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Research Article

Enhancement of heavy metals desorption from the soil by eddy deep leaching in hydrocyclone

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ABSTRACT

An eddy deep leaching technology was developed in this paper to address the challenge of treating heavy metal contaminants in industrial mining areas. The desorption effect of As, Cd, Sb and Pb was investigated utilizing chemical leaching and physical eddy techniques. It was found that the heavy metals concentration increased with decreasing particle size. The highest proportion of Cd in the form distribution of soil was in the bound to iron and manganese oxides, while the maximum proportion of As, Sb and Pb were in the residual. The optimal solid-liquid ratio of the hydrocyclone was 1:20, and the corresponding separation efficiency and flow rate were 84.7% and 1.76 m^3/hr, respectively. The grade efficiency of soil particle separation increases with particle size and exceeds 99% for particles above 1,000 µm. Leaching experiments have revealed that oxalic acid (OA) and a combination of oxalic acid and EDTA (OAPE) were more efficient than citric acid (CA) and a combination of citric acid and EDTA (CAPE) for the desorption of heavy metals, respectively. The comparison of OAPE and eddy leaching found that the latter improved the desorption efficiency by 9.4%, 7.5%, 7.2% and 7.8% for As, Cd, Sb and Pb compared to the former, respectively. The results demonstrated that the eddy leaching technique could further enhance the desorption efficiency of heavy metals. It is expected to provide technical support for soil remediation with reduced usage of leaching agents.

Introduction

As the primary industry of a country, the smelting industry not only brings a massive engine for economic development but also brings a lot of pollution problems to the ecological environment (Xing et al., 2020; Zhou et al., 2021). Currently, a large area of soil pollution has been caused by non-ferrous metal smelting in central and southern China (Liu et al., 2020). Heavy metal pollution in this region is the most severe group of non-ferrous metals, with features of complicated pollution, environmental impact, and ecological damage. Furthermore, the soils in central and southern China are acidic, and heavy

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metals are incredibly active and transferrable in an acidic environment (Liu et al., 2020; Shibayama et al., 2010). Simultaneously, the soil contaminated by heavy metals is saturated with water and has a high viscosity, making treatment and remediation difficult (Liew et al., 2016).

Furthermore, there are colossal engineering and equipment challenges for the separation and remediation of heavy metals in highly viscous soils (Dermont et al., 2008; Shim et al., 2014). The pollutants are mainly attached or adsorbed to the soil with small particle sizes (Ayoubi et al., 2018). However, fine particles have a higher concentration of soil contaminants, making separation and remediation more difficult than coarse particles (Gong et al., 2018; Peng et al., 2018).

There are many remediation techniques for heavy metals in soils, including leaching (Sun and Yi, 2021), electrokinetic remediation (Wen et al., 2021), chemical oxidation remediation (Lu and Astruc, 2018), solidification/stabilisation (Gao et al., 2021; Zhang et al., 2020), bioremediation (Priyadarshanee and Das, 2021) and physical separation (Dermont et al., 2008; Sanderson et al., 2019). However, the principles and applicability of the different techniques vary in different areas.

Electric remediation techniques are highly effective in removing heavy metals from soils in the water-soluble and exchangeable state, while the removal of heavy metals in the sulphide, organically bound, and residue form is more complex (Gong et al., 2018). Furthermore, it is only appropriate for limited contaminated regions and acidic environments susceptible to the dissolution and desorption of contaminants (Peng et al., 2009). Chemical oxidants like potassium permanganate, ozone, hydrogen peroxide, Fenton's reagent, and sodium persulfate are often used to clean up heavy metals from soil (Koul and Taak, 2018; Yuan et al., 2020). Remediation technology of Chemical oxidation has stable and reliable results, simple equipment and other advantages, but there are expensive oxidants and the possibility of secondary pollution of the environment (Forsey et al., 2010; Liao et al., 2018). The solidification/stabilisation technique is distinguished by the fact that it does not remove or diminish contaminants in the soil but somewhat limits the effectiveness of the contaminants to the environment (Wang et al., 2014). However, its long-term effectiveness is called into question as contaminants immobilised by microorganisms and acids and bases may be re-released over time, bringing a threat to the environment (Gong et al., 2018; Wang et al., 2016). Bioremediation is an inexpensive green method of soil remediation with low soil disturbance and good ecological, social and economic benefits (Ali et al., 2013). However, there are some restoration disadvantages and concerns for microbial remediation and phytoremediation. On the one hand, microbial remediation is inefficient and incapable of remediating highly contaminated soils, and the competition between strains, as well as the mutagenesis influence of the environment on microorganisms, are still unknown (Akcil et al., 2015). On the other hand, the phytoremediation process is relatively slow and has inapparent remediation effects on soils contaminated with multiple heavy metals in combination (Ali et al., 2013).

