Study on Penetration Effect of Heavy Metal Migration in Different Soil Types

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Abstract. Soil column permeability experiments were conducted in the laboratory to study the transport characteristics of five heavy metal ions of Mn$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, Cr$^{2+}$, and Cu$^{2+}$ in saturated loess, sandy soil and compound soil. The results showed that the texture of soil and the characteristics of heavy metal ions have a common effect on the transport of heavy metal ions. The migration process of five metals in eight soils is different, and the same soil conditions, different metals, and the migration process are different. Very large, the same metal, different soils are also very different. The penetration rates of the five heavy metal ions were Mn$^{2+}$ > Ni$^{2+}$ > Cd$^{2+}$ > Cu$^{2+}$ > Cr$^{2+}$. Mn$^{2+}$ is the most easily migrating in both soils, requiring the shortest penetration time and a smaller retardation factor than other metals, suggesting that the resistance to penetration is minimal. The penetration time of all metals in sandy soil and compound soil is less than that in loess, and the pore flow velocity is much higher than the pore flow velocity in loess. The migration resistance of loess to all metals is much higher than that of sandy soil and compound soil. Metal migration resistance. The adsorption performance of the five heavy metal ions on the five heavy metals is higher than that of the sandy soil and the compound soil. The sandy soil originates from the impact slope of the flood land. The soil clay, cation exchange capacity and organic matter are all lower than that of the loess, and the adsorption of heavy metal ions is better. weak. Heavy metal ions are easy to migrate in sandy soils in the mining area, which infiltrate deep into the soil or into groundwater, causing pollution. Heavy metal ions in loess do not migrate easily and can be adsorbed on the surface or shallow surface for a short time. It is not easy to cause deeper contamination of groundwater, but it also causes As surface runoff migrates laterally to rivers or other areas and expands the area of pollution, no matter which kind of metal in the mining area, the content of which is too high can cause pollution to the environment and cause adverse effects.
1. Introduction
As a typical porous medium, the solute transport occurred relatively complex and has been paid attention by researchers [1]. The solute transport in the soil is dominated by the migration of metal ions. Previous studies have mostly concentrated on the effects of salinity and nutrient transport processes on the soil [2].

In recent years, due to the intensification of industrial pollution, heavy use of agricultural chemical fertilizers, and the incorporation of exogenous heavy metals such as landfills of solid waste into soil, unlike general pollutants, they disappear due to volatilization, degradation, and metabolism. Adsorption can accumulate heavy metals in the soil environment. When sewage containing heavy metals is used to irrigate farmland soil, it will cause heavy metal elements to accumulate on the soil surface. Under the effect of rainfall, snowfall and irrigation, accumulated heavy metals may be affected to varying degrees. Leaching down, some of them leach into the groundwater, leading to groundwater pollution, a serious threat to human health [3-5]. Once groundwater is contaminated, it is very difficult to recover and manage [6-9]. Studies have shown that the hazards of heavy metal contaminants to soil are mainly as follows [11-16]: The degradation cycle of heavy metals is very long. Heavy metals are bound in the soil by organic or inorganic ligands in the soil to form complexes, thereby reducing their mobility. Certain heavy metals can be converted into more toxic metal organic compounds under the action of microorganisms, and the heavy metal pollution into the soil will produce microbial reproduction and metabolism, and affect the normal growth and survival of animals and plants; in addition, it may cause pollution to the surrounding environment. The heavy metals in the soil can enter surface water and groundwater under leaching conditions, which will increase the pollution of water bodies and affect aquatic organisms. At the same time, heavy metals in the soil will diffuse into the atmosphere through the action of chemical or microbiological substances, causing pollution to the atmosphere; heavy metal content in soil When it exceeds the standard, it causes secondary pollution through crops and eventually enters the human body, causing harm to human health.

2. Research method

2.1. Fill the soil column
According to the bulk density of dry soil, the screened soil shall be filled in 4 layers, each time filling 10 cm. The amount of soil needed for each filling shall be calculated according to the following formula:

\[
\text{Total soil mass} = [\text{column volume} \times \text{soil bulk density} \times (1 + \text{initial mass moisture content})]
\]

In addition to compaction with a plastic compactor, and the surface of the compacted soil is feathered and the next loading is continued to ensure uniform distribution of all soil particles in the soil column. A layer of filter paper is laid on the upper and lower ends of the soil column to prevent the surface soil from being subjected to strong impact and the bottom end soil particles blocking the outlet.

