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The general methods of mine water treatment in China

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ABSTRACT

Mine water is a by-product of the process of coal mining, which is a huge amount (about 7.0 × 10^{10} m^3 in 2016 only in China). For coal mine water including different ingredients, the different water treatment methods have been used. In China, utilization of the treatment methods is summarized, which presents the application situation, technical characteristics, economy, project place and etc. The development trend of mine water treatment technology is discussed, and the main uses of the treated mine water are given. On the whole, electrodialysis is easy to scale, but it requires high pre-treatment of water in the engineering cases. In recent years, for the treatment of high salinity mine water in China, it has been gradually replaced by reverse osmosis. With environmental protection requirements and shortage of water resources, integration and optimization of technology will be an important trend in the development of coal mine water treatment technology.

Keywords: Mine water treatment; Treatment methods

1. Introduction

China's coal production and the number of mines are considerable, ranking the highest in the world, and the annual discharge of mine water is also the highest. The essence of mine water is groundwater, which is accompanied by the development of coal resources into the mine and must be discharged [1]. China's coal mine water treatments and reuse researches started late, and the comprehensive utilization rate was low [2]. In 2006, the discharge of mine water in the mining area of China was more than 4.9 × 10^{10} m^3, accounting for 10% of the national wastewater discharge, accounting for 15% of the national industrial wastewater discharge. However, the comprehensive utilization rate was still less than 50%. Therefore, the utilization potential of mine water in China is huge and the prospect is broad. According to the content of soluble solids in coal mine water, the majority of cations (Na^+, $0.5O_4$·0.5 Ca_2^+, 0.5 Mg_2^+) and the mole fractions of most anions (Cl^{-1}, HCO_3^-) are comprehensively classified, which could be divided into 7 categories [3,4]: sodium water, magnesium water, calcium water, sodium magnesium water, sodium-calcium water, magnesium calcium water and sodium magnesium calcium water. By the soluble solid content in mine water, it could be concluded as three-level: high soluble solid water (>1,000 mg/L), medium soluble solid water (500~1,000 mg/L) and low soluble solid water (<500 mg/L). Considering the mole fraction of anions in the mine water, it has been

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divided into the following classes: chloride water, sulfuric acid brine, hydrogen carbonate brine, chloride sulfuric acid brine, chloride carbonate water, chloride hydrogen carbonate brine, sulfate hydrogen carbonate brine, chloride sulfate hydrogen carbonate brine, etc. The main different types of mine water are shown in Fig. 1. After treated, it could be used for crop irrigation, municipal greening or to be discharged into rivers.

In China, mine water purification treatment technology began at the end of the 1970 s. There are the largest coal production and the largest number of mines in the world. The annual discharge of mine water is also the highest in the world, which is a type of wastewater that has been introduced into the mining space along with coal mining. It is characterized by a large amount of emissions. Except for acid mine water, the pollution level is generally light, and it is a good renewable water resource after treatment [5].

The average coal-water flow in China's mines is 3.5~4.0 m^3/h, and the difference is obvious in each region, with 2.0~3.0 m^3/h in the north-eastern region and 3.0~5.0 m^3/h in most mining areas in North China, East China and Henan [6], the western mining area is below 1.6m^3/h. Based on this calculation, the mine water discharge in China in recent years is 4–5 billion m^3/y [7]. Most of the mine water contains pulverized coal, rock powder, bacteria and other pollutants, which cannot be directly used without treatment.

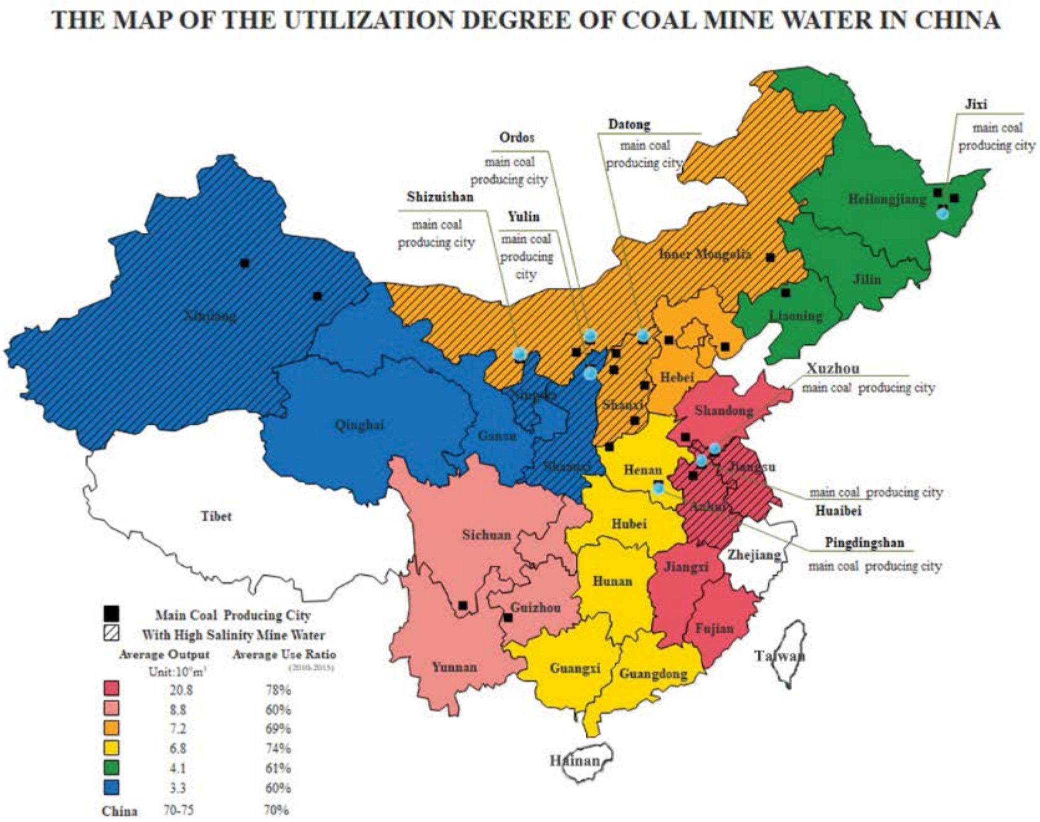
Coal mine water can be roughly divided into the following four types of water quality according to the main types of harmful substances.

- Coal mine water with suspended solids. Groundwater is discharged after physical, chemical and biochemical reactions in contact with coal and rock formations. Therefore, the mine water generally contains solid particles such as coal powder, rock powder and clay, and the main component is coal powder. The density of pulverized coal is generally only 1.5 g/cm, which is much smaller than the density of sediment particles in surface water systems (the average density is generally 2.4~2.6 g/cm). The suspended solid particles in coal mine water have the characteristics of small density and slow sedimentation speed [7,8].
- High salinity coal mine water. The most common inorganic constituents in high salinity coal mine water are Ca^{2+}, Mg^{2+}, K^+, Na^+, $SO4^{2-}$, Cl^-, HCO^{3-} [9,10]. The total amount of these examples is more than 1,000 mg/L. Most of the water quality is neutral or alkaline, with a bitter taste. High salinity coal mine water can be divided into brackish water (mineralization degree 1,000~50,000 mg/L) and saltwater (mineralization degree 10,000~50,000 mg/L). The salt content of coal mines in China is generally from 1,000 to 4,000 mg/L. High salinity mine water is mainly distributed in the northern mining areas of China, the western plateau, the Huanghuai plain and the coastal areas of east China.
- Acidic coal mine water. Acid mine water will corrode the drainage equipment during the drainage process, and will also endanger the growth of aquatic plants and surrounding crops. Acid mine water can be divided into strong acid type (pH < 3) and weak acid type according to pH value (3 < = pH < = 6.5) [11].
- Coal mine water with trace elements. Such mine water often contains harmful components such as trace radioactive elements, heavy metals, fluorine, and petroleum.

For the different mine water in China, the utilization degree of coal mine water is shown in Fig. 2. In China, the main coal-producing regions are Shanxi Province, Xinjiang Province, Shaanxi Province, Hebei Province, etc [12–15]. For the mining areas, the mine water is handled in different methods [16–18], the utilization degree of mine water is different [19,20]. Utilization degree in Jiangsu Province and Anhui Province is about 78%, utilization degree in Shanxi Province and Inner Mongolia Province is about 69%, and utilization degree in Xinjiang Province is only 60%. With the enhancement of environmental protection regulations, the requirement for mine water treatment is necessary in China. So the characteristic of different mine water treatment methods should be known to make better.

The major coal-producing countries around the world and the main treatment methods for coal mine water are shown in Fig. 3. From Fig. 3, the main coal-producing regions in the world are China, Australia, South Africa, the United States, Russia and Europe [21–24]. The main treatment methods for coal mine water are lime process, reverse osmosis and forward osmosis in China, these methods are also used in Australia and South Africa. In the United States and Europe, the main mine water treatment method is reverse osmosis. In general, most countries have begun to carry out the mine water treatment, and reverse osmosis technology is widely used. China as a big coal producer in the world, the mine water treatment is particularly necessary. Then the mine water treatment methods in China mainly will be summarized in order to provide more situations about the mine water treatments.

Fig. 1. The main different types of mine water. (a) High suspended mine water, (b) acid mine water, and (c) high salinity mine water.



CITY NAME	COAL MINE WATER DESCRIPTION
Ordos	Output:51.39 million tons Utilization Amount:16.38 million tons Utilization Ratio:32% (2010)
Shizuishan	Utilization Amount:1.5 milliom tons Treatment Cost:0.308¥/t PH<7 (1998)
Yulin	Output:100 million tons Utilization Ratio:20% (2016)
Datong	Water Discharge:51 thousand m^3/d Utilization Amount:31 thousand m^3/d (2003)
Jixi	Output:3 thousand m^3/d Utilization Amount:16.35 million m^3 Treatment Cost:0.519¥/m^3 Utilization Ratio:60% (2010)
Xuzhou	Treatment Cost:0.659¥/t Water Discharge:68.86 million tons (2000)
Huaibei	Utilization Amount:10.61 million m^3 Utilization Ratio:45% (1998)
Pingdingshan	Utilization Amount:37 million tons Utilization Ratio:84% (2001)

Reference: National Development and Reform Commission document. Special Plan for Mine Water Conservancy. 2006.
National Bureau of Statistics of the People's Republic of China.

Fig. 2. Utilization degree of coal mine water in China.

2. Coal mine water treatment in China

Coal mine water (CMW) is the groundwater around the mining area and roadways, sometimes it contains a small amount of infiltrated surface water. As the country with the highest coal mine output, China also has a higher production of coal mine water to be dealt with. There are mainly five types of CMW in China [25–28]: Clean coal mine water, coal mine water with suspended solids, high salinity CMW, acidic coal mine water and coal mine water with trace elements. As for the acidic CMW, neutralization always is used to purify. The treatment flow chart for different kinds of coal mine water is shown in Fig. 4.

The technology classification for main coal mine water treatments is summarized in Fig. 5. The neutralization, removal of suspended solids and removal of ions are analyzed in detail as follows.

2.1. Neutralization

Comparing with a high PH of CMW, the acidic CMW quality is more complicated. At the same time, it will corrode mine pipelines and equipment, pollute surface water and soils, destroy the landscapes, and even affect the health of miners directly. Acidic CMW is common in the southern coal mines of China. It generally contains metal ions, such as Fe^{2+}, Ca^{2+}, Mg^{2+}, Mn^{2+} and anions, such as SO_4^{2-}, Cl^-, HCO^{3-} [29,30]. The main treatment process is shown as follows.