As one of the common techniques for removing heavy metals from soil, leaching technology is famous for its high removal efficiency and wide application range. As far as the bioleaching is concerned, some species of micro-organisms, such as *Aspergillus* and *Penicillium*, have shown excellent potential for metal leaching (Kour et al., 2021). Metal bioleaching is generally an indirect process involving microbial synthesis of amino acids, organic acids, and other metabolites. These metabolites dissolve metals in minerals by replacing metal ions in the soil matrix with hydrogen ions, or by the formation of soluble metal complexes and chelates (Ren et al., 2009). Nevertheless, it has a slower reaction rate, a strict incubation environment and a longer operating time. It also faces the risk of secondary contamination of the environment by the leaching solution (Nguyen et al., 2021). For chemical leaching, it is suitable for sandy, gravel and sedimentary soil (Lin et al., 2017). Initially, strong inorganic acids such as HCl, HNO_3, H_2SO_4 and H_3PO_4 are employed in the leaching technology to treat heavy metal contaminated soils (Stylianou et al., 2007). Nevertheless, the application of strong acids, as described above, has been found to have a strong ability to destroy soil structure and kill soil micro-organisms, resulting in a significant loss of soil components. It requires the introduction of low molecular weight organic acids such as citric acid (CA) and oxalic acid (OA), which constitute a group of weak organic acids and chelating reagents, including ethylene diamine tetraacetic acid (EDTA) and nitrilotriacetic acid (Gluhar et al., 2020). The widespread application of chelating agent has a strong affinity with metal ions and possess significant properties of oxidizing and forming complexes with metal cations (Nowack, 2002).

Because of heavy metal complex contamination, especially in saturated soil with high viscosity, there is still a lack of practical and effective remediation engineering technology and application equipment (Gong et al., 2018; Liu et al., 2018). Hydrocyclone separation, as a physical separation technique, is the separation or classification of solid particles employing a centrifugal field generated by the rotational flow process of the liquid (Li et al., 2022; Niazi et al., 2017). Hydrocyclone separation technology has been extended from traditional mining engineering to river silting, soil cleaning and many other new fields (Tian et al., 2018). Nevertheless, the hydrocyclone only serves the purpose of quick solid-liquid separation in the current soil hydrocyclone washing and remediation system. Moreover, the application of hydrocyclone separation technology in the remediation of heavy metal contaminated soil is rare.

An eddy leaching technique was developed based on chemical leaching agents to enhance the removal effect of heavy metals from contaminated soil. In this paper, the size and form distribution of heavy metals in soil and the separation performance of hydrocyclone were investigated. Meanwhile, chemical leaching experiments of CA, OA, the combination of CA and EDTA (CAPE) and the combination of OA and EDTA (OAPE) were conducted in the agitating vessel. To further improve the desorption efficiency of heavy metals in soil, the eddy deep leaching experiment was also performed based on OAPE. The efficient desorption of heavy metals from soil particles was realized by strengthening mass transfer, cavitation and shear by the eddy leaching. It is expected to provide favourable technical support for comprehensive prevention and safe utilization of smelting sites.

1. Materials and methods

1.1. Materials

The heavy metals contaminated soil used in the experiments was sourced from the Zhuzhou smelting site in south-central China. EDTA, OA and CA are widely used to treat various soil types because of their strong chelating ability for heavy metals. Moreover, these acids are low molecular weight organic acids that are inherently biodegradable and will not cause secondary contamination. Therefore, the contaminated soil was subjected to a chemical leaching with 0.2 mol/L CA (Aladdin, Shanghai, China), 0.2 mol/L OA (Aladdin, Shanghai, China), 0.1 mol/L EDTA (Sigma, Gaoxin Co., Ltd., Shanghai, China) and their combinations (CAPE and OAPE) in the agitating vessel, and an enhanced eddy leaching with OAPE in the hydrocyclone. Scanning electron microscope-energy dispersive X-ray spectroscope (SEM-EDS; S-3400N, Hitachi Corporation, Japan) was used to observe the microstructure and composition of the soil particle. In addition, the samples were analyzed by X-ray diffraction (XRD, 18KW/D/max2550VB/PC, Rigaku Corporation, Japan) to test the mineral composition of the soil. The results showed that the main components of the heavy metals contaminated soil were quartz, calcite and muscovite (Appendix A Fig. S1). The contents of As, Cd, Sb and Pb in the soil samples were 298 mg/kg, 13.1 mg/kg, 15.8 mg/kg and 1,282 mg/kg, respectively. Moreover, the particle size distribution of the contaminated soil was analysed using a Mastersizer 3000 particle size analyser (Malvern Panalytical, England), as shown in Appendix A Fig. S2.

1.2. Experiment design

As shown in Fig. 1, the main apparatus for the experiment consists of a screening machine, a vibrating screen, a slurry pump, a hydrocyclone and a tubular eddy scrubber. Large stones and gravel are removed from the contaminated soil by the action of a wet screening machine. The photos of the field experiments are also presented in Appendix A Fig. S3. Further, particulate matter larger than 2,000 μm was removed by a vibrating screen, while the qualified soil sample finer than 2,000 μm is fed into the mixing barrel in a particular proportion with water and leaching agents. The solid-liquid ratios in the experiments were 1:15, 1:20, 1:25 and 1:50, and the temperature of the slurry liquid was 20°C. The stirring motor in the agitating vessel was set at 45 r/min. The slurry pump was employed to provide circulation power to solid, acidic slurry liquids. Pressure gauges and mass flowmeters were used to monitor pipe pressure and slurry flow to ensure smooth operation of the pipe. In practice, the content of contaminants in the supernatant obtained from the overflow of hydrocyclone was still high. Therefore, a tubular eddy scrubber was positioned downstream of the overflow outlet to perform deep leaching of fine particles in the supernatant.