2.2. Test device
The total height of soil column is set to 50cm, the thickness of overburden is 40cm, the soil column is an organic glass tube with an inner diameter of 8cm, the upper part is open, the outlet hole is evenly meshed at the bottom, the bottom is connected with the water center, and the bottom side mouth rubber tube is connected with water. The specific device is shown in Figure 1.
2.3. **Set up the infiltration solution**
The permeate solution Cu was set at 400 mg/L, Mn was 350 mg/L, Ni was 200 mg/L, Cr was 300 mg/L, and Cd was 1.0 mg/L.

2.4. **Penetration test**
Deionized water is first added to the soil column to moisten the soil and make it full. The soil column was filled with permeate from the top as shown in Fig. 1. The soil column had 1 cm permeate head. Sampling is performed manually throughout the entire time of penetration, that is, once every 2-4 hours since the beginning of the infiltration, and the corresponding sampling time is recorded. When the concentration of the outflow liquid is equal to the entering solution, the penetration test ends. The samples were sent to the laboratory immediately after they were collected for testing.

2.5. **Water quality monitoring method**
Test indicators include Cu, Mn, Cr, Ni, and Cd, and were measured by Inductively Coupled Plasma Mass Spectrometry ICP-MS (Aglient 7700e).

3. **Results and discussion**
In the process of penetration, when the concentration begins to increase, it is the initial penetration, and the corresponding time is the initial penetration time; the concentration of the outgoing liquid ions finally does not change, and this is called full penetration, and the corresponding time is called For complete penetration of time.

3.1. **The penetration of heavy metal ions in loess**
As can be seen from Figure 2, nearly 600 hours after the breakthrough test, the heavy metal ions Mn$^{2+}$, Ni$^{2+}$, and Cd$^{2+}$ in the outflow from the loess soil columns have a slight upward trend, and the concentration of other heavy metal ions is almost zero, indicating that the heavy metals have not yet
been found in the loess. Penetration means that the loess has a strong adsorption capacity for heavy metal ions and therefore has greater resistance to migration.

![Graph showing different heavy metal ion penetration in loess](image1)

**Fig. 2** Curves of different heavy metal ion penetration in loess

### 3.2. **The penetration of heavy metal ions in sand**

As can be seen from Fig. 3, the heavy metal ions in the outflow liquid of the column after 100h penetration test did not penetrate except for \( \text{Cr}^{2+} \) but the remaining heavy metal ions \( \text{Mn}^{2+}, \text{Ni}^{2+}, \text{Cd}^{2+}, \) and \( \text{Cu}^{2+} \) completely penetrated the sand column. From the perspective of the penetration rate of heavy metal ions, \( \text{Mn}^{2+} > \text{Ni}^{2+} > \text{Cu}^{2+} > \text{Cd}^{2+} \). The migration of \( \text{Mn}^{2+} \) and \( \text{Ni}^{2+} \) in the sand is evident in the migration experiment for 10 h, \( \text{Cd} \) at 12 h, and \( \text{Cu}^{2+} \) at 20 h; while the \( \text{Mn}^{2+}, \text{Ni}^{2+}, \text{Cd}^{2+}, \) and \( \text{Cu}^{2+} \) ions are completely The time of sand penetration was 16h, 16h, 22h, and 80h, respectively; until the experiment was performed for about 250h, \( \text{Cr}^{2+} \) ions penetrated completely.

![Graph showing different heavy metal ion breakthrough curves in sand](image2)

**Fig. 3** Different heavy metal ion breakthrough curves in sand
3.3. The penetration of heavy metal ions in soft rock

It can be seen from Fig. 4 that nearly 300 hours after the breakthrough test, the heavy metal ions Mn$^{2+}$ and Ni$^{2+}$ in the sandstone column completely penetrated the soil column one after another. The Cd$^{2+}$ ion has an upward trend, and the remaining ions have not changed significantly; Mn$^{2+}$ and Ni$^{2+}$ are in the migration in sandstone was obviously in the migration experiment for 306h and 330h, while the time for Mn$^{2+}$ and Ni$^{2+}$ ions to completely penetrate sand was 414h and 494h, respectively.