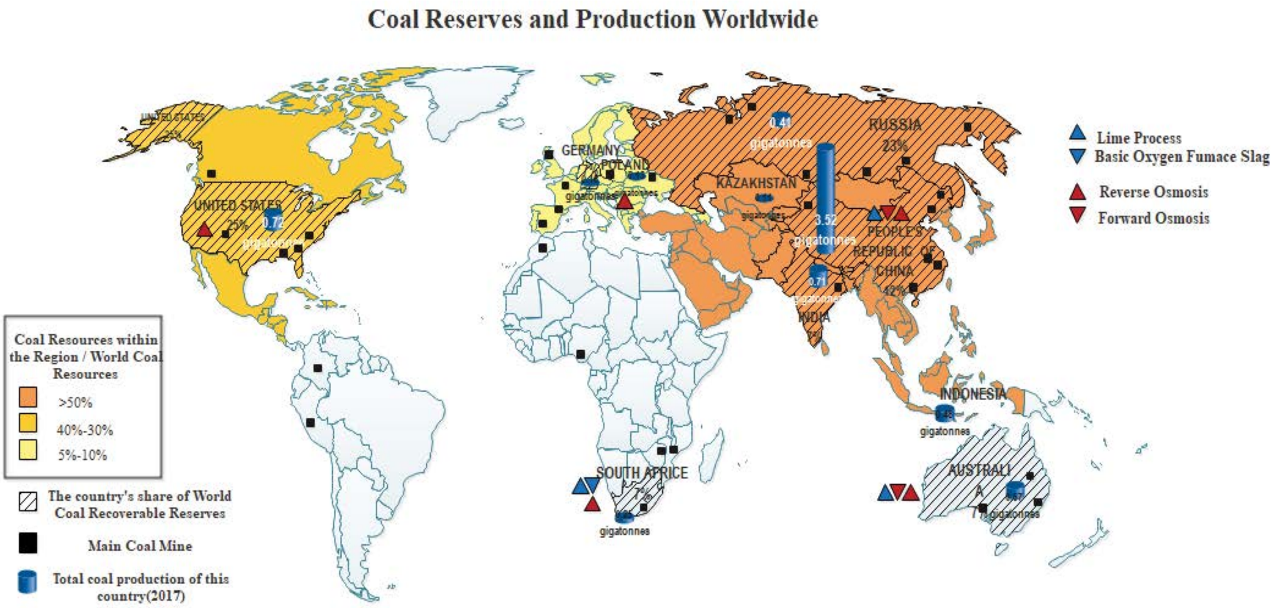


Fig. 3. Major coal-producing countries and main treatment methods for coal mine water.

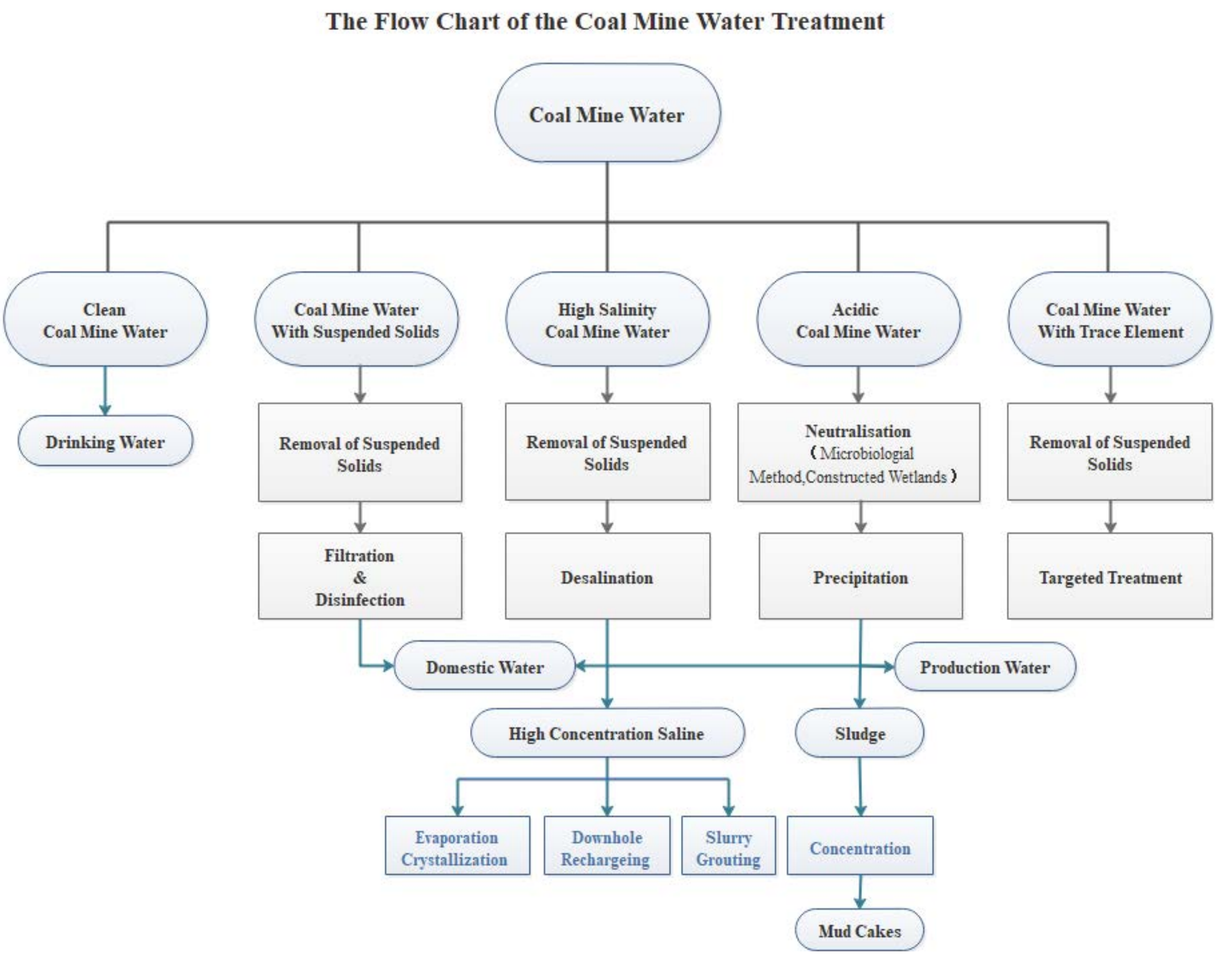


Fig. 4. Treatment for different kinds of coal mine water.

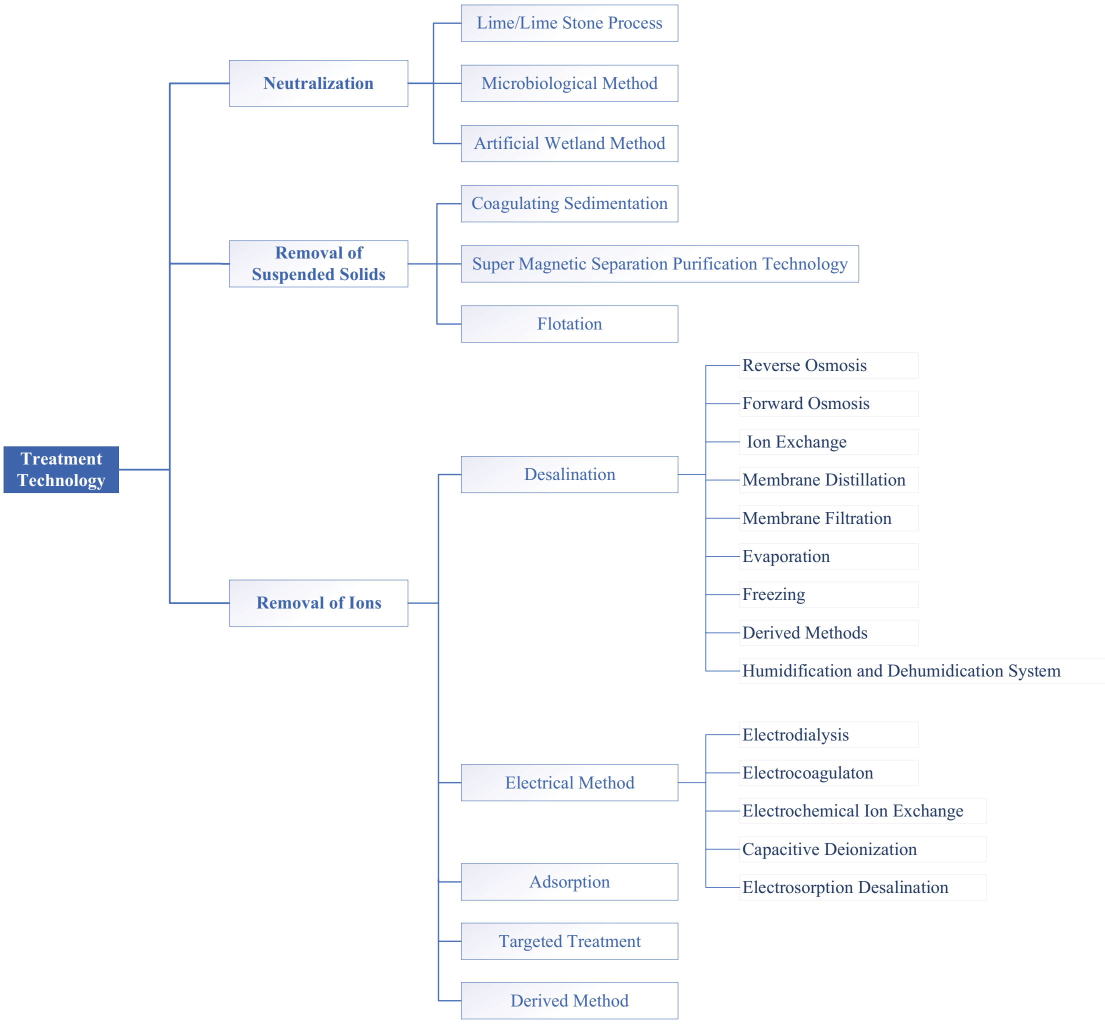


Fig. 5. Technology route for main coal mine water treatment.

2.1.1. Lime/lime stone process

The acid-base neutralization reaction is used in this process. The alkali will increase the PH so that the metal ions in the CMW from the low solubility hydroxide or carbonate precipitate to purify the sewage. Commonly neutralizers used are CaO, $Ca(OH)_2$, Na_2CO_3, NaOH, etc. Among them, traditional neutralization treatment has used the lime (limestone) [31,32], which can be seen in Fig. 6. The main process flow is adding the lime (limestone) into the regulation pool while being fully stirred by mechanical agitation. After precipitation and filtration, the clean water will be drained.

This process is simple and the operation is convenient. At the same time, it can reduce the concentration of Fe^{2+}, Fe^{3+} and SO_4^{2-} in the CMW. The PH value of effluent water can reach 6–9. It is suitable for strongly acidic mine water [33]. However, the lime (limestone) process is prone to generate fouling substances, such as $CaSO_4$ and causes secondary pollution. At the same time, it has poor buffering capacity, difficulty in monitoring the dosage and high cost.