1.3. Analysis methods

1.3.1. Performance of hydrocyclone

Performance indicators for hydrocyclones include total separation performance and grade efficiency. The pressure drop is also an important index of the hydrocyclone's performance since it represents the scale of the hydrocyclone's energy consumption (Appendix A Fig. S4). The total separation efficiency of the hydrocyclone refers to the ratio of the solid mass flow rate M_u of the underflow to the solid mass flow rate M_i of the

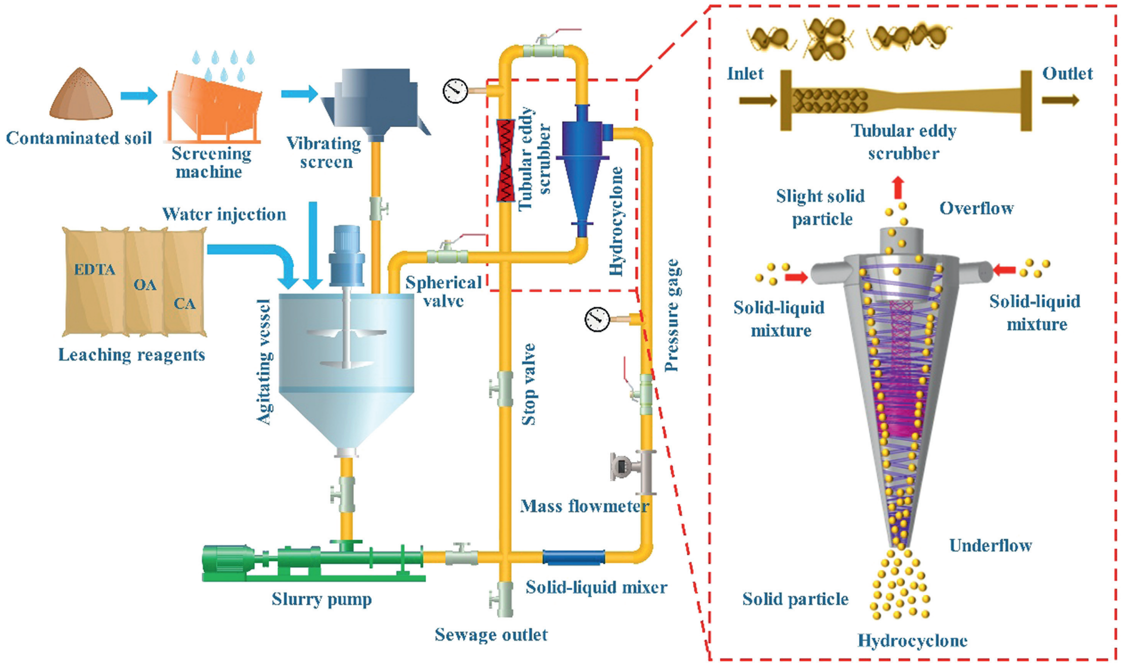

Fig. 1 – Schematic diagram of eddy deep leaching and desorption in heavy metal contaminated soil.

