaminants present in the wastewater [10].

Furthermore, RBC reactor is highly suitable for treating industrial wastewater and sewage [11] owing to the combined action of both suspended growth and fixed film microorganisms present in this reactor system. Although RBC reactors involve high initial investment cost, simple process control, low operation and maintenance costs make these reactors technically feasible for large scale applications [12–14].

The utility of RBC reactors have been examined at the laboratory scale for removal of chemical oxygen demand (COD) from textile dying and synthetic wastewater [15]. However, it has not been tested for the removal of heavy metals by biogenic sulfide precipitation. Hence, this study was focused on evaluating the performance of a laboratory scale anaerobic rotating biological contactor (An-RBC) reactor in treating synthetic metallic wastewater containing heavy metals, namely Cd(II), Cu(II), Ni(II), Fe(III), Pb (II) and Zn(II) at different initial concentration. Further, the effect of residence time (RT) (24 h and 48 h) on heavy metal removal in the An-RBC system was examined. Metal precipitation by SRB occurs in the range of within a few days to 5 days [16] and therefore, these two RT values were chosen, which was also based on field application and economic viability. For characterization of the bio-support material used for SRB immobilization in the An-RBC reactor, field emission scanning electron microscopy (FESEM) was used.

2. Materials and methods

2.1. SRB source and growth conditions

Mixed SRB consortium used in this continuous An-RBC reactor study was acquired from a laboratory scale upflow anaerobic packed bed reactor treating sulfate rich wastewater [2,17,18]. Microbial community analysis of the mixed consortia showed that the SRB consisted of *Desulfovibrio* species [17]. Modified Postgate medium was used for the SRB growth with the following composition (g/L): 1 NH_4Cl, 1.47 Na_2SO_4, 0.2 tri-sodium citrate, 0.1 ascorbic acid, 0.1 $CaCl_2{\cdot}2H_2O$, 0.5 KH_2PO_4, 0.2 ethylene diamine tetraacetic acid (EDTA) [19], 0.2 bromo ethane sulfonic acid (BESA) [20], 0.15 $FeSO_4{\cdot}7H_2O$ [21]. 60% v/v of sodium lactate was used as the carbon source. During these experiments, sulfate and COD concentration in the influent were adjusted so as to maintain COD/SO_4^{2-} ratio of 0.67 ± 0.08. The pH of the solution was adjusted to 7 using 1 N NaOH. All the chemicals and reagents used in this study were of analytical grade.

2.2. An-RBC reactor setup

A laboratory scale An-RBC reactor with a total working volume of 3 L was fabricated using polymethyl methacrylate (PMMA) material and operated as detailed in a previous study [10]. Table 1 presents the design specifications of the An-RBC reactor used in this study, and a schematic of the reactor is shown in Fig. 1. The SRB was immobilized by allowing it to grow onto the An-RBC discs enclosed with polystyrene mesh and polyurethane foam (PUF), which served as the bio-support material in the reactor. For SRB growth during the reactor startup phase, modified Postgate medium without any added metal and with the SRB biomass was supplied to the reactor. The An-RBC reactor was operated at an ambient temperature of 25 ± 2 °C in batch mode and the reactor was recharged with a fresh medium (medium with above composition) every five days for over three months during this startup phase. In general, suspended biomass is measured in terms of mixed liquor volatile suspended solids (MLVSS). However, no efforts were made to measure the amount of biomass immobilized in the reactor. Later, the An-RBC reactor was operated under continuous mode by supplying the medium at a constant flow rate. Samples collected at regular intervals of time were centrifuged at 8000×*g* for 5 min, and the supernatant obtained was analyzed for metal, sulfate, sulfide and COD concentrations. Color change of the input medium from colorless to black due to the formation of FeS and generation of hydrogen sulfide during this startup phase confirmed SRB growth and activity in the reactor [22–24].

2.3. Heavy metal removal experiments

Experiments for studying heavy metal removal by sulfide precipitation using the An-RBC reactor were carried out under continuous mode of operation. Individual metal stock solutions of Cd(II), Ni(II), Cu(II), Pb(II), Zn(II) and Fe(III) of 10,000 mg/L concentration each were prepared using $Cd(NO_3)_2{\cdot}4H_2O$, $NiCl_2{\cdot}6H_2O$, $CuCl_2{\cdot}2H_2O$, $PbNO_3$, $Zn(NO_3)_2{\cdot}6H_2O$ and $FeCl_3{\cdot}6H_2O$, respectively. The modified Postgate medium as described earlier was added with the corresponding metal stock solution so as to obtain a desired concentration of the heavy metals in each of the experimental phases. The initial concentration for each of the metals Fe(III), Pb(II), Ni(II), Zn(II) and Cd(II) were chosen as 50, 75 and 90 mg/L. Whereas, in case of Cu(II), these values were 100, 150 and 175 mg/L. All these initial levels of the heavy metals were chosen based on a previous heavy metal removal study using the same anaerobic biomass containing SRB [2,18]. Phase wise operational conditions followed with the An-RBC reactor are presented in Table 2. Reactor perfor-

Table 1
Design specification of the An-RBC reactor.

Specifications	Values
Number of stages	2
Number of discs in each stage	7
Diameter of each disc	16 cm
Spacing between each stage	2 cm
Total working volume	3 L
Disc Submergence	40%