For the latest research progress, in order to solve the shortcomings of the lime (limestone) treatment process,

Fig. 6. Limestone.

using the caustic-burned magnesia powder as the neutralizer will cost less, buffer better and get the more compact precipitation. The Fig. 7 shows the common treatment of acid coal mine water by using the limestone. Now, limestone or lime is used widely for acidic mine water, because the treatment process of calcium hydroxide is simple and easy to realize automatic control.

2.1.2. Microbiological process

The microbiological process is the latest method for treating acidic mine water at home and abroad, which is shown in Fig. 8. Its principle is to use some microbial properties to convert some of the ions in the wastewater into treatable substances. After neutralization, precipitation and filtration, the clean water will be discharged. Currently, there are mainly sulfate-reducing bacteria, thiobacillus ferrooxidans and some biochemical reactions, which involve photosynthetic sulfur bacteria or colorless sulfur bacteria.

Simple and easy to use and low cost is the advantages of this method. It can not only recycle the iron but also effectively remove nutrients, such as P and N from water to solve the secondary pollution. It will achieve high efficiency and low energy consumption so that it has broad prospects in China.

As for the disadvantages, microorganisms require higher conditions for PH and temperature. Therefore, it needs further research. In China, this method has not been widely used.

2.1.3. Constructed wetlands

Constructed wetland for the acidic mine water treatments is widely used abroad in the 20th century and has developed rapidly in recent years in China. Its basic principle is to build a constructed wetland unit, which is referred to as lots of single impervious pond, filled with various sandstones, soil and other media. It is also planted with aquatic plants to obtain specific decontamination effects, which is shown in Fig. 9. Making use of specific plants in the wetlands can reduce the metal ions in acidic mine water, allowing acidic mine water to slowly flow through artificial plant communities to achieve the live filtration. At the same time, the wetland can also provide an interface for the attachment growth of the microbial community. In addition, the water flow and the artificial wetland unit have a certain neutralization effect. It has a simple treatment process and relatively little equipment. But it needs to cover a huge area and take a long time (about 5–10 d) to react [34]. And it has difficulties to control the wetlands, especially in the cold regions.

In a word, the constructed wetland combines the natural ecology with artificial treatment, which is especially for acid mine water. When constructing the wetland, it uses some plants with strong tolerance, such as rushes, cattail, etc. With the improvement of the mining environment in China, the advantage of this method is gradually prominent and its application will be more and more extensive.

2.2. Removal of suspended solids

Most CMW in China belong to CMW with suspended solids, and other types of mine water also contain a certain amount of suspended solids. So the study on treatment of CMW with suspended solids is meaningful. The main components of suspended solids are pulverized coal and rock power. The suspended solids have a small particle size, low density and poor sedimentation effect. Generally, mine water

Fig. 8. Microbiological process.

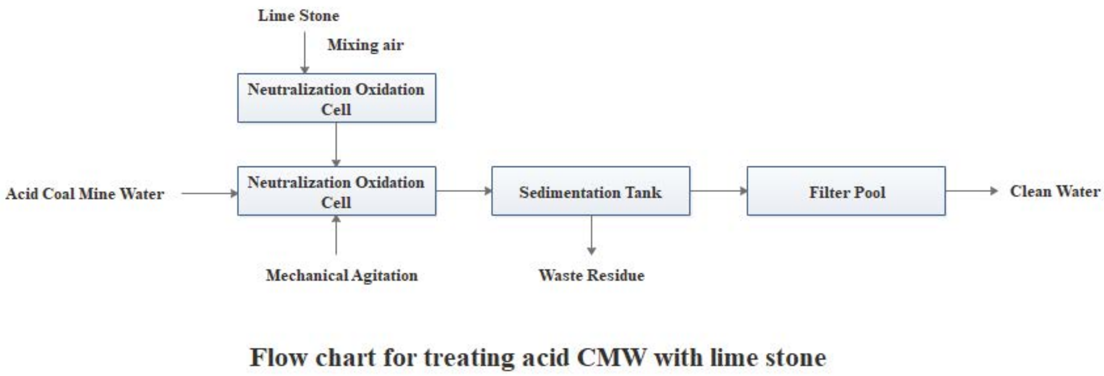


Fig. 7. Lime/limestone process.

Fig. 9. Constructed wetlands.

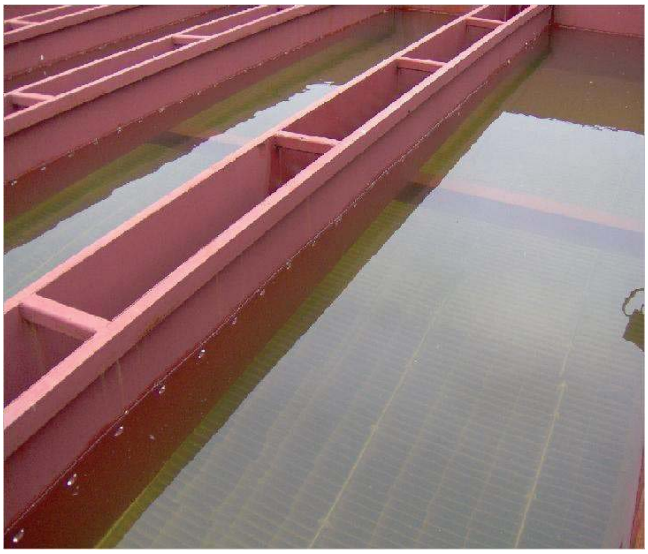


Fig. 10. Coagulating sedimentation tank.

will naturally settle in the underground water tank for a period of time, and the large-sized coal and rock partials are precipitated [35]. According to the characteristics of CMW with suspended solids, the existing level of technology, capital investment and so on, here are three main ways to remove the suspended solids from CMW.

2.2.1. Coagulating sedimentation

China started to study the treatment of mine water with suspended solids in the 1970 s, which is shown in Fig. 10. The treatment of coal mine water with suspended solids generally uses the coagulation, sedimentation, filtration and disinfection processes [36,37]. The treated water is used for production and domestic water. Coagulation is the most critical process during the removal of suspended solids. The selection of coagulant, dosing amount and the hydraulic condition of the reaction will influence the effect and cost of the treatment.

The poly-aluminum chloride (PAC) as a kind of relatively mature inorganic polymer flocculants is one of the most widely used coagulants in the treatment of mine water currently. Due to its wide supply, moderate price, a wide range of applications and good flocculation effect, PAC has been recognized by the water treatment field. At the same time, it is usually mixed with polymer flocculants polyacrylamide (PAM) to enhance the effect. However, PAC still has some shortcomings owing to the special industry characteristics of mine water. For example, the suspended solids in coal mine water are small and light, so that it is difficult to completely flocculate the suspended particles and colloids in the mine water. At last, the amount of PAC added is still large. Besides that, PAC does not have a good removal effect on some oils and organic substances which are commonly found in mine water. And it also brings difficulties in the management and operation of the flocculants dosing system, the slime water discharge system and the slime water pressure filtration system.

Polyaluminum ferric chloride (PAFC) owns the advantages of aluminum and iron salts, which can solve the above problems well. The cost of PAFC treatment of coal mine water is also less than PAC [38]. Table 1 gives the economic comparison of PAC and PAFC.

Table 1
Economic comparison of PAC and PAFC

Flocculant type	PAC	PAFC
Optimum dosage of flocculant (mg/L)	250	200
Flocculant price (¥/t)	1,500	1,800
Flocculant consumption (t/d)	0.75	0.6
Tons of water treatment costs (¥)	0.375	0.36
Water turbidity (NTU)	5.8	4.9

In a word, the coagulation–sedimentation method is the most critical process for removing suspended solids impurities. The choice of coagulant, the dosage and the hydraulic conditions of the reaction directly affect the treatment effect and operation cost. Now, many coal mines in China use integrated water purifiers to treat suspended mine water, which includes reaction, precipitation and filtration.

2.2.2. Super magnetic separation purification technology

This treatment is mainly divided into three parts: pre-sedimentation, coagulation, super magnetic separation purification process. The mine water passes through the grille to remove the suspended solids with a larger diameter and enters the pre-sedimentation tank firstly, then the large particles and dense substances in water precipitate in the pre-sedimentation tank. The pre-sedimentation tank is equipped with a sewage pump, which discharges the sediment from the bottom into the sludge pool regularly. Then pumped to the filter press for dewatering, dewatered mud cakes are outward transport. The precipitated water enters the super magnetic separation and the coagulation system. By adding the magnetic species and coagulants (PAC, PAM) in the coagulation system, suspended particles from a "micro floccules" with magnetic species as the carrier within a short period. At last, the water gets into the super magnetic separator to achieve the fast solid–liquid separation by a permanent magnetic field. And making the water quality reaches the designed effluent standard [39]. Then the magnetic species are recovered and used in the next cycle. The process of super-magnetic separation purification technology is shown in Fig. 11.

ReCoMag super magnetic separation purification technology mainly includes recurrence, coagulation and magnetic separation. Micro-magnetic coagulation technology makes the suspended solids which are non-magnetic, and then remove suspended solids by adsorption of magnetism. Magnetic species recovery technology is used to recover the magnetic species from waste residues which includes the magnetic species and suspended substances in order to reduce operating cost [40].

At present, the main disadvantages of conventional purification treatment (coagulating sedimentation) are large floor space and long hydraulic retention time. While, the super magnetic separation purification technology has the advantages of small floor space, good yielding water quality and quick separation of mud and water. Therefore, this method has broad prospects in the mine water treatment [41].

Take the treatment station with 600 m^3/h processing scale as an example, to make a comparison of the economic indicators between the super magnetic separation purification technology and the traditional coagulating sedimentation process, which is shown in Table 2.

2.2.3. Flotation

In the mid of 1970 s, the flotation treatment technology has attracted considerable attention in the field of water treatment in China, which is shown in Fig. 12. As an efficient and fast solid–liquid separation technology, it has been widely applied to water supply, especially for low temperature, low turbidity, algae rich water purification, municipal sewage and industrial wastewater.

The flotation uses highly dispersed micro-bubbles as a carrier to adhere to the suspended matter in the wastewater and makes its density less than water and floats to

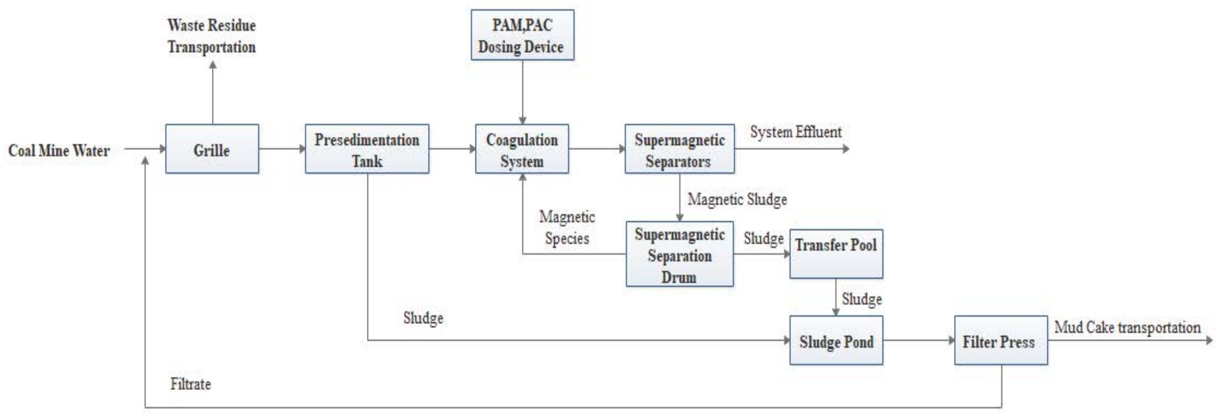


Fig. 11. Process of super magnetic separation purification technology.