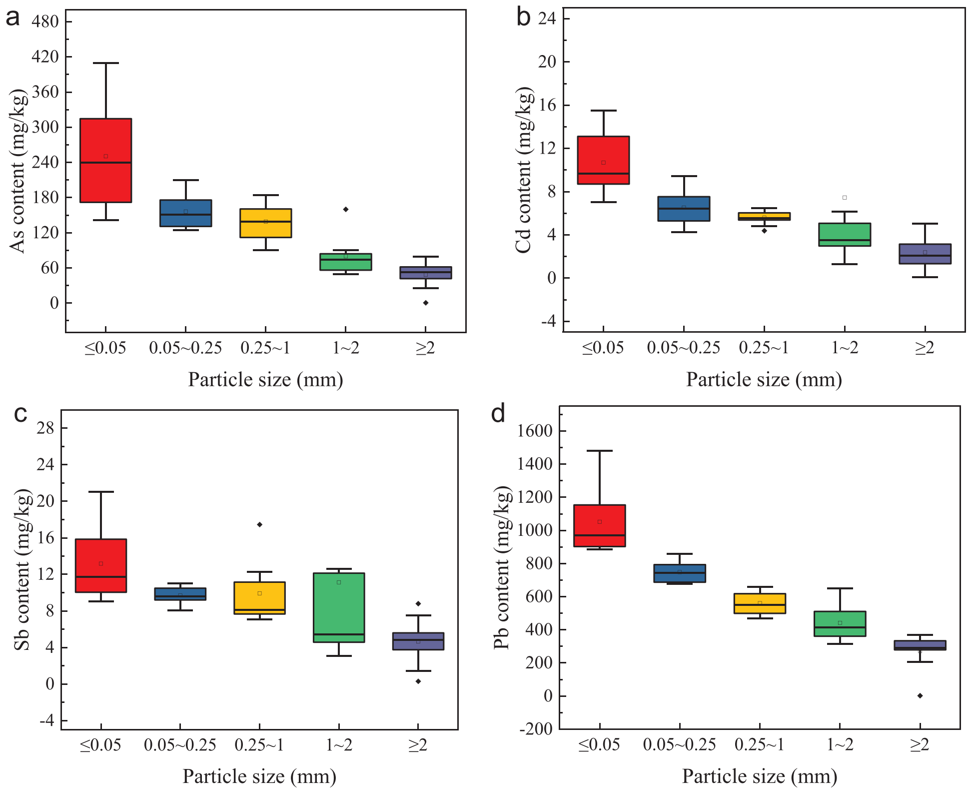

Fig. 2 – Content distribution of As, Cd, Sb and Pb in soils with different particle sizes.

feed, which can be expressed as:

$$E = \frac{M_u}{M_i} \times 100\% \tag{1}$$

The grade efficiency G is the efficiency of the separation of particles at all levels of particle size in the solid phase of a slurry fluid. The particle size of a given grade in the slurry fluid is denoted by d_k ($k = 1, 2, \ldots\ldots, n$), and the corresponding grade efficiency can be expressed as:

$$G = \frac{(m_u)_{d_j}}{(m_i)_{d_j}} = \frac{m_u f_u(d_k)}{m_i f_i(d_k)} \times 100\% \tag{2}$$

where, m_i (g) and m_u (g) are the mass of solid particles at the inlet and underflow outlet of the hydrocyclone; f_i and f_u are the mass percentage of particles with a size of d_k in the hydrocyclone inlet and underflow outle, trespectively.

1.3.2. *Desorption efficiency of heavy metals*

The ratio of the measured heavy metal mass m_t to the soil sample mass m_s was defined as the residual heavy metal content γ in the experiment, which can be described as:

$$\gamma = \frac{m_t}{m_s} \tag{3}$$

The heavy metal desorption efficiency in the experiment can be presented as follows:

$$\eta = \frac{|\gamma_1 - \gamma_2|}{\gamma_1} \times 100\% \tag{4}$$

where, γ_1 (mg/kg) and γ_2 (mg/kg) were the sample's initial and residual heavy metal content, respectively.

2. Results and discussion

2.1. *Heavy metal distribution of soil particle*

2.1.1. *Concentration distribution of heavy metal*

As demonstrated in Fig. 2, the As, Cd, Sb, and Pb concentrations in this experiment increased as particle size decreased. These four heavy metals are concentrated in soil particles smaller than 1,000 µm. The outcome is consistent with the findings of several researchers. (Gong et al., 2018; Peng et al., 2018). They account for 98% of the overall cumulative frequency (Appendix A Fig. S2). In addition, the contents of As, Cd, Sb and Pb in particles less than 1,000 µm account for 81%, 72%, 63% and 77%, respectively. The results are due to the higher specific surface area, clay minerals, organic matter content and Fe-Mn oxide fraction of fine particle size soils. The highest levels of As and Pb in the soil were 409 mg/kg and 1,481 mg/kg, respectively (Fig. 2a, b). The As was mainly enriched in particle sizes less than 1,000 µm, while Pb was enriched in particle sizes no more than 2,000 µm. Moreover, the highest concentrations of Cd and Sb in soil were 35 mg/kg and 42 mg/kg, respectively (Fig. 2c, d). Although Cd and Sb tend to follow the rule that the finer the particle size was, the higher the content was, they reached the maximum concentration in the soil particle size range of 1,000-2,000 µm. The results could be as a result of clay minerals like montmorillonite and kaolin adsorbing metals and transferring them to these soil particles (Uddin, 2017). These trace metal elements are readily absorbed by clay

