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Characteristics and utilizations of high salt water that comes from CBM development in western mining

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ABSTRACT

The large-scale exploitation of coal-bed methane (CBM) produces a large amount of water simultaneously, especially in Western mining areas of China, where water resource is scarce and the ecosystem is fragile. Improper disposal of the produced water will cause serious environmental pollution and ecological damage. Therefore, the optimal collection scheme, purification process and resource utilization are the subject of urgent research. In this paper, the study found that western mining Jurassic middle Yanan group overall in the higher salinity of groundwater, through the water chemical analysis and hydrological studies have found that high hardness, high salinity and high chloride is the typical mining area of CBM produced water quality, water chemical types are gradually by bicarbonate to sulfate and chlorate, salinity increased; Based on the analysis of fracturing fluid composition of coal-bed gas, the effect of fracturing fluid on the water quality of CBM is relatively small. By analyzing and comparing different schemes, it is recommended that the appropriate scale centralization scheme can be used to set up the collecting pipeline and reduce the cost. According to the characteristics of water quality, treatment requirements and current technological level, it is recommended to apply softening, coagulate sedimentation and filtration + electrodialysis technology to treat CBM in this area.

Keywords: Western mining area; Coal-bed methane produced water; High salt characteristics; Utilizations

1. Introduction

The geological resources of coal-bed methane (CBM) buried in 2,000 m underground are about 3.681 billion cubic meters in China [1], which is one of the most abundant coal-bed methane resources in the world [2]. CBM mining generally adopts drainage gas production process [3], its gas mining process will inevitably produce CBM produced water [4,5], especially in the Western mining area where water resources is scarce and the ecosystem is fragile simultaneously [6], the problem of environmental pollution and ecological damage caused by improper treatment of effluent is particularly prominent [7–9]. The rationalization of collecting water, processing and resource utilization is the topic of widespread concern based on some factors such as the distribution of the gas field [10,11], terrain barrier, well layout [12] and piping direction [13]. The problem of how to control the environmental pollution of water produced by local conditions and to realize the harmless and resource of coal-seam gas production effluent at the same time is urgently needed to study. In this paper, high salinity characteristics of CBM extraction effluent in this area are clarified by the analysis of the influence factors of water quality [14,15] in western China. Through the comparison of the desalination process and the gathering scheme, the optimum scheme of collecting, disposing and utilizing the gas production effluent from high salinity coal seam is discussed, and the resources utilization and suggestions of the standard water are given on this basis.

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2. Influencing factors and characteristics of water qualities in mining effluent

The research area is situated in the Jing-he river basin, sloping from the Loess Plateau of the two sides to the valley, and the terrain is broken and full of gullies. In view of the formation of the fact that CBM reservoirs need more stable hydrodynamic conditions [16], and CBM coexists with a large amount of coal-seam water [17]. Influenced by groundwater quality of coal-bearing strata and adjacent aquifers, the coal-seam gas mining effluent tends to contain higher salinity and chloride ions [18]. In addition, the initial fracturing fluids of CBM can affect the water quality of mining effluent [19].

2.1. Influence of formation water on water quality of CBM mining effluent

The researched area is rich in coal resources, and the coal-bearing strata are Yan'an formation in the Middle Jurassic. The main coal mining layer is Coal seam 4 of the lower part of the Yan'an group, the distribution is more stable in the whole region, which provides sufficient conditions for generation and storage of CBM. The hydrological comprehensive column chart of the research area is shown in Fig. 1, which is the main source of CBM produced water of Yan'an group in Jurassic.

The chemical characteristics of groundwater in this area are mainly controlled by the ancient geographical environment and the recharge, runoff and excretion conditions. In this region, phreatic water is generally good for the physical properties of neutral freshwater, low salinity and good water quality. The bedrock pressure water increases with the depth, the sedimentary age is aging, the groundwater movement is slow, exchange is not active, the water chemical type is gradually converted from the heavy carbonate to sulfate and chlorinated salt, and the salinity rises gradually (Table 1).

According to the characteristics of coal-seam distribution, the water-containing rock component are divided into two