Table 2
Comparison between super magnetic separation purification and coagulating sedimentation

Comparison project	Super magnetic separation purification technology	Traditional craft (coagulating sedimentation)
Investment in per ton (¥/t)	<500	1,000–1,300
Running cost in per ton (¥/t)	<0.2	>0.4
Equipment area (M^2)	300	750
Hydraulic detention time (min)	3–5 min	30–240 min Longer time is better
Financial estimate of investment in civil engineering and mine construction in the preliminary stage (10^4¥)	1,029.97	1,452.99
Financial estimate of equipment investment and installation fee in the preliminary stage (10^4¥)	1,723.74	1,607.01
Downhole applicability	Good equipment integration; small size; high security; suitable for downhole water	Long hydraulic detention time; large size; not suitable for downhole water

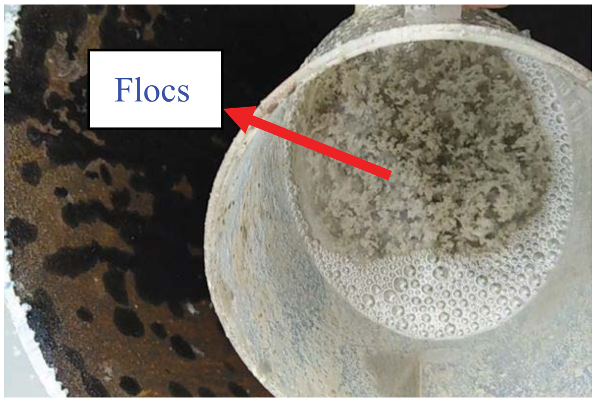


Fig. 12. Flotation tank.

surface to achieve solid–liquid separation process. It can be used for the separation of solid and solid in water, solid and liquid, liquid and liquid, ions in the solute and even the solute [42].

Compared with the precipitation method, the flotation has four advantages: (1) flotation equipment is less occupied and the investment in infrastructure is saved; (2) good yielding water quality, it can deal with the low turbidity algae laden water and raw plankton in the raw water which are difficult to be removed by precipitation; (3) its amount of medicament needed is less than the precipitation method; (4) the useful material can be recycled. But the treatment process of this method is relatively complex, with high technical requirements and large energy consumption. In China, the application of this method is not very large.

2.3. Removal of ions

When the concentration of salt in the coal mine water is higher than 1,000mg/L, it is called the high salinity mine water. It usually contains a large number of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, SO_4^{2-}, Cl^{-}, HCO_3^{-} etc. And most of the water quality is neutral or alkaline, with a bitter taste, commonly known as brackish water in China [43]. In the Chinese northwest and northern mines where water shortage is common, high salinity mine water is often discharged. There is high salinity mine water distribution in Shaanxi, Gansu, Ningxia, Xinjiang, Inner Mongolia, Shanxi and so on [44]. Reverse osmosis technology is widely used in the coal mines of the above regions.

If the mine water with high salinity is discharged directly without treatment, it will be harmful to the ecological environment, which is mainly manifested as an increase in the salt content of the sewage, the elevation of the shallow groundwater level, the salinization of the soil, the reduction of crop production and so on [45].

The treatment of high salinity mine water includes pretreatment and desalination. Pretreatment is mainly conventional coagulation sedimentation or downhole super magnetic separation. Their main purpose is to remove the suspended solids in the mine water, while the key process to deal with high salinity mine water is desalination. Among them, the mature desalination process of low/medium salt concentration in mine water mainly includes ion exchange, membrane process [46] (reverse osmosis, nanofiltration, etc.) and demineralization (DM).The high concentration salt concentration mine water treatment technology includes a multi-effect evaporation process, cyclic evaporation process of mechanical vapor recompression and so on.

2.3.1. Desalination

2.3.1.1. Ion exchange

Ion exchange is a chemical reaction between the ions in the liquid phase and the ions in the solid phase. In order to maintain the electroneutrality of the aqueous solution, ion exchange solid needs release equivalent ions back into the solution [44]. It can extract most of the ions. The process has high removal capacity for low-salt incoming water, the salt rejection rate and the recovery rate can reach above 99%, and the effluent water quality is better, and it is suitable for applications where the product water quality requirements are high, such as boiler water and high purity water. The equipment in this process has a simple structure, convenient operation and management, fewer moving parts and low maintenance. However, the ion exchange has been used widely for many years in various water treatment practices, it has not been actively studied as a desalination technique until fairly recently. Because its costs are excessive, the requirement for using water (usually product water) to rinse the regenerating solutions away from the resin and the excessive salt concentration will affect the normal progress of the ion exchange process. At the same time, its equipment covers a large area and is usually twice as large as the reverse osmosis process.

There has been a recent revival in consideration of ion exchange as a desalination process. This trend may be attributed to three factors:

- Development of high capacity ion exchangers for the DM process.
- Development of ingenious techniques for efficient use, recovery, and reuse of resin regenerant.
- Introduction of exotic, non-resin, ion exchange techniques.

New processes using these approaches include the Desal process, Sul-bi-Sul process, Sirotherm process, continuous ion exchange process (Graver C.I. process), and a liquid ion exchange process for concentrating and removing magnesium selectively from brackish water [47].

2.3.1.2. Membrane distillation

Membrane distillation (MD) is one of the emerging non-isothermal membrane separation processes, which still needs to be improved for adequate industrial implementation [48] and the process is shown in Fig. 13. It is the vapor extraction process from aqueous solution at the temperature which may be much lower than the boiling point of the solution. The operation is realized by means of a microporous hydrophobic membrane separating a solution from a cooler chamber that contains either liquid or gas. The membrane distillation has been used to concentrate at high-level different kinds of solutions, to remove salt from seawater in semi-industrial applications and to separate alcohol-water solutions in biotechnological systems. Recently, the process has been used in water desalination and wastewater treatments [49], which has been used in China coal mine to deal with coal mine water, such as Chifeng Coal Mine of Inner Mongolia Province.

MD presents several significant benefits compared to other separation processes, such as multi-stage flash distillation (MSF), reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF), which are the lower operating temperatures than in distillation process, and lower hydrostatic pressures than in pressure-driven processes. In addition, high salt rejection factors are achievable, especially during the treatment of water containing non-volatile solutes. Moreover, the possibility of using waste heat or alternative energy sources, such as solar and geothermal energies, MD could be combined with other processes into integrated systems, representing more promising separation techniques for industrial applications.

For several different MD modes, the driving force could be used which are direct contact membrane distillation (DCMD), air gap membrane distillation (AGMD), sweeping gas membrane distillation, vacuum membrane distillation (VMD) and osmotic membrane distillation. So far, the essentially two different configurations of membrane distillation processes have been used, which are DCMD and AGMD.

For DCMD, the hot solution is in direct contact with the surface side of the membrane. Therefore, the evaporation of the solvent takes place at the feed-membrane interface. The vapor is transported across the membrane to the permeate side and condensed in the cold permeate inside the membrane module. Because of the hydrophobic character of the membrane, the feed cannot penetrate the membrane without applying additional pressure, and only the gas phase is transported within the membrane pores.

For AGMD, the hot feed solution is in direct contact with the membrane surface, whereas on the permeate side, a stagnant gas layer exists between the membrane and the cold condensation surface is located in the membrane module. The vapor crosses the air gap and condenses on the cold surface inside the membrane module. The benefit is the reduced conduction heat losses. AGMD is less versatile than DCMD because permeate is condensed on a chilled surface rather than directly in the chilled permeate.

For VMD, a convective transport process occurs in VMD using a vacuum pressure on the permeate side of the membrane to reduce the pressure below the saturation pressure of the feed solution. The hydrophobic nature of the membrane prevents the liquid solution from entering its pores and assists in the creation of a liquid-vapor boundary layer. The VMD system has a number of advantages over conventional MD techniques. Perhaps the most significant advantage is the production of pure distilled water at lower operating temperatures, resulting in lower operating costs [50]. For this new method, the industrial application has not been widely promoted in the China mine water treatment. It needs to obtain a stable operation and a better economy.

2.3.1.3. Pervaportion

The fundamental of membrane and membrane process is shown in Fig. 14. Pervaporation (PV) is a relatively new membrane process used for the separation of liquid mixtures. In PV, a liquid mixture is brought into contact with one side of a membrane and the permeation is removed as low-pressure vapor from the other side. Transport through the membrane is induced by the vapor pressure difference between the feed solution and the permeate vapor [51], which is shown in Fig. 15.

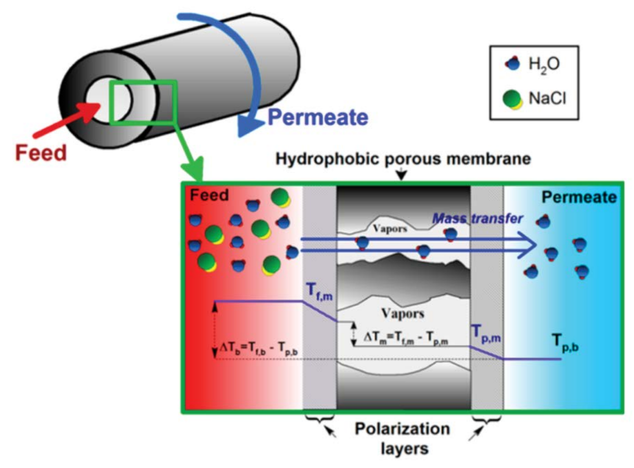


Fig. 13. Mass transfer across the ceramic membrane [48].

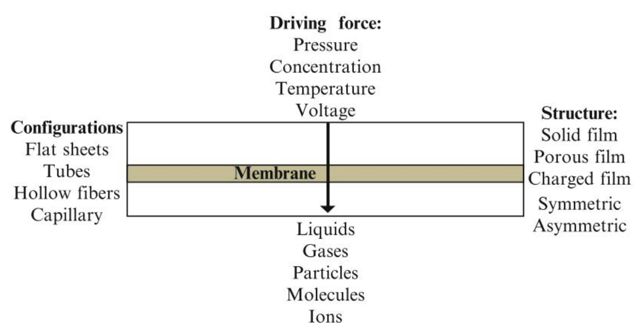


Fig. 14. Fundamentals of membrane and membrane processes.

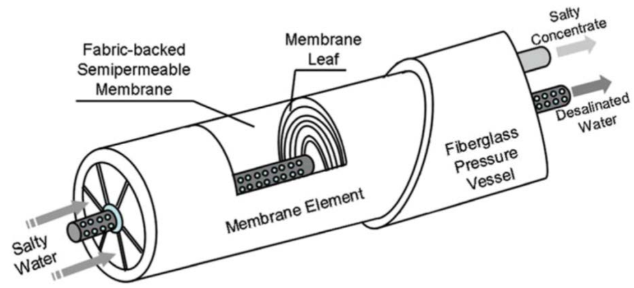


Fig. 15. Diagram of spiral-wound module [53].

Separation is achieved based on the sorption and diffusion differences between the feed components, which are mainly controlled by the complex interactions between the feed components, the membrane materials, and the permeation. PV has certain common elements with both RO and gas separation. Nevertheless, it is different from RO, UF, or MF, as PV involves a change of the permeating species from liquid to vapor phase, and the driving force of the process is provided by lowering the chemical potential of the permeate stream.