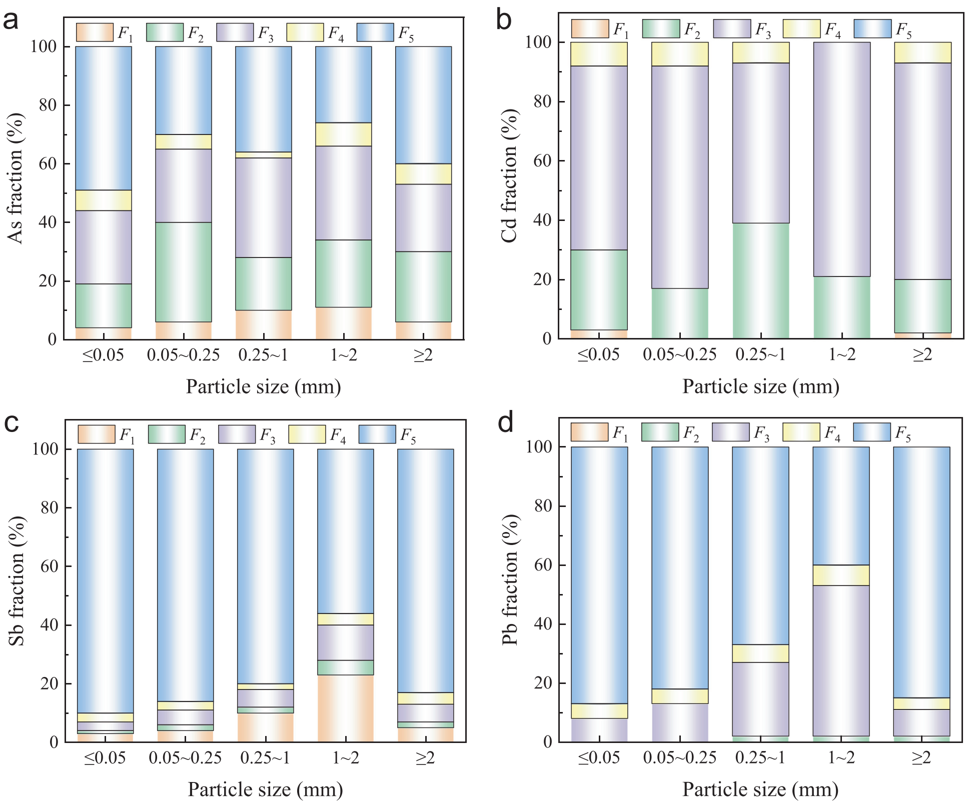

Fig. 3 – Forms distribution of four elements in soils with different particle sizes. The five forms are exchangeable (F_1), bound to carbonates (F_2), bound to iron and manganese oxides (F_3), bound to organic matter (F_4) and residual (F_5).

minerals during the copper smelting and coal combustion (Dhaliwal et al., 2020).

2.1.2. *Forms distribution of heavy metal*

According to Tessier's five-step extraction method, the forms of heavy metals in soil were classified as exchangeable (F_1), bound to carbonates (F_2), bound to iron and manganese oxides (F_3), bound to organic matter (F_4) and residual (F_5) (Tessier et al., 1979). All five forms of As were found in soils of varying particle sizes, and the proportion of F_2 and F_3 was 40%-60% (Fig. 3a). The As content of the F_3 in the range of 250-1,000 µm soil particles was five times that of the F_4. Moreover, the As was distributed to varying degrees in each particle fraction, indicating that the As was active in the soil environment and readily migrated between particles (Weerasundara et al., 2021). The Sb and As belong to the same nitrogen elements and have similar chemical properties and morphological distribution (Li et al., 2020). It was found that the content of Sb in F_1 accounted for 4%-24% in different particle size fractions, while that in F_5 was 56%-90% (Fig. 3c). The content of Sb in the F_5 increases with decreasing particle size for different particle sizes and was up to 90% in particles less than 50 µm. This result indicates that Sb has been enriched into the fine particle's most difficult form of desorption. The Cd was readily enriched in the F_3, and the content of different particle sizes was 54%-79%. It was followed by the F_2, which accounts for 18%-40%. Less than 9% of the F_4 and none of the F_5 were detected in any particle-size fractions (Fig. 3b). The Pb did not contain the F_1 in the different soil particle sizes. The F_5 included the highest concentration of Pb, ranging from 39% to 86%. It was followed by the F_3, which ranged from 9% to 50%. The F_3 content of Pb reduces with decreasing particle size. By contrast, the F_5 content gradually increases with decreasing particle size (Fig. 3d). Consequently, the desorption of Sb from the soil is undoubtedly tricky based on the proportion of F_5 in the soil.

2.2. *Effects of solid concentration*

2.2.1. *Total separation efficiency*

The experiments illustrated in Fig. 4 show that the highest separation efficiency of solid-liquid ratios of 1:50, 1:25, 1:20 and 1:15 were 73.5%, 75.3%, 84.7% and 79.3%, respectively. The corresponding inlet flows of hydrocyclone were 1.74, 1.79, 1.76 and 1.81 m^3/hr, respectively. The separation efficiency increases and then decreases as the inlet flow rate increases. It is because the low inlet flow rate of the hydrocyclone means a low fluid flow velocity. The centrifugal force generated by the cyclone was insufficient to provide the kinetic energy for the solids to migrate toward the inner wall of the tube (Zhao et al., 2022). The result is that the two-phase mixture cannot be separated effectively. With the increase in inlet flow rate, the centrifugal force produced by the fluid in the hydrocyclone gradually increases, and the separation efficiency also increases.

Nevertheless, the residence time of the solid particles in the hydrocyclone was shortened when the flow rate was too

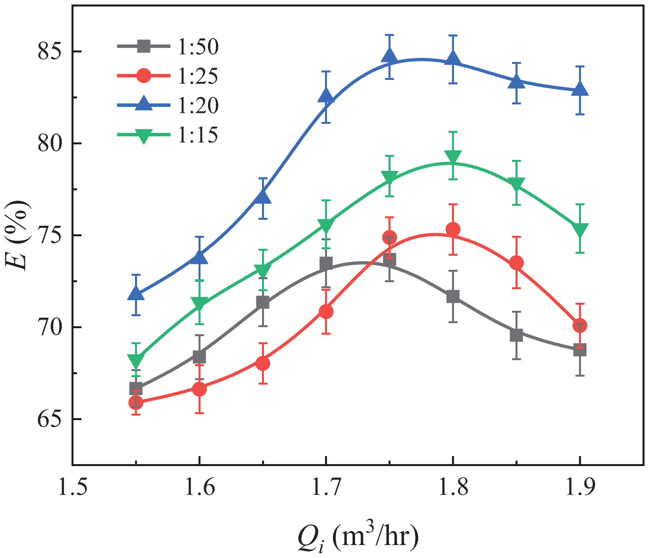

Fig. 4 – Relationship between separation efficiency E and inlet flow rate Q_i at different solid-liquid ratios.