![Fig. 4 The penetration curves of different heavy metal ions in soft rock](image)

3.4. The penetration of heavy metal ions in compound soil

3.4.1. Soft rock: sand=1:1. As can be seen from Figure 5, the penetration experiment was carried out for nearly 600 hours. Only heavy metals Cu$^{2+}$ and Cr$^{2+}$ in the complex soil and soil column outflow liquid did not penetrate, and the remaining heavy metal ions completely penetrated the mixed soil and soil column. The migration of Mn$^{2+}$, Ni$^{2+}$, and Cd$^{2+}$ in the sandstone-sandstone 1:1 complex soil was obviously around 120h, 184h, and 462h in the migration experiment, and the complete breakthrough time was 152h, 312h, and 534h. The penetration of heavy metal ions in the initial concentration for a long time is 0, with the passage of time, the concentration of the outflow of the liquid gradually increased, and eventually reached a stable, the formation of "S" curve.

![Fig. 5 Penetration of heavy metal ions in compound soil (soft rock: sand = 1:1)](image)
3.4.2. Soft rock: sand=1: 2. As can be seen from Figure 6, the penetration experiment was carried out for nearly 600 hours. The heavy metals Mn$^{2+}$, Ni$^{2+}$, and Cd$^{2+}$ had completely penetrated in the outflow solution of the soil and soil column, and the Cu$^{2+}$ would have to penetrate completely. The Cr$^{2+}$ concentration was almost zero. The migration of Mn$^{2+}$ in the compound sand with 1:2 soft rock: sand is obviously at 92h, 96h, 168h, and the complete penetration time is 148h, 196h and 248h.

![Fig. 6 Penetration of heavy metal ions in compound soil (soft rock: sand = 1:2)](image)

3.4.3. Soft rock: sand=1: 3. As can be seen from Fig. 7, the penetration experiment was carried out for nearly 600 hours. The heavy metals Mn$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, and Cu$^{2+}$ in the outflow of the soil and soil column had completely penetrated, and the concentration of Cr$^{2+}$ ions was basically zero. The migration of Mn$^{2+}$, Ni$^{2+}$, Cd$^{2+}$ and Cu$^{2+}$ in the compound sand with 1:3 soft rock: sand is clearly at 80h, 92h, 176h and 260h, respectively, and the complete penetration time is 184h, 172h, 216h and 480h.

![Fig. 7 Penetration of heavy metal ions in compound soil (soft rock: sand = 1:3)](image)

3.4.4. Soft rock: sand=1: 4. It can be seen from Fig. 8 that the penetration experiment was carried out for nearly 600 hours, and the heavy metals Mn$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, and Cu$^{2+}$ in the mixed solution of soil and soil column had completely penetrated, and the concentration of Cr$^{2+}$ was basically zero. The time
when Mn$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, and ionic concentrations in the compound sand with a 1:4 sand ratio increased significantly from 20 to 68 hours, 22 to 72 hours, 52 to 84 hours, and 148 to 528 hours in the infiltration experiment.

![Fig. 8 Penetration of heavy metal ions in compound soil (soft rock: sand = 1:4)](image)

3.4.5. **Soft rock: sand = 1:5.** It can be seen from Fig. 9 that penetration experiments have been carried out for nearly 600 hours, and the heavy metals Mn$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, Cu$^{2+}$, and Cr$^{2+}$ have completely penetrated in the mixed soil and soil column outflow liquid. The time when Mn$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, and ionic concentration in the complex sand with a sandstone of 1:5 were significantly increased from 12 to 44 hours, 16 to 44 hours, 29 to 44 hours, 104 to 468 hours, and 426 to 570 hours in the infiltration experiments.