Solar water evaporation is thought to be a promising solution to address the issues of water scarcity. However, it is particularly difficult to achieve an idealized thermal photo conversion membrane with all the required structural characteristics such as wide spectrum absorption, ultrathin and porous, low thermal conductivity, and ease to scale-up, thus leading to the reducing of water evaporation efficiency. Recently, the researches on solar enabled desalination have focused on the localized heating of interfacial water for solar vapor generation based on nanomaterials with light absorption capabilities, such as noble metallic nanoparticles, polypyrrole organic polymers, and carbon-based nanomaterials.

2.3.1.4. Reverse osmosis

Reverse osmosis is based on applying excess pressure to reverse the spontaneous process of osmosis, where water in solution moves across a semi-permeable membrane from lower to higher solute concentration. Reverse osmosis (RO) is now the most commonly used desalination process in China, which accounts for 61% of the global share, followed by MSF at 26% and multi-effect distillation at 8% [52]. The world's first commercial RO plant in Coalinga, California, US, began operation in 1965 to produce pure water from brackish groundwater at a capacity of up to 22.7 kL/d (6,000 gallon/d) [53].

RO desalination is a technology that is now in common practice for developing new water sources via desalting of seawater, brackish surface water and groundwater, as well as municipal wastewater [54]. The real engineering in Inner Mongolia of China is shown in Fig. 16. However, RO with semipermeable polymer membranes is an attractive option, but there is a need to improve the penetrance of water while keeping the salt rejection ratio at acceptable levels. Additionally, biofouling for RO membranes is a major problem, causing both reduced flux and high maintenance cost [55].

While the forward osmosis process is an emerging low energy desalination technology, water naturally traverses the semi-permeable membrane from a lower solute concentration feed solution to a higher solute concentration solution, known as the draw solution [56]. The common treatment for coal mine water with high suspended solids and high salinity is shown in Fig. 17.

Compared with electrodialysis, reverse osmosis has a high recovery rate of raw water, up to 80%, which can effectively remove inorganic salts, low molecular organics and bacteria in sewage. However, RO needs strict pretreatment in use, with high operating pressure, complex equipment and high investment. With the progress of technology, its treatment effect and investment, it would become more and more mature, and widely used in China.

2.3.1.5. Humidification–dehumidification process

This method is in-depth in seawater treatments, but because of its advantages, it has broad prospects for mine water treatment. In order to save more energy, this method is combined with solar energy function to compose the solar humidification and dehumidification device.

The humidification–dehumidification desalination technology is the process of heating, evaporation and condensation. In this way, a targeted technology can be used to strengthen the various heat and mass transfer processes

Fig. 16. Reverse osmosis system of mine water treatment in Wuhai City, Inner Mongolia.

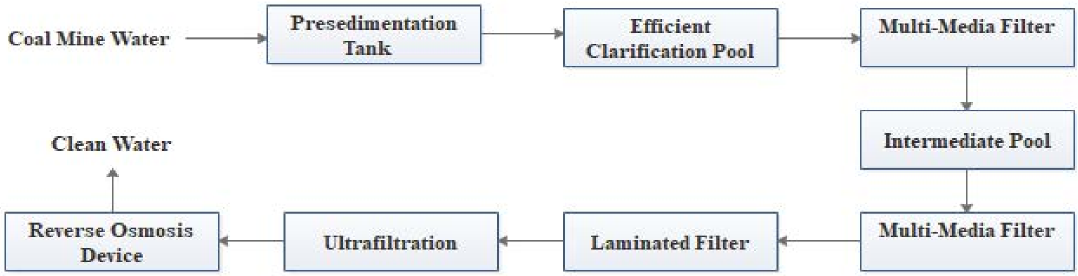


Fig. 17. Common treatment for coal mine water with high suspended solids and high salinity.

and improve the energy utilization efficiency of each process. In addition, it has the advantages of simple control, stable water production, normal pressure operation, easy combination with renewable energy. The use of solar energy for humidification and dehumidification of brackish water (or seawater) desalination technology provides the required heat energy, which can not only save the investment cost of the desalination device but also reduce the pollution to the soil and the atmosphere. Based on the above characteristics, this system is considered to be one of the most promising ways to efficiently use solar energy to produce freshwater [57].

The method corresponds to a variety of different devices. Differentiated by the treatment of brackish water, the device has the bubbling type, spray type and so on. They all have their own advantages. For example, bubble column humidification and dehumidification system for coal mine wastewater effectively can avoid the clogging problem while increasing the reaction area [58]. The water production process is shown in Fig. 18, which can use different low-grade heat sources. This method can use solar energy to drive the system, and the thermal energy consumption is moderate, which is about 700.0 kJ/kg. Compared with the other methods, its energy consumption is smaller and has a good application prospect.

2.3.1.6. Freezing

Freezing is one of the methods used for desalination. Although different from the reverse osmosis and distillation, freezing can be used for remote areas, cold regions and for small and remote societies [59–61].

The freezing concentration process refers to cooling the solution until the water partially freezes into ice crystals, then separates the ice crystals from the solution, thereby increasing the concentration of the solution [62], and the flow diagram is shown in Fig. 19. This method is mainly applied to seawater desalination projects in the early stage, so it is still in the exploration stage in mine water treatment. However, it has shown greater advantages than

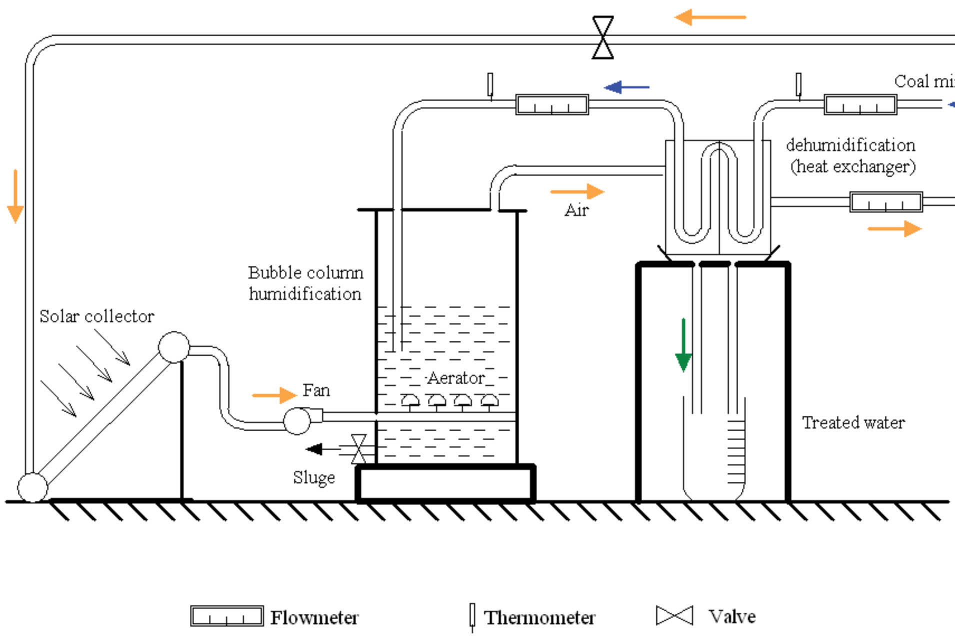


Fig. 18. Bubble column humidification and dehumidification system.

traditional water treatment methods. Moreover, most of China is a continental climate and rich in natural cold energy. Therefore, it has a broad prospect for development.

The research shows that more cation can be removed than anion after being frozen. The removal rate is affected by freezing time, freezing temperature and initial concentration of the ion. The removal rate increases with the increase of freezing time, the raise of freezing temperature, the reduction of the initial concentration of ion and the adding of seed ice. The freezing method used to treat mine water is not very mature in China, the economic comparison is given in Table 3.

Because the reverse osmosis method needs pretreatment of the seawater strictly, the membrane used in general needs to be replaced for 3–5 y, and the replacement cost is about 40% of the total cost. Therefore, considering various factors, the freezing method has certain advantages both economically and technically [63]. The different treatments for coal mine water are compared in Table 4.

2.3.2. Electrical method

2.3.2.1. Electrodialysis

In 1957, the electrodialysis method [64–67] was started to produce deionized water. The electrodialysis cell could compete with a still for producing "distilled water" for four reasons:

- Cell produces deionized water equivalent in quality to distilled water at a power consumption rate several hundred times less than that of a still of similar capacity.
- Cell operates at room temperature.
- Cell can act as its own storage tank for limited quantities.
- Scale removal is less of a problem than for a still, since much of the salt removed from the water is carried away in the waste stream.

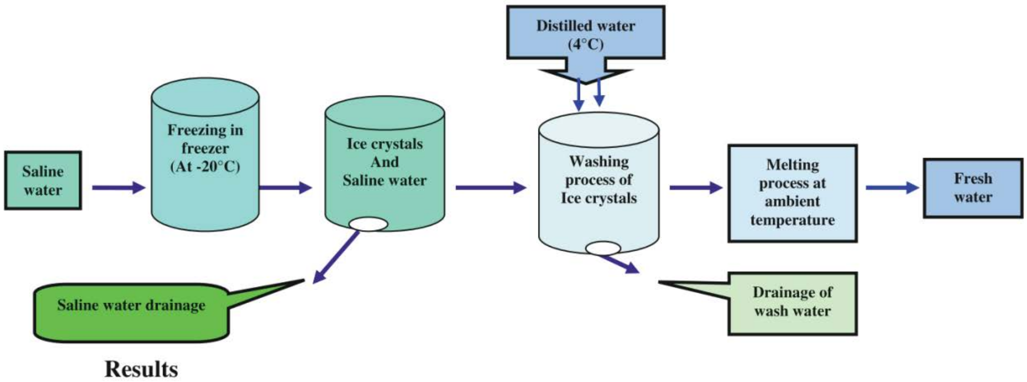


Fig. 19. Flow diagram of the freezing-melting cycle [62].

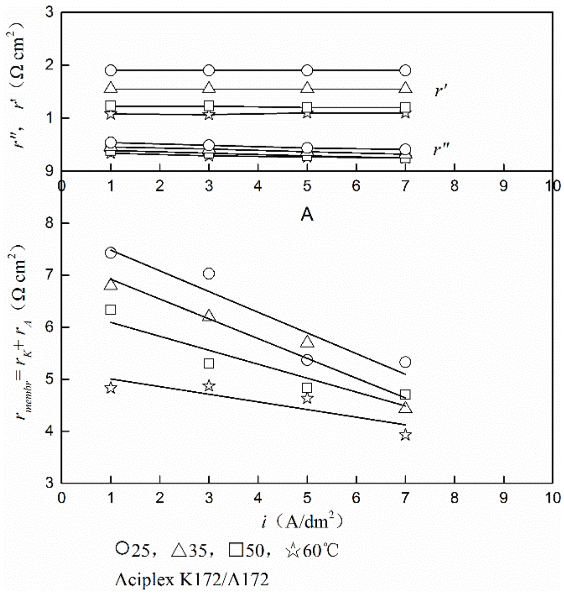


Fig. 20. The electric resistance of a desalting cell, a concentrating cell, and an ion-exchange membrane pair for Aciplex K172/A172 [68].