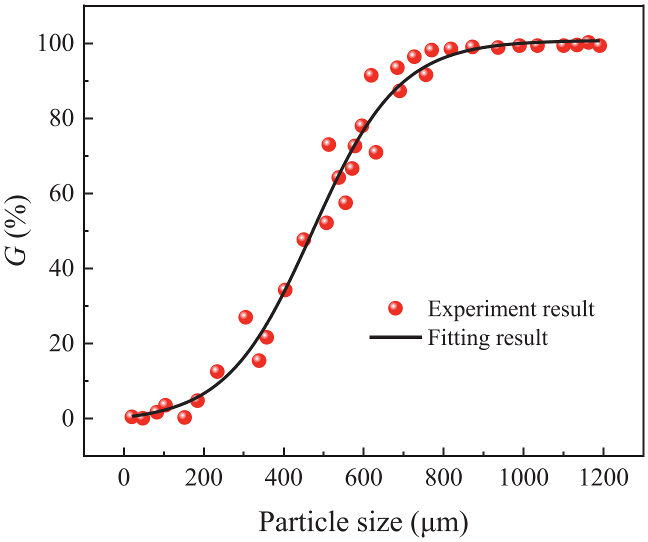

Fig. 5 – Grade efficiency of hydrocyclone at a solid-liquid ratio of 1:20.

high. The result is that the particles are not enough to be separated in time. Meanwhile, the increased turbulence in the hydrocyclone's internal flow field allows some of the already separated particles to be remixed, resulting in a reduction in the separation efficiency of the hydrocyclone (Gent et al., 2018). Therefore, the optimum solid-liquid ratio for the experimental setup was 1:20, and this condition was used as the basis for the later heavy metal eddy elution experiments.

2.2.2. *Grade efficiency*

The variation of the grade efficiency curve for different soil particle sizes is displayed in Fig. 5. The experimental results indicated that the grade efficiency of soil particle separation increased with increasing particle size (Yu et al., 2017). The hydrocyclone grade efficiency for extremely fine particles below 50 μm did not exceed 1%, while the grade efficiency for particles above 1,000 μm was over 99%. Furthermore, 50% of the hydrocyclone grade efficiency corresponds to a particle size of 470 μm. The results show that most of the soil particles in this experiment can be effectively separated by the hydrocyclone.

2.3. *Leaching effect*

2.3.1. *Leaching effect of CA and OA*

In the agitation leaching experiment of a single agent, the removal effects of 0.2 mol/L CA and 0.2 mol/L OA on heavy metals in soil were shown in Fig. 6. Experiments showed that the levels of the four elements As, Cd, Sb and Pb all decreased gradually with time under agitated leaching at 0.2 mol/L CA and 0.2 mol/L OA (Fig. 6a, b). The former had the highest desorption efficiencies of 61%, 46%, 35% and 65% for As, Cd, Sb and Pb (Fig. 6c), while the latter had the maximum desorption efficiencies of 69%, 65%, 55% and 76% for heavy metals respectively (Fig. 6d). The results showed that OA was superior to CA for the removal of these heavy metals, but none of them had a desorption efficiency of more than 80% (Sun et al., 2019; Wei et al., 2016). This result may be due to it is difficult for a single agent to remove multiple heavy elements with high efficiency (Dhaliwal et al., 2020). In addition, the quartz component of the experimental soil sample has a negative surface charge in solution, while the calcite component results in an increase in the pH of the solution (Romero et al., 2011). Both of these components in the soil sample contribute to heavy metals being firmly adsorbed on the surface of the solid particles. Therefore, further explorations to improve the desorption efficiency of heavy metals in soil were yet to be executed.

2.3.2. *Leaching effect of combinations*

Based on the unsatisfactory leaching effect of CA and OA, leaching experiments in the agitating vessel were performed with 0.2 mol/L CA and 0.2 mol/L OA in combinations (CAPE and OAPE) formed with 0.1 mol/L EDTA, respectively. Experiments showed that the contents of these four heavy metal elements in soil decreased gradually with time under the mixture of CAPE and OAPE (Fig. 7a, b). The maximum desorption efficiencies of CAPE solution for As, Cd, Sb and Pb were 81%, 77%, 67% and 84% (Fig. 7c), while the highest desorption efficiencies of OAPE for heavy metals were 85%, 80%, 69% and 90% (Fig. 7d). The results indicated that the CAPE and OAPE combinations formed by adding EDTA to CA and OA effectively improved the desorption efficiency of heavy metals from the soil. Moreover, OAPE outperformed CAPE regarding overall desorption efficiency for heavy metals in the soil and reached 90% for Pb. It is probably due to the high initial concentration of Pb resulting in a high desorption efficiency compared to the other three low concentrations of heavy elements (Geng et al., 2020; Sun et al., 2019). Furthermore, EDTA enters the soil and forms soluble organic binders with heavy metal elements through coordination bonds or functional groups to remove heavy metal elements in the soil (Zhang et al., 2021).

