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Viewpoint

A Novel Device for the In Situ Enrichment of Gold from Submarine Venting Fluids

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Abstract: Gold and other metals (Cu, Zn, Ag, etc.) are enriched in vent fluids, approximately 3–5 orders of magnitude higher than those in seawater, and this leads to the formation of sulfide enrichment in Cu, Zn, Au, and Ag deposited on the mid-ocean ridge and island arcs, as well as in back-arc basins. We developed a device that can extract the elements such as Cu, Zn, Au, and Ag from the vent fluids before the formation of the hydrothermal plume, sulfide deposit, and metalliferous sediment at the seafloor over a long period, which is beneficial to collecting hydrothermal resources effectively and avoiding the damage of ecological environments caused by mining the polymetallic sulfide resources. The application of this device will have significance for the development and utilization of seafloor hydrothermal resources, the sustainable development and implementation of the blue economy, and the construction of the marine ecological civilization in the future.

Keywords: metal element extraction; vent fluids; hydrothermal resources; seafloor mining

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1. Introduction

Since the first observations of submarine hydrothermal discharge at the Galápagos Rift in 1977 [1], more than 700 confirmed submarine hydrothermal venting sites have been identified (http://www.interridge.org, accessed on 21 March 2020). Although the stability of hydrothermal activities is linked to the nature and location of the underlying heat source, as well as the subsurface fluid flow pathway, some show rapid variations, whereas others exhibit stable fluid chemistries over many years, such as the Trans-Atlantic Geotraverse (TAG) hydrothermal field on the Mid-Atlantic Ridge and South Cleft at the Juan de Fuca Ridge [2]; therefore, the release of vent fluids at the seafloor will persistently influence the elemental contribution to the ocean. Owing to the important role of hydrothermal fluid flow in transferring mass from the crust and mantle into the oceans, determining the magnitude of their flux has been the overriding question that many scientists have tried to assess [2–9]. It has been estimated that the fluid flux is ~375 $\times$ 10^{16} g/year at the ridge axis if 20% high-temperature (350 °C) and 80% low-temperature (5 °C) hydrothermal fluids are expelled from the seafloor. However, the fluid flux through hydrothermal plumes is ~11,000 $\times$ 10^{16} g/year if 20% of the fluids circulating at high temperature through young ocean crust are entrained into hydrothermal plumes [9]. The low-temperature fluid fluxes at ridge flanks could be greater, 2000–54,000 $\times$ 10^{16} g/year [8]. This combined flux is greater than the global riverine water flux of ~4000 $\times$ 10^{16} g/year and is sufficient for circulating the mass of the entire ocean (1.37 $\times$ 10^{21} kg) through the ocean crust in less than 1 million years [2,9,10].

The metals of the vent fluids are thought to be the result of the interaction of fluid with the ocean crust at high temperature [11]. In some cases, particularly in back- and island-arc settings, magmatic degassing can also add metals to the circulating fluids [2]. Therefore, in vent fluids, some metals are enriched relative to seawater, e.g., the concentration of Cu, Zn, Au, and Ag in vent fluids reach 162 μmol/kg, ~3100 μmol/kg, 250 pmol/kg, and 230 nmol/kg, respectively [11–14], which is approximately 3–5 orders of magnitude higher than those in seawater (Cu 0.004 μmol/kg, Zn 0.006 μmol/kg, Au 0.15 pmol/kg, and Ag 0.025 nmol/kg) [15,16]. This leads to the formation of sulfide enrichment in Cu (0.3–24.9 wt%), Zn (0.1–31.4 wt%), Au (0.1–88.9 ppm), and Ag (7–2305 ppm) deposited on the mid-ocean ridges and island-arcs, as well as in the back-arc basins [10,17]. Recently, it has been proposed that the base and precious metals can be obtained through cultivating seafloor sulfide deposits at artificial seafloor hydrothermal vents with further exploration for commercial mining [18]; however, the artificial hydrothermal vents created by boreholes could impact the ecological environment.

Therefore, if we are able to intercept the large amount of vent fluids and enrich Cu, Zn, Au, and Ag in the fluids artificially before the formation of the hydrothermal plume, sulfide deposit, and metalliferous sediment at the seafloor over a long period, the hydrothermal resources will be obtained effectively, and the damage to the ecological environment caused by mining the polymetallic sulfide resources can be avoided; thus, we developed a device that can enrich the elements such as Cu, Zn, Au, and Ag from the vent fluids. The application of this device will have significance for the development and utilization of seafloor hydrothermal resources and the preservation of a green and healthy ocean in the future.