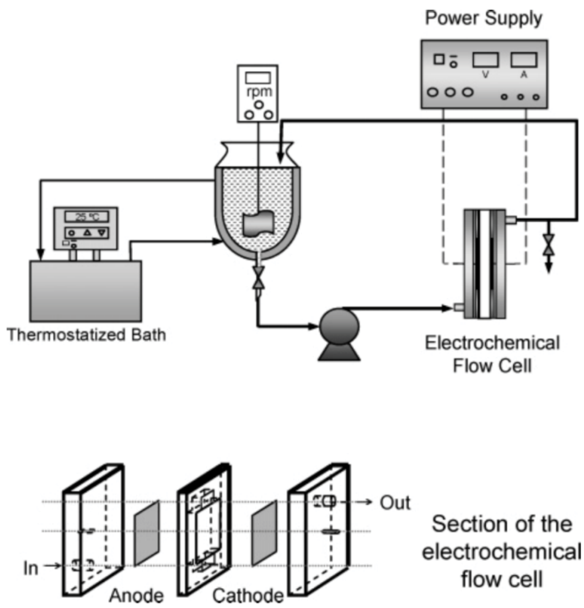


Fig. 21. The layout of the bench-scale plant. Detail of the electrochemical flow cell [73].

Table 3
Economic comparison (¥/t)

Project	2,000m^3/d product water			37,850m^3/d product water		
	Multi-stage distillation	Reverse osmosis	Freezing	Multi-stage distillation	Reverse osmosis	Freezing
Equipment investment	0.65	0.56	0.6	0.56	0.43	0.41
Energy consumption	1.48	1.19	0.76	0.7	0.4	0.435
Medicament fee	0.32	1.67	0	0.1	0.15	0.01
Membrane substitution fee	0	0.37	0	0	0.45	0
Labour force	0	0	0	0.15	0.1	0.1
Total	2.45	3.79	1.36	1.51	1.53	0.95

Table 4
Comparison of different treatments for coal mine water in many ways

Treatment	Processing Range	Salt Removal Rate	Advantages	Disadvantages
Reverse osmosis	3,000–10,000mg/L	95%–98%	Flexible configuration; small footprint; lightweight; short construction period	Easy to scale, limits its ability to handle high concentrations of mine water
Membrane distillation			Lower operating temperatures; lower hydrostatic pressures	
Ion-exchange	500 mg/L	99%	Simple structure; easy to operate and manage; low maintenance	Large footprint; effect of concentrated brine is not good

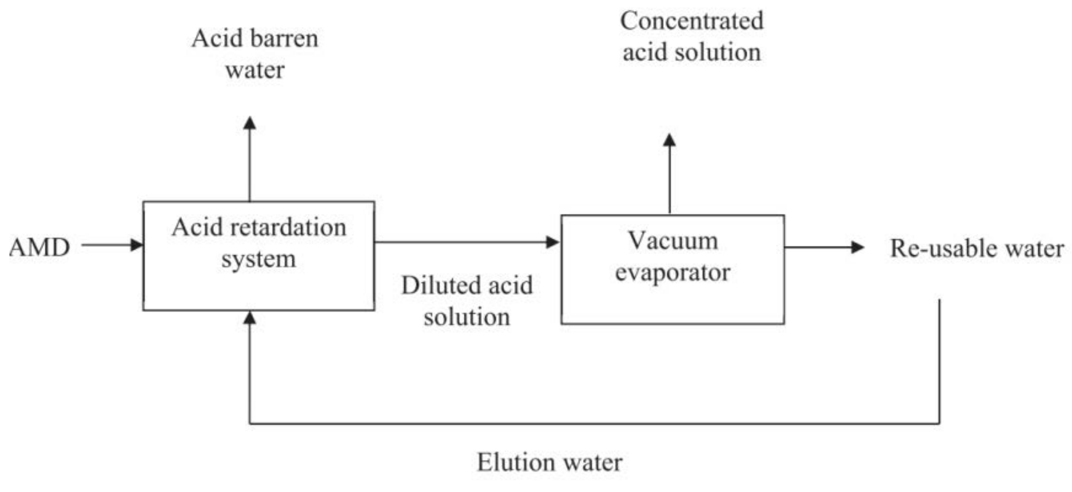


Fig. 22. Proposed acid retardation set up for sulphuric acid recovery from acid mine drainage [76].

Many new development is carried out to promote this method in engineering application [68,69]. The electric resistance of a desalting cell, a concentrating cell, and an ion-exchange membrane pair is shown in Fig. 20. The advantage of this method compared to a microbial fuel cell approach is that the potentials between the electrodes can be better controlled, and the hydrogen gas that is produced can be used to recover energy to make the desalination process self-sustaining with respect to electrical power requirements.

An electrodialysis plant of high salinity mine water in XUZhou ZhangJi coal mine of JiangSu Province is established, which produces daily water 1,500.0 t. The water quality is shown in Table 5 and the actual operating costs are shown in Table 6. The electrodialysis is mainly used for desalination with a salt content of 500–4,000 mg/L, but it cannot remove organic matters and bacteria in water, and the operational energy consumption of the equipment is high. In the past, the majority method used is electrodialysis. Now, with the reverse osmosis improvement, there is

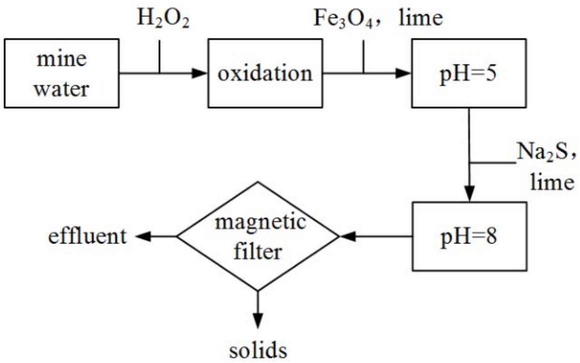


Fig. 23. Flowsheet of the proposed precipitation process [78].

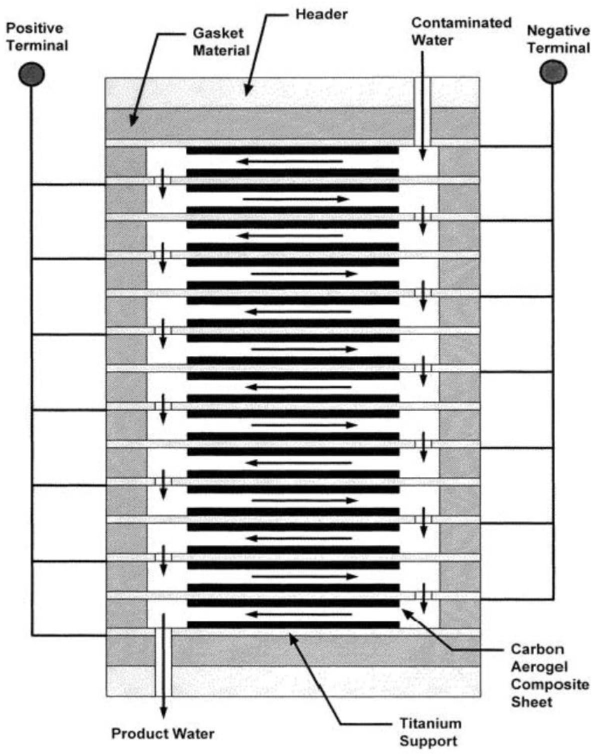


Fig. 24. Schematic representation of an electrochemical adsorption-regeneration cell [96].

Table 5
Water quality of ZhangJi coal mine

Cation	Ion concentration (mg/L)	Anion	Ion concentration (mg/L)
K^+, Na^+	313.74	Cl^-	256.96
Ca^{2+}	104.21	SO_4^{2-}	451.00
Mg^{2+}	60.77	HCO_3^{2-}	439.83
Fe^{3+}	0.10	CO_3^{2-}	0.00
Fe^{2+}	0.00	NO_3^-	0.00
Salt content	1,852.61 mg/L		

a tendency to replace the electrodialysis in the mine water treatment.

2.3.2.2. Electrocoagulation

A new strategy combining iron-electrocoagulation and organic ligands cooperative chelation was proposed to screen and precipitate low concentrations (0–18.52 μmol/L) of uranium contaminant in aqueous solution [70,71]. The removal of sulfonated humic acid from water through hybrid electrocoagulation–ultrafiltration treatment process and influence factors [72–74] are analyzed to study the influence of the different operating conditions in the process [75]. The detail of electrochemical flow cell is shown in Fig. 21. However, this method is not greater used in China for its control and electrical corrosion.

2.3.2.3. Electrochemical ion exchange

Nleya et al. [76] discussed traditional wastewater treatment methods such as neutralization, precipitation, membrane processes, ion exchange and biological sulfate removal, which indicated acid mine drainage with serious threats to the environment due to its toxic constituents. The process flow is shown in Fig. 22.

The solution is proposed which is through optimized pretreatment, reverse osmosis (RO) or electrodialysis reversal concentrates and regenerates from cation and anion exchangers, and can be used as feed solutions for the production of an acid and a base by electrodialysis with bipolar membranes [77,78]. The proposed precipitation process is shown in Fig. 23.

Table 6
Actual operating costs

Category		Fee (¥/t)		Percentage of cost (%)
Power consumption of equipment	Percentage of cost	0.182	0.698	63.46
	Water pump	0.516		
Lighting		0.013		1.15
Labor cost		0.086		7.69
Depreciation		0.240		21.54
Equipment maintenance		0.069		6.16
Total		1.11		100.0

2.3.2.4. Capacitive deionization

Capacitive deionization (CDI) was proposed to remove salt and improved continuously to enhance the desalting effect of the method [79–82]. Carbon aerogels are considered as promising materials for use in supercapacitors and in CDI and other separation processes based on electro-adsorption [83–87]. The materials, their uses for different applications, and the methods of their preparation are covered by a series of patents held by the University of California and the USA Department of Energy (e.g., [88–90]) and other bodies (e.g., [91,92]). Farmer et al. [93] first studied the treatment of heavy metal (Cr^{+6}) by CDI. Oda et al. [94] studied the removal of Cu^{2+} and Zn^{2+} using activated carbon electrodes.

CDI is based on the recognition in which the high-surface-area electrodes can quantitatively adsorb ionic components from water when electrically charged, thereby resulting in desalination [95,96]. The electrochemical adsorption-regeneration cell is shown in Fig. 24. Flexible 3D nanoporous graphene is used for desalination and bio-decontamination of brackish water via asymmetric CDI [97]. The energy consumption during ion removal in seawater concentration (600 mM NaCl) is low (17.0 kT), which would be impossible to accomplish with conventional carbon electrodes operated with CDI. This method is promising in coal mine water treatment, which could be widely used with technological progress.

2.3.2.5. Electro-absorption desalination

Ayranci et al. [98] adopted a porous carbon as an electrode to remove salt from water. The electro-absorption technology is used to the regenerative treatment technology of waste drilling fluid and realized the removal of the inferior solid phase of waste drilling fluid without adding chemical treatment agent, and improved regeneration [99]. The performance of drilling fluids provides a new way for the recycling of waste drilling fluids.

The relationship between the adsorption capacity of different saline ions and its equilibrium concentration is good, complying with Freundlich isotherm, and the Lagergren quasi-second-order kinetic equation could describe the whole stage of the electro-absorption process quite well [100]. It contains saline ion solutions with different valence states. The higher the valence state is, the better the adsorption effect is.

Each of the above technologies has advantages and disadvantages, which are shown in Table 7, and the reasonable method should be considered for the specific application, according to CMW characteristics, geographical locations, applicable regulations, and costs.