![Fig. 9 Penetration of heavy metal ions in compound soil (soft rock: sand = 1:5)](image)

In summary, the processes of migration of five metals in eight soils are different, and the same soil conditions, different metals, and migration processes are quite different. The same metals have different soils. Figure 1-9 shows the relationship between the permeation time and concentration of
Mn^{2+}, Ni^{2+}, Cd^{2+}, Cr^{2+}, Cu^{2+}, and C/C_{0} in loess, sand and five kinds of compound soils. As can be seen from the figure, the adsorption capacity of five heavy metal ions in soil gradually increased with the adsorption time. The adsorption process of Mn^{2+}, Ni^{2+}, Cd^{2+}, Cr^{2+}, and Cu^{2+} in soil can be divided into three stages. In the first stage of adsorption, the apparent adsorption capacity increases slowly, the apparent adsorption rate in the second stage increases rapidly, and the third stage apparent adsorption The increase is slow. The reason for the emergence of three stages is that with the prolongation of adsorption time, metal ions adsorbed on the surface of soil particles will diffuse into the soil particles and form complexes with the soil particles. When the adsorbed surface sites and internal precipitation sites are occupied After the adsorption of metal ions reaches a saturated state, the apparent adsorption amount remains basically unchanged. Comparing the penetration rates of the five heavy metal ions, it can be seen that Mn^{2+} > Ni^{2+} > Cd^{2+} > Cu^{2+} > Cr^{2+}. Mn^{2+} is the most easily migrating in both soils, requiring the shortest penetration time and a smaller retardation factor than other metals, suggesting that the resistance to penetration is minimal. 5 The penetration of heavy metals from easy to difficult is Mn^{2+}, Ni^{2+}, Cd^{2+}, and Cu^{2+}. The penetration time of all metals in sandy soil and compound soil is less than that in loess, and the pore flow velocity is much higher than the pore flow velocity in loess. The transport resistance of loess to all metals is much higher than that of sandy soil and compound soil. Metal migration resistance, which is mainly due to differences in soil properties, especially in terms of organic matter content and particle composition, the organic content of loess is nearly twice that of sandy soil. The important chelating agent in soil is organic matter, and heavy metal energy and organic matter are contained. The carboxyl group, hydroxyl group, amino group, etc. form a chelate so that it is fixed in the soil. The adsorption performance of the five heavy metal ions on the loess soil is higher than that of sandy soil and compound soil. During the process of loess formation, the process of aluminiferous soil formation is retarded and delayed by the calcium-containing loess parent material, the viscous process is relatively strong, the soil mass is heavy, and the soil salt is Saturation or basic saturation, forming a higher substitution of cations, while the content of ferrosilicon clay is also high, so the heavy adsorption of heavy metal ions in the yellow cinnamon soil is strong; and sandy soil is derived from the floodplain Sex, soil clay, cation exchange capacity and organic matter were all lower than those of loess, and their adsorption to heavy metal ions was weak.

4. Conclusion
Soil column permeability experiments were conducted in the laboratory to study the transport characteristics of five heavy metal ions of Mn^{2+}, Ni^{2+}, Cd^{2+}, Cr^{2+}, and Cu^{2+} in saturated loess, sandy soil and compound soil. The results show that the soil texture and the characteristics of heavy metal ions have a common effect on the migration of heavy metal ions. The process of migration of the five metals in the eight soils is different. The same soil conditions, different metals, and migration processes are very different. The same metals have different soils. The penetration rates of the five heavy metal ions were Mn^{2+} > Ni^{2+} > Cd^{2+} > Cu^{2+} > Cr^{2+}. Mn^{2+} is the most easily migrating in both soils, requiring the shortest penetration time and a smaller retardation factor than other metals, suggesting that the resistance to penetration is minimal. The penetration time of all metals in sandy soil and compound soil is less than that in loess, and the pore flow velocity is much higher than the pore flow velocity in loess. The migration resistance of loess to all metals is much higher than that of sandy soil and compound soil. Metal migration resistance. The adsorption performance of the five heavy metal ions on the five heavy metals is higher than that of the sandy soil and the compound soil. The sandy soil originates from the impact slope of the floodland. The soil clay, cation exchange capacity and organic matter are all lower than that of the loess, and the adsorption of heavy metal ions is better. Heavy metal ions are easy to migrate in sandy soils in the mining area, which infiltrate deep into the soil or into groundwater, causing pollution. Heavy metal ions in loess do not migrate easily and can be adsorbed on the surface or shallow surface for a short time. It is not easy to cause deeper contamination of groundwater, but it also causes As surface runoff migrates laterally to rivers or other areas and expands the area of pollution, no matter which kind of metal in the mining area, the content of which is too high can cause pollution to the environment and cause adverse effects.
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