2. Metal Element Extraction Device

In this proposal, for the enrichment and recovery of the base and precious metals from a vent fluid site, a metal element enrichment device (MEED) based on the "KEXUE" vessel is developed. A remote operated vehicle (ROV) is used to carry the MEED and place it near the seafloor hydrothermal vent sites. When the MEED is operated, the hydrothermal vent fluid is pumped into the device, and the particles are filtered into a tank. Gold and silver are extracted in the tank loaded with anion resin, and iron, copper, and zinc are extracted in the tank loaded with cation resin. When fully loaded the MEED is stopped and the device recovered. In the laboratory on the ship, the metal elements chelated by the anion/cation resin core equipped in the MEED will be quantitatively eluted. The design of the MEED is as follows:

The MEED includes a fluid recovery faucet (1); a telescopic pipe which is convenient for placement above the hydrothermal vent (2); a pipeline switch valve (3); a T-handle operated by a ROV manipulator (4); a rotatable joint, which controls the direction of the telescopic pipe (5); a vent fluid inlet pipe (6); a gravity settling tank for large particles in the vent fluid (7); a vent fluid centrifugal settling tank (8); a fine filter tank for filtering fine particles in the vent fluid (9) an ultrafiltration core for filtering soluble solid particles in the vent fluid (10); vent fluid sample tank (11); an anion adsorption tank (12) installed with an anion resin core (13); the adsorption of the anion resin is strengthened through a negative electrode column (14); a cation adsorption tank (15) installed with a cation resin core (16); a positive electrode column (17) strengthens the adsorption of cations such as iron, copper and zinc; a deep-water pump (18); a waste liquid outlet pipe discharging the waste liquid (19); a telescopic pipe (20), which discharges the waste liquid, and a protective shell (21) protecting the MEED from damage (see Figure 1). This design has been granted a patent (number 2021/05673) authorized by the republic of South Africa [19].

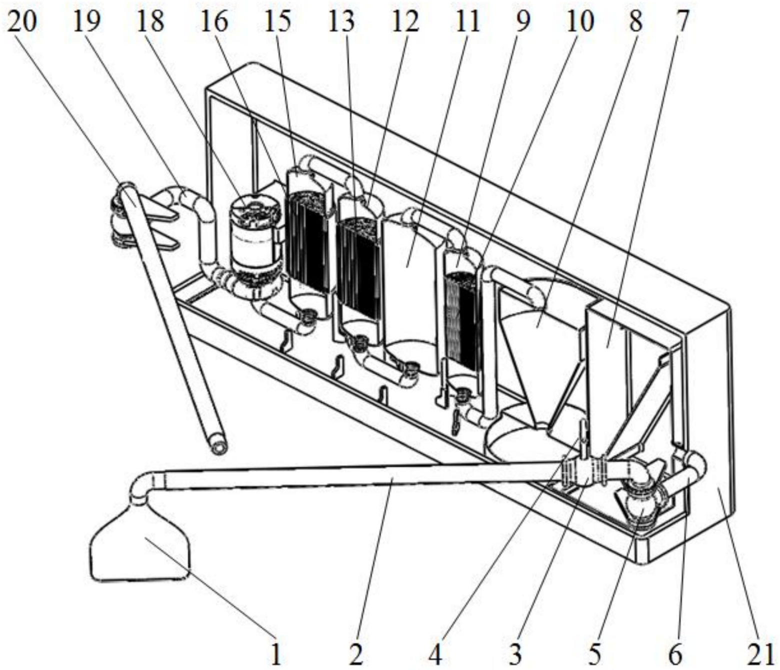

Figure 1. Design of the MEED; 1, fluid recovery faucet; 2, telescopic pipe; 3, pipeline switch valve; 4, T-handle; 5, rotatable joint; 6, vent fluid inlet pipe; 7, gravity settling tank; 8, vent fluid centrifugal settling tank; 9, fine filter tank; 10, ultrafiltration core; 11, hydrothermal fluid sample tank; 12, anion adsorption tank; 13, anion resin core; 14, negative electrode column; 15, cation adsorption tank; 16, cation resin core; 17, positive electrode column; 18, deep water pump; 19, outlet pipe; 20, telescopic pipe; and 21, protective shell.