3. Reutilization of mine water in China

The coal mines in China began to pay attention to the utilization of mine water from 1960, and directly used underground drainage for coal washing or after natural precipitation and filtration for bathing. After 50 y, coal mining technology in China has developed rapidly, and water treatment technology is also improved [101]. China's coal mine drainage and sewage treatment engineering was built after the 1980s, such as mine water treatment projects in Datong, Pingdingshan, Xuzhou and etc.

In general, the coal mine water contains all kinds of pollutants, which should be treated effectively before being discharged. The general processing flow is as follows: pretreatment, coagulation sedimentation, filtration, advanced treatment of mine water (including removal of harmful substances and desalting of high salinity mine water), disinfection treatment. The general process is shown in Fig. 25.

3.1. Pretreatment

The mine water is mainly used to remove the larger pollutants in the sewage through the grid. Through the limestone process, microbiological process or wetlands, the acidic CMW is neutralized. Pretreatment of coal mine water is the guarantee of post-processing.

3.2. Coagulation sedimentation

The use of coagulation and sedimentation can remove the suspended matter in the water, regulate the water quality, and appropriately reduce the color, hardness, bacterial count, etc. The principle of selecting coagulants is that it can produce large, heavy and strong alum, with good water purification effect and no adverse effect on water quality. This process is widely used in China mine water treatment.

3.3. Filtration

After coagulation and sedimentation, the water also contains particles (less than 5 μm) of suspended solids and colloids, through the quartz sand multi-layer filtration to achieve further in-depth treatment.

3.4. Advanced treatment of mine water

For the mine water with high salinity, when the salt content is less than 500 mg/L, the ion exchange method can be used; when the salt content is 500–3,000 mg/L, the membrane separation (electrodialysis, reverse osmosis) can be used in consideration of technical economy. The salt content of mine water in China is generally 1,000–3,000 mg/L, which is suitable for membrane separation. Electrodialysis is easy to scale, and it requires high pretreatment of water. In recent years, for the treatment of high salinity mine water in China, it has been gradually replaced by reverse osmosis. However, the main disadvantages of RO are high operating pressure, high energy consumption and complex equipment. At the same time, the membrane is easy to pollute and scale, so the pretreatment process needs to be added. Generally, mechanical filtration + activated carbon filtration + security filter are used for three-stage filtration, and ultrafiltration can also be used instead of three-stage filtration.

3.5. Disinfection treatment

After purification and advanced treatment, the mine water must be disinfected to kill the harmful pathogenic

Table 7
Summary of the principles, advantages, and disadvantages of the different technologies

Treatment technology	Principle	Advantages	Disadvantages
Lime/alkali	PH adjustment	Can release anion and adjust the PH of the water	Poor Ca^{2+}, Mg^{2+} removal. New matter is added
Bioremediation	Fermentable waste materials used to facilitate microbial processes	Natural processes can be designed for use as a passive system	Poor Ca^{2+}, Mg^{2+} removal. Require further treatment to obtain low TDS effluent
Biological sulfate reduction	Process-based on sulfate reduction in an anaerobic reactor	Sulfide can be partially oxidized to sulfur	Biomineralization of metallic contaminants present in the mine water
Membrane filtration	UF and NF use direct filtration using a medium with small enough pores to retain dissolved solids	Can operate at lower pressures and higher fluxes than RO	Membranes are sensitive to oxidative chemicals and can be damaged by sharp particles
Reverse osmosis	Applied pressure overcomes the osmotic pressure of a semipermeable membrane	Low energy required; low cost	Prone to biofouling and scaling
Distillation	Uses heat to vaporize water	Produces low conductivity water	Cost of energy can be 50% of the total cost
Precipitation	Removes ions by the formation of an insoluble solid with a reagent	Simple systems, easy to combine with other treatments	Generates more waste than other technologies
Capacitive deionization	Uses voltage applied to porous carbon electrodes	No applied pressure required, efficient for water	Requires optimization for efficient TDS removal
Electrocoagulation	Uses electrolytic cells to remove Ca^{2+}, Mg^{2+}	No chemicals; produces highly stable sludge	High initial investment; sacrificial electrodes are dissolved in wastewater
Electrochemical ion exchange	Ion exchange media is incorporated in an electrodialysis stack	Initial high efficiency and waste reduction compared to regular ion exchange	Membranes are costly and prone to scaling, which decreases removal efficiency
Ion exchange	Physical separation process by which dissolved ions are exchanged for different ions from the ion exchange material	Low cost and easy to operate	Regeneration of material requires the addition of chemicals
Adsorption	Ions are attracted and bound to the adsorbent surface	Established technology; adsorbents readily available	Most TDS ions are only adsorbed to a limited extent
Arsenic removal/ molybdenum removal	Metals removal from mine drainage by specific means	Specified removal for the single matter	Induce new matter

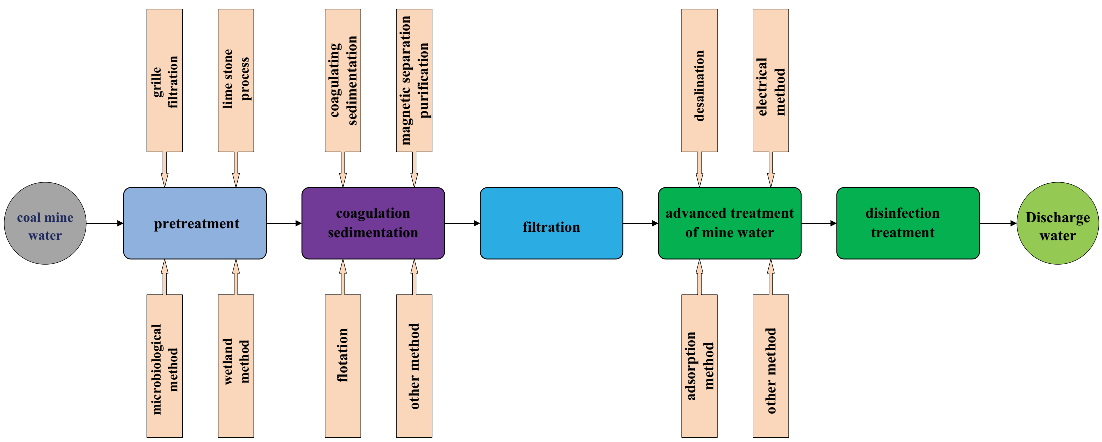


Fig. 25. The general process of mine water treatment process.

microorganisms in the water. In general, China's coal mines use chlorine dioxide for disinfection, which is low cost and harmless to the human body.

In recent years, the related works have continued to be carried out. The average cost of different kinds of mine water treatments is given in Table 8.

While the cost per unit of water of tap water in China (including operation cost) is 1.3–1.8 ¥/t. Therefore, from the perspective of industrial water and domestic water, mine water treatment costs have a certain cost advantage over tap water [102].

Five kinds of typical desalting engineering cases for high salinity mine water are shown in Table 9. RO is used in the coal mine of Jizhong energy [52], the energy consumptions are about 3.96 MJ/t and the cost is about 2.09 ¥/t; for water quality fluctuating greatly of Huainan coal mine [103], electro-absorption method is used, the energy consumptions are about 3.6 MJ/t and the cost is about 1.5 ¥/t; total dissolved solids (TDS) is about 11,052 mg/L in Coal mine of Shenhua, with the desalination load increasing, the energy consumptions are about 6.41 MJ/t and the cost is about 2.92 ¥/t; the mine water treatment project of Hongqinghe coal mine in Ordos is the first zero discharge project in China, in which RO + ion-exchange + RO + multi-effect evaporation is used, the energy consumptions are about 16.5 MJ/t and the cost is about 7.89 ¥/t; even Henan Xinzhuang coal mine adopting low energy consumption electrodialysis process, the cost is about 1.05 ¥/t.

According to Table 9, the performance for the above type desalting engineering cases is obtained from Fig. 26.

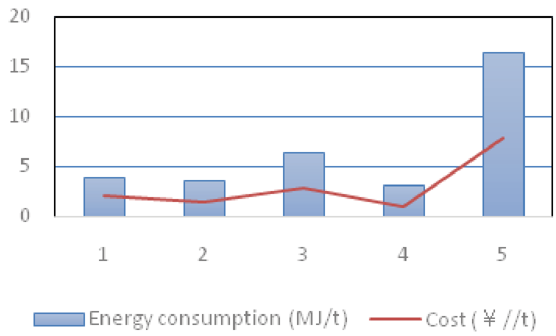


Fig. 26. Performance for the above type desalting engineering. (1) Sink tank + filtration + ultrafiltration + RO; (2) reaction tank + sedimentation tank + filtration + electroabsorption; (3) sink tank + filtration + ultrafiltration + RO; (4) sink tank + filtration + electrodialysis; (5) pretreatment + RO + ion exchange + RO + multi effect evaporation.

Table 8
Average cost of different kinds of mine water treatment

Type of CMW	Production water production cost (¥/t)	Infrastructure investment (¥/t)	Operating fee (¥/t)	Total processing cost (¥/t)
Clean CMW	Simple processing and low cost			
CMW with suspended solids	0.28	400	0.04	0.32
Acidic CMW	0.48	750	0.07	0.55
High salinity CMW	0.65	1,100	0.11	0.76

Table 9
Typical desalting engineering cases in China coal mines

Coal mine	Water processing capacity (m^3/d)	Water quality (mg/L)			Major craft	Energy consumption (MJ/t)	Cost (¥/t)
		TDS	Total hardness	Sulfate			
Coal mine of Jizhong energy	500	1,148	818.8	596.4	Sink tank + filtration + ultrafiltration + RO	3.96	2.09
Coal mine of Huainan		2,000–3,500	200–400		Reaction tank + sedimentation tank + filtration + electro-absorption	3.6	1.5
Coal mine of Shenhua	10,000	11,052	153	3,415	Sink tank + filtration + ultrafiltration + RO	6.41	2.92
Xinzhuang coal mine in Henan	440	3,018–3,034	9.6–11.06	1,547–1,565	Sink tank + filtration + electrodialysis	3.15	1.05
Hongqinghe coal mine in Ordos	600	3,011		1,264	Pretreatment + RO + ion exchange + RO + multi effect evaporation	16.5	7.89

Cost in Table 9 cost includes equipment depreciation charge (depreciated by 20 y) and operation cost.

From Fig. 26, the trend of energy consumption and cost are basically identical. For the Hongqinghe coal mine in Ordos has the higher requirements for drainage in coal mines, the energy consumption and cost are 16.5 MJ/t and 7.89 ¥/t respectively which are higher because more processes (retreatment + RO + ion-exchange + RO + multi-effect evaporation) are adopted. In general, the economy of reverse osmosis is near to the electrodialysis. Just reverse osmosis has a high recovery rate of raw water, up to 80%, which can effectively remove inorganic salts, low molecular organics and bacteria in sewage. For the different requirements of coal mine water treatment, the economic and science treatment processing flow should be adopted on the basis of comprehensive consideration.

Combined with the current situation of mine water treatment engineering, the energy consumption is reduced by increasing the magic concentration multiple for the existing high salinity mine water using RO, but it is not advantageous for high pressure and high salt. It is difficult to judge the application scope of electrodialysis because of the complexity of salt in high salinity mine water. Hence, new technologies and methods could be integrated on the basis of existing treatment methods, such as combining new energy technology with the existing treatment methods, to achieve low energy consumption desalination. The main development ideas are shown as follows:

- Properly combine NF, electrodialysis (ED) with RO to reduce desalting energy consumption, which is called a desalting combination process and shown in Fig. 27;
- In the proper conditions, solar energy and geothermal energy could be brought into the thermal method of mine water treatment; which is shown in Fig. 28;
- Combined with the environmental greening project, the mine water could be treated with the constructed wetland method, so as to achieve the integration of economic and environmental remediation for the mining area;
- Further strengthen the salt recovery of the treated tailwater to realize the integrated recovery and utilization of water and salt;
- Enhance policy guidance and encourage coal mines to vigorously carry out mine water treatment and reuse.