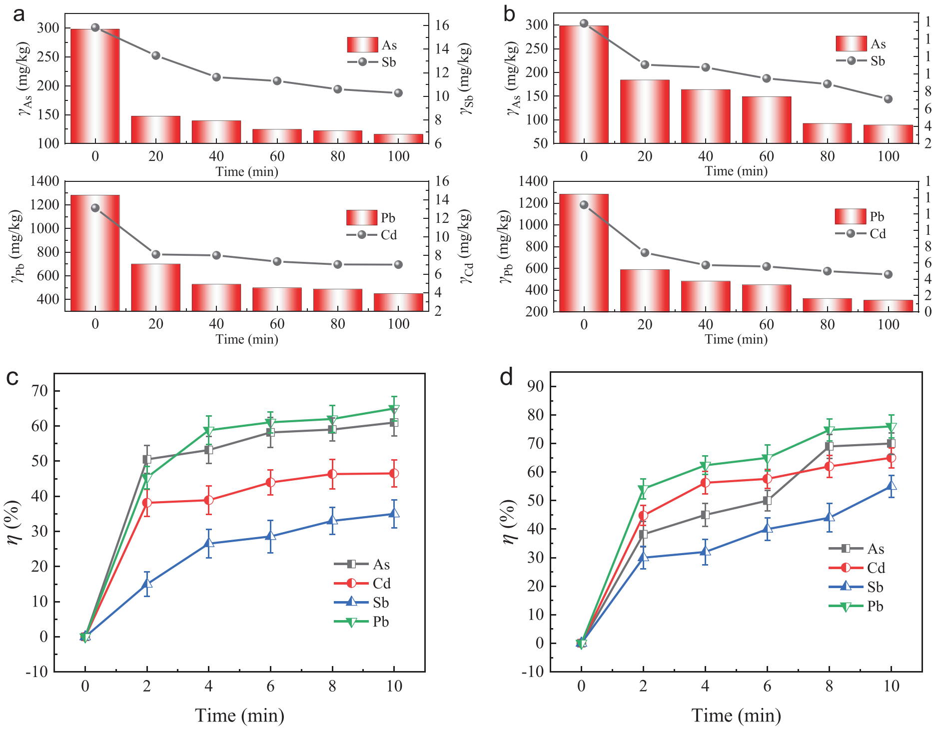

Fig. 6 – Leaching effect of CA and OA in the agitating vessel: (a) residual content at 0.2 mol/L CA, (b) residual content at 0.2 mol/L OA, (c) desorption efficiency at 0.2 mol/L CA and (d) desorption efficiency at 0.2 mol/L OA.

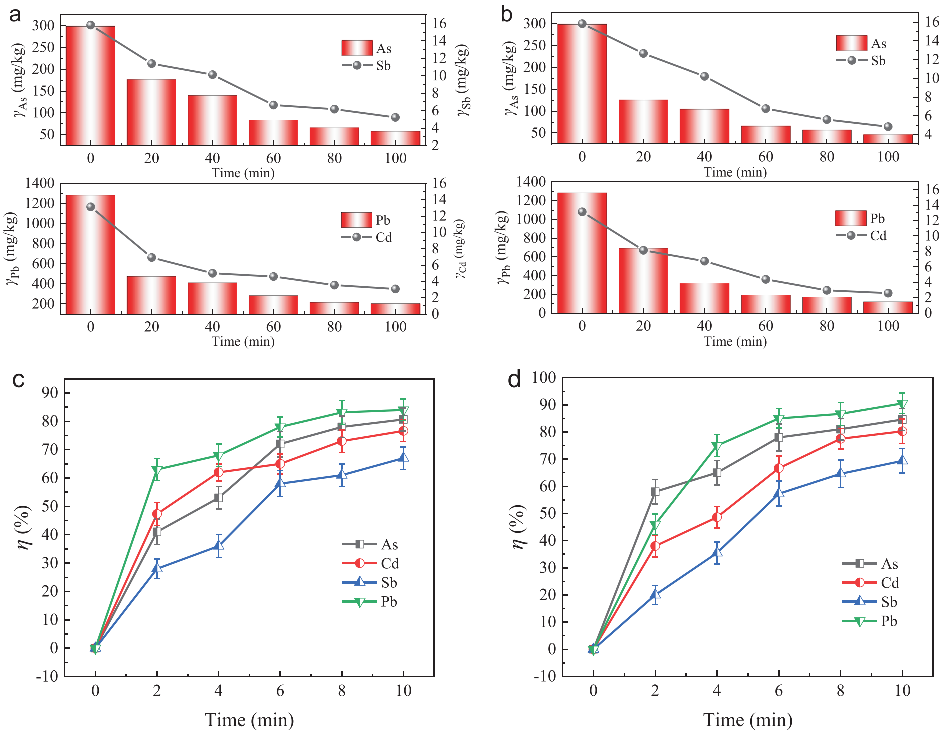

Fig. 7 – Leaching effect of combinations in the agitating vessel: (a) residual content at CAPE, (b) residual content at OAPE, (c) desorption efficiency at CAPE and (d) desorption efficiency at OAPE.