The MEED and its fixing and recovery devices are carried by the ROV to the seafloor near the hydrothermal vent. The fluid recovery faucet (1) of the MEED is placed directly above the active hydrothermal vent, the length and angles of the suction telescopic pipe (2) and discharge telescopic pipe (20) are adjusted, and the discharge outlet of the telescopic pipe (20) is placed away from the vent to reduce the interference of the discharge liquid on the sampling. Then, the ROV manipulator is used to control the T-handle (4) to open the switch valve (3). Next, the power of the deep-water pump (18) is opened, and the negative (14) and the positive electrode columns (17) are connected. The vent fluid enters the gravity settling tank (7) through the suction faucet (1), the suction telescopic pipe (2), the switch valve (3), the rotatable joint (5), and the inlet pipe (6). Owing to the small diameter of the inlet pipe (6) and the large section at the entrance of the gravity settling tank (7), the flow rate of the fluid is greatly reduced after entering; thus, it is convenient for the settlement of large particles in the fluid, and the fluid impacts the inclined surface in the gravity settling tank (7), allowing for the large particles to accumulate gradually. The preliminarily separated fluid enters the centrifugal settling tank (8) and the supernatant liquid enter the fine filter tank (9) through the pipeline from the outlet. After the liquid flows through the ultrafiltration core (10), all particles have been removed at the centrifugal settling tank (8) and the fine filter tank (9). The liquid passes through the ultrafiltration core (10) and enters the tank (11). Then, the liquid flows from the fluid tank (11) into the anion adsorption tank (12). The Au, Pt, etc., anionic complexes are adsorbed by the anion resin core (13) under the combination of the anion resin core (13) and the negative electrode column (14). Then, the liquid enters into the cation adsorption tank (15), and the cations such as Cu^{2+}, Zn^{2+}, etc., are adsorbed by the cation resin core (16) under the combination of the cation resin core (16) and the positive electrode column (17). The waste liquid is discharged into the sea through the output pipe (19) and the discharge telescopic pipe (20) by the deep-water pump (18). After a set period, the pump will be stopped and the recovery apparatus reacted. When the ship sends the recovery signal, the recovery device and the connected MEED rise to the sea surface by automatically releasing the anchor system. The location is transmitted to the ship through the positioning signal transmission device. After receiving the signal, the ship salvages the MEED (see Figure 2).

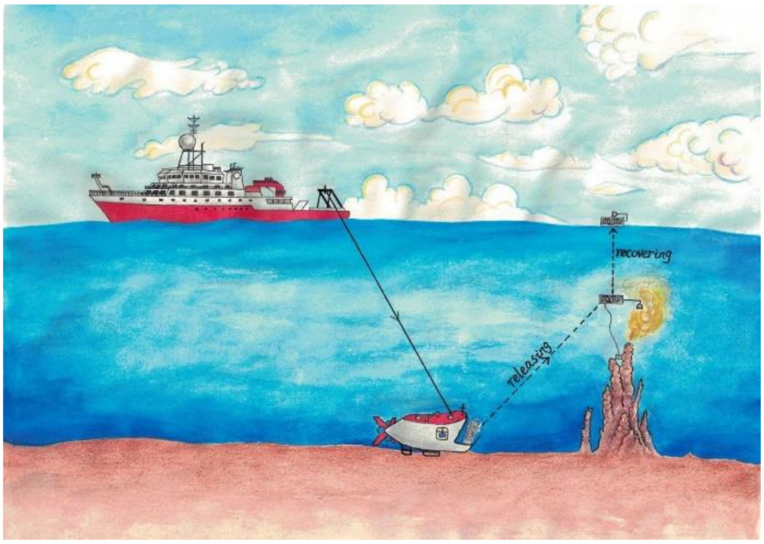

Figure 2. Sketch of the MEED in operation.

3. Conclusions

We can combine the geophysical prospecting, geochemical exploration, and biological exploration techniques with drilling to explore the seafloor polymetallic sulfide and hydrothermal vent. Based on understanding the resource potential of seafloor polymetallic sulfide deposit by using the four exploring technique systems, employing the MEED can concentrate metal elements from vent fluids without destroying the hydrothermal ecological environment. The MEED is a potential tool for the sustainable development and implementation of a green and healthy ocean and the construction of marine ecological civilization.

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