The treated mine water can be used as production, living and ecological water after treatment in China [104]. After treatment, the coal mine water is mainly used in the following aspects: mining area production, greening, dust prevention, industrial supplementary water for enterprises around the mining area, irrigation water for farmland around the mining area and domestic water for residents.

For China, the specific reuse pattern of mine water with suspended solids after treatment is shown in Fig. 29. The principal proportion of the main reuse pattern is shown in Fig. 30. For the treated mine water, about 34% of the treated mine water is used in the coal mine production process, about 28% of the treated mine water is used in the coal mine process, about 28% of the treated mine water is used in the coal mine process, about 23% of the treated mine water can be used for industrial and agricultural production around the mining area, about 15% of the treated mine water can be used for municipal greening of the mining area. In general, the treated mine water can be used for industrial, agricultural and domestic water around the mining area, which greatly alleviates the water shortage in the mining area.

4. Conclusion

For the mining area, the mining water treatment is an important issue because of water shortage, and the treatment for mine water is significant for environment preservation and water resources recycling. In this paper, the main treatment methods of mine water in China are presented, which shows the engineering situation of different treatments. It could provide the characteristic of the methods, and the basis for the selection of the methods. In China, after pretreatment/coagulation sedimentation/filtration, the coal mine water is

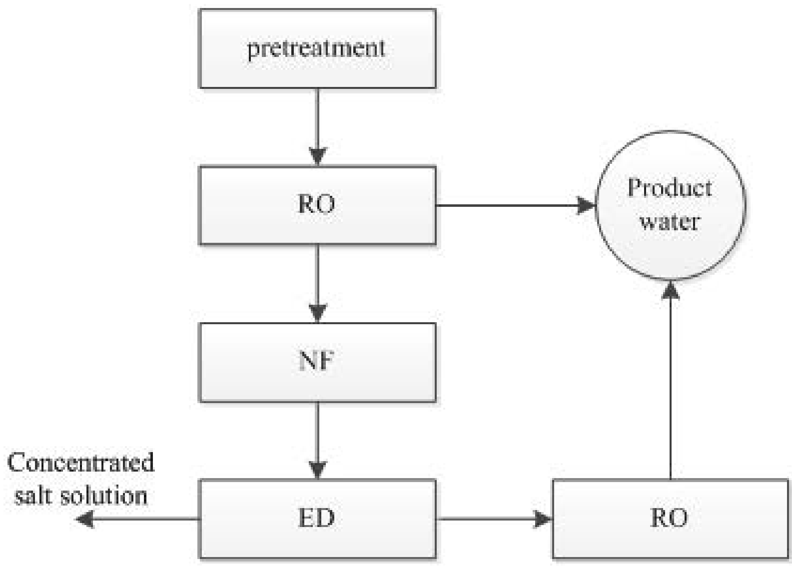


Fig. 27. Desalting combination process.

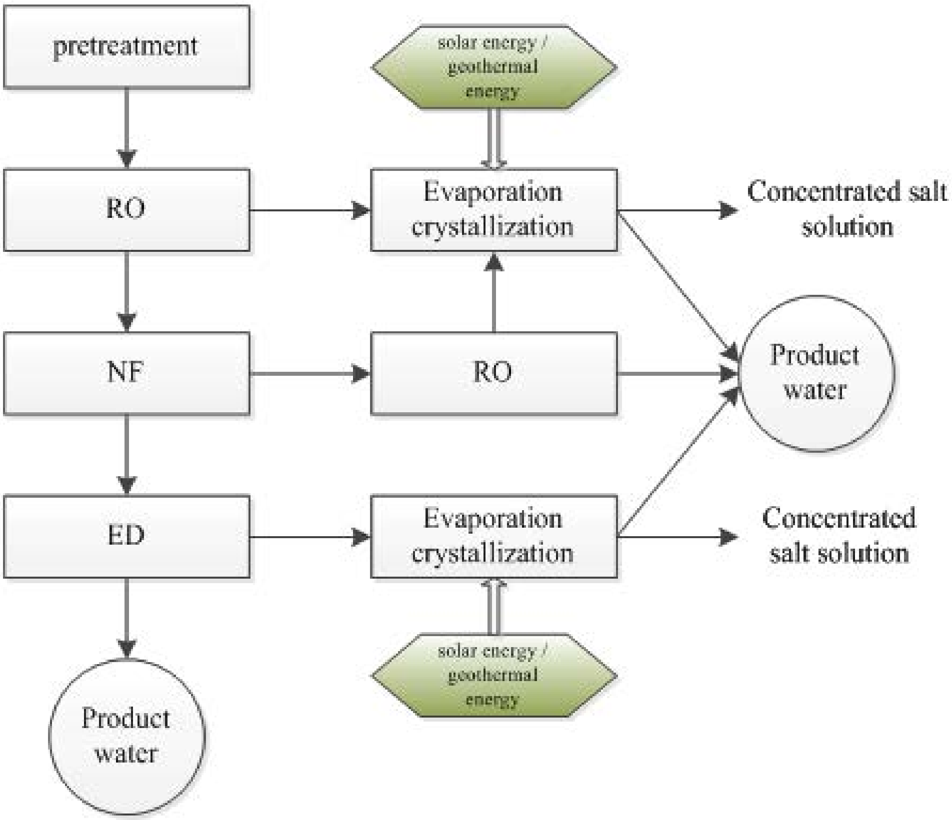


Fig. 28. Desalting process combination with solar energy/geothermal energy.

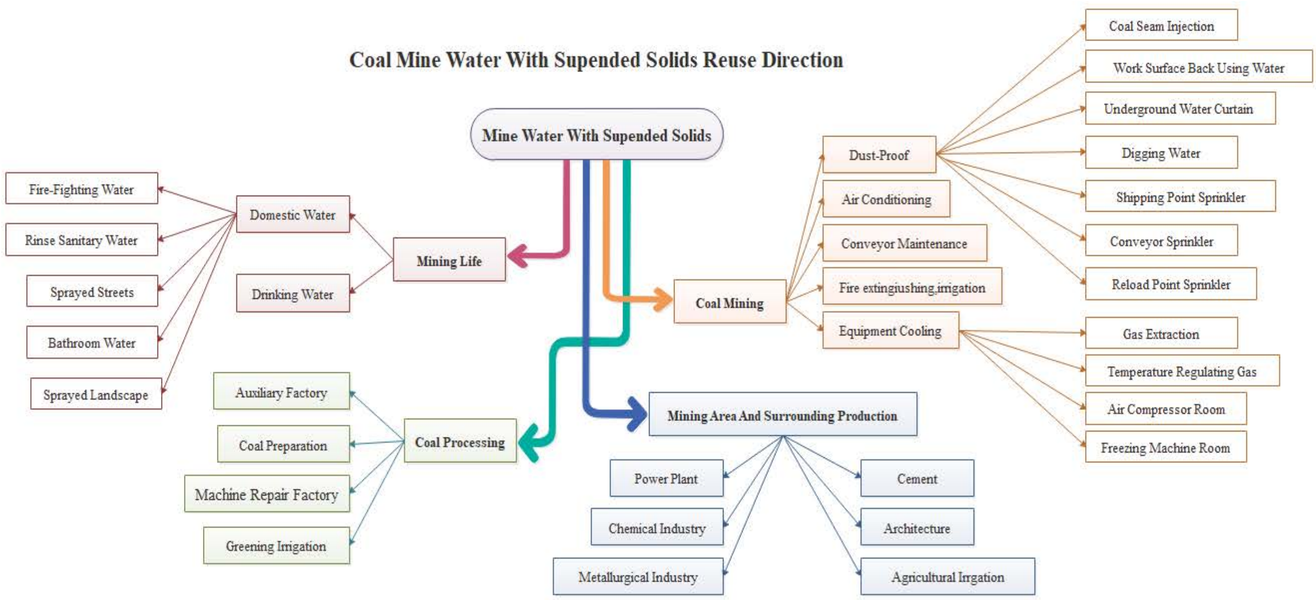


Fig. 29. Reuse pattern of mine water.

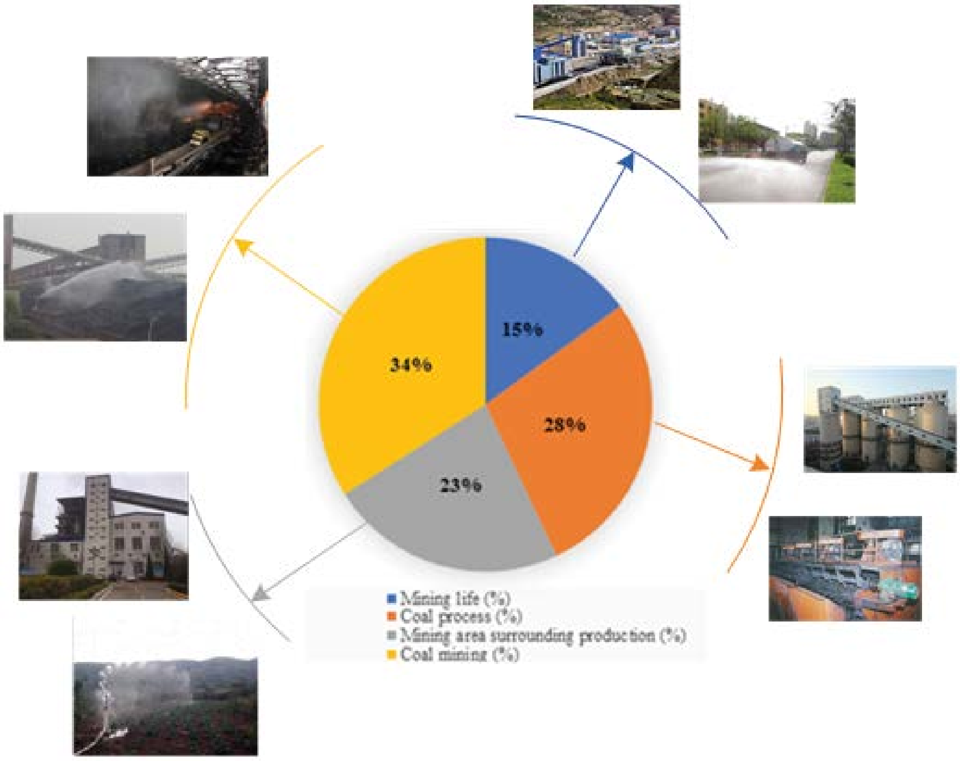


Fig. 30. The principal proportion of the main reuse pattern.

further dealt with the advanced treatments which include different methods. The ion exchange method is used for the salt content of less than 500 mg/L; the membrane separation (electrodialysis, reverse osmosis) can be used for the salt content is 500–3,000 mg/L. The electrodialysis is easy to scale, but it requires high pretreatment of water. In recent years, for the treatment of high salinity mine water in China, it has been gradually replaced by reverse osmosis. In the future, the new technologies and methods could be integrated on the basis of existing treatment methods, such as combining the new energy technology with the existing treatment methods, to reduce energy consumption and processing costs. In practical engineering, scientific and effective treatment technology should be selected according to the mine water quality, effluent requirements, investment, etc.

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