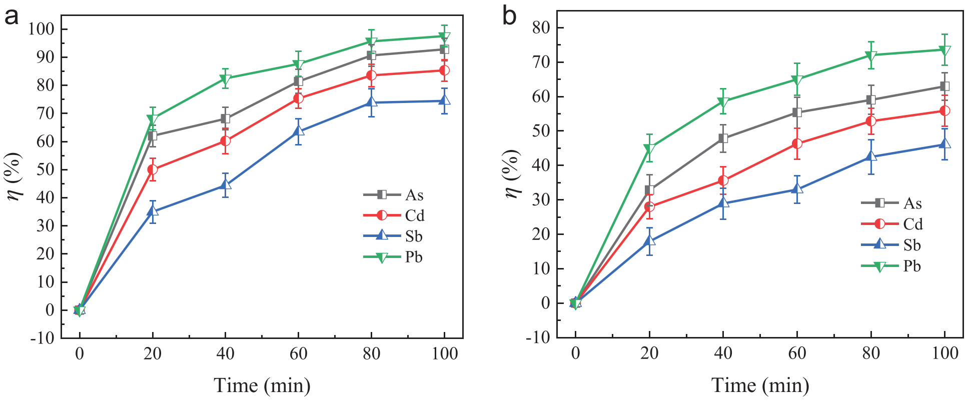

Fig. 8 – Desorption efficiency of heavy metals eddy leaching at the (a) underflow and (b) overflow of hydrocyclone under OAPE condition.

2.4. *Enhanced effect of eddy leaching*

According to the total separation efficiency and the results of the leaching experiment in the agitating vessel, the experiment of eddy deep leaching under OAPE conditions was undertaken to improve further the desorption efficiency of heavy metals from the soil. The eddy leaching experiment showed that the highest desorption efficiencies of As, Cd, Sb and Pb in soil were 93%, 86%, 74% and 97% at the underflow (Fig. 8a). The maximum desorption efficiencies of heavy metals at the overflow were 63%, 56%, 46% and 74% (Fig. 8b), respectively. The results demonstrated that in comparison with OAPE, the underflow desorption efficiency of As, Cd, Sb and Pb increased by 9.4%, 7.5%, 7.2% and 7.8% by eddy leaching, respectively. It is due to the enhanced strength of the fluid disturbance in the eddy field by shear forces and the promotion of inter-particle friction and collisions (Zhao et al., 2022). Meanwhile, the tubular eddy scrubber with a venturi structure was able to take advantage of the turbulence, interfacial, and aggregation effects caused by the phenomenon of hydraulic cavitation to increase the micropore diffusion and mass transfer area of the particles, resulting in improved mass transfer efficiency and depth of heavy metal desorption (Shi et al., 2020). Nevertheless, the efficiency of the eddy leaching of heavy metals at the overflow was generally low, and none of the desorption efficiencies exceeded 75%. It was attributed to the fact that the soil particle size at the overflow was small compared to that at the underflow and was limited by scale effects in the flow field (Yu et al., 2017). Besides, the experiments revealed that the desorption efficiency of Sb was consistently the lowest among all the heavy metals in the soil. This reason was that the initial concentration of Sb was low, and the desorption efficiency was affected by concentration effects (Geng et al., 2020). Furthermore, the hard-to-desorb F_5 form was the primary form of Sb in the soil. In terms of the occurrence characteristics of Cd, it has a greater tendency to enter the lattice of calcite-type structures or to be adsorbed onto the surface of carbonate minerals. The result is increased difficulty in desorption of the element (Liu et al., 2021). Besides, the SEM-EDS analysis also demonstrated that eddy leaching effectively removes heavy metals from soil (Appendix A Figs. S5 and S6).

3. Conclusions

To enhance the desorption efficiency of heavy metals from industrial mining soils, an eddy deep leaching technology was developed in this paper. Experiments on the chemical leaching of As, Cd, Sb, and Pb from soil were conducted in an agitating vessel utilising CA, OA, CAPE and OAPE leaching agents. Meanwhile, the eddy deep leaching experiment was also carried out on the basis of OAPE to improve the desorption efficiency of heavy metals in soils. The conclusions can be summarised as follows:

(1) In this experiment, the concentrations of As, Cd, Sb, and Pb in soil drop as particle size increases. The content of Sb in F_5 accounted for 56%-90% in different particle size fractions and was up to 90% in particles less than 50 μm. This finding means that the removal of Sb from the soil in this experiment was undoubtedly the most difficult compared to other elements.
(2) The desorption efficiency of OA was higher than that of CA for the chemical leaching of heavy metals in soil. Experiments involving the chemical leaching of heavy metals with OAPE were more effective than those with CA, OA, and CAPE.
(3) On the basis of OAPE, the desorption efficiency for As, Cd, Sb and Pb by eddy leaching was 93%, 86%, 74% and 97%, respectively. The results demonstrate the ability of eddy leaching to enhance the desorption effect of heavy metals in soil.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A Supplementary data

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jes.2022.12.005.

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