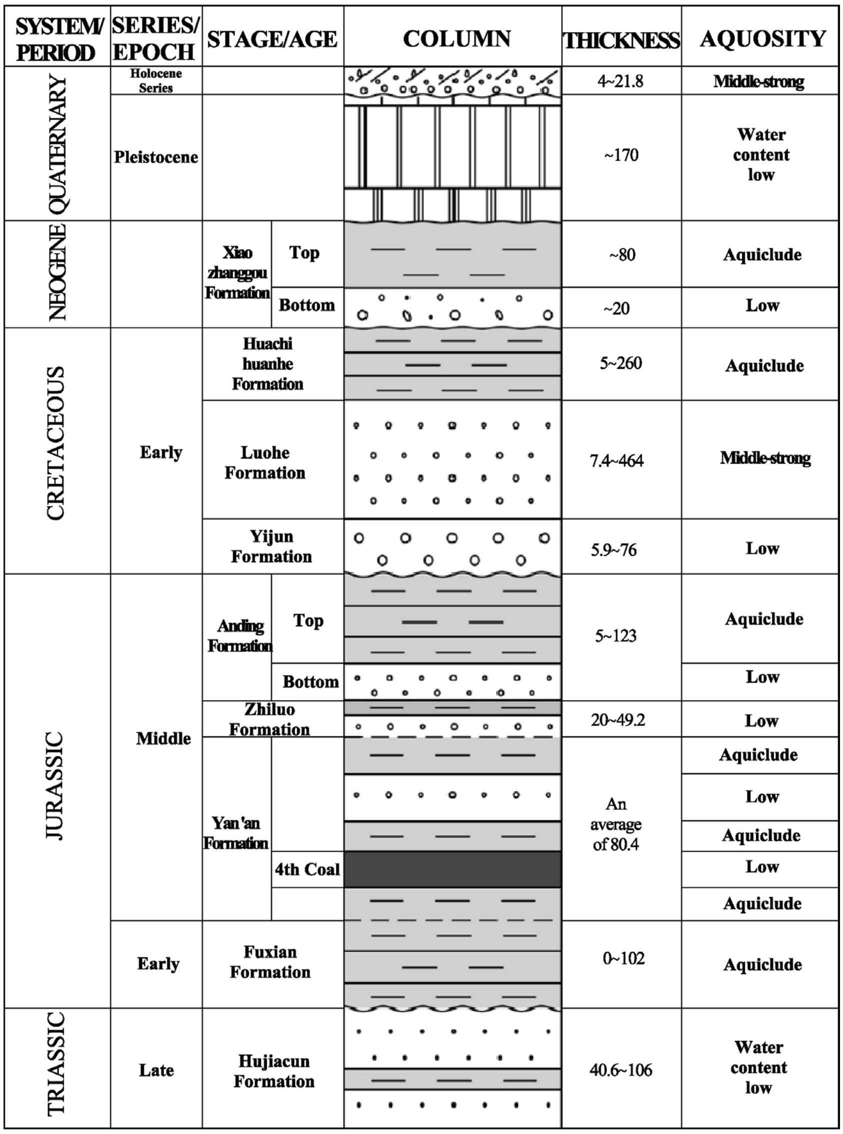

Fig. 1. Hydrological comprehensive column chart of the research area [20].

water-bearing strata, there are fissure confined aquifer above coal seam 4 upper and fissure confined aquifer between coal seam 4 upper and coal seam 4. (1) The fissure confined aquifer above coal seam 4 upper: The aquifer is composed of medium-grained sandstone and a small amount of coarse sandstone with gravel. Thickness is 4.6–13.1 m, and the thickest reaches 28.28 m. The water yield property is weak; the water quality type is Cl–Na type, salinity 16.15 g/L. The aquiclude layer consists of mudstone, sandy mudstone and silty sandstone, and the thickness is generally 16.2–33.5 m. (2) The fissure confined aquifer between coal seam 4 upper and coal seam 4: The aquifer consists of coal seam 4 upper and indirect roof of the middle–coarse sandstone gravel composition. The thickness is generally 6.75–25.34 m, and the thickest reaches 44.99 m. The aquosity is low, and the quality type is Cl–Na type, salinity 13.78–13.88 g/L. The aquiclude generally has two layers, a layer of coal seam 4 floor, the thickness of 0.4–14.2 m, lithology of mudstone and aluminum mudstone; another layer is coal seam 4 roof septum, thickness 0.5–30.27 m, general 5–20 m, lithology of mudstone, sandy mudstone and powder sandstone.

The study of Yan'an group in Jurassic Middle in the mining area is in higher salinity, the water quality is the SO_4–Cl–Na type, and the Southeast local area is Cl–Na type.

2.2. Effect of fracturing fluids on water quality of CBM mining effluent

At present, the fracturing fluids used in CBM wells are mainly active water, foam and gas enrichment fracturing fluids [21]. According to the use of single well fracturing fluid and the calculation of pumping flow in CBM mining, the effect of fracturing fluid on the water quality of mining effluent [22] lasts about 1 year, and its group is mainly water, 1% potassium chloride, 0.05% Shui-based fracturing sealant and thickener.

Water-based fracturing fluids [23] (gel breaker for fracturing fluid) mainly include sulfate, hydrogen peroxide, potassium permanganate, amylase, etc. Thickener (thickeners; thickening agent), also known as thickener, the main ingredients for guar gum and its derivatives, field deafness gum and its derivatives. Cationic guar is a water-soluble polymer, belonging to natural semi-milk mannose, whose chemical name is guar gum hydroxypropyl trimethyl ammonium chloride. Due to the small proportion of breaking agent and thickener used, their impacts on the quality of CBM water are basically negligible.

2.3. Characteristics of water quality of mining effluent

The results of typical water quality analysis are shown in Table 2.

It is clear that the main pollutants from the effluent are suspended solids dissolved total solid (salinity), chloride and six chromium. The type of contamination and the formation water quality are basically consistent, affected by the water quality of fracturing fluids slight. The above factors lead to high hardness, high salinity and high chloride, which are typical characteristics of the water quality of CBM production in the mining area.

3. Processing technology selection and a typical case

3.1. Processing technology selection

It is known from Table 2 that the CBM produced water in the researched area is characterized by high salinity. The applicable treatment technologies mainly include reverse osmosis (RO) [24], nanofiltration, ion exchange, capacitive deionization, electrodialysis (ED), multi-effect

Table 2
Typical water quality of CBM production

Monitoring projects	Water quality
pH	8.21–8.22
SS (mg/L)	104–186
Ca^{2+} (mg/L)	79.2–148
Mg^{2+} (mg/L)	183–754
TDS (mg/L)	12,444–22,491
Total alkalinity (mg/L)	12.2–29.2
TN (mg/L)	3.57–16.2
Phosphate (in P) (mg/L)	0.241
Cl^- (mg/L)	5,088–8,658
F^- (mg/L)	2.26–9.83
Cr^{6+} (mg/L)	0.10–0.13
COD (mg/L)	59.4
BOD (mg/L)	37.9

Table 1
Mining area groundwater hydrochemistry characteristic study table

Water samples		Aquifer age	Total hardness (mg/L)	Salinity (mg/L)	pH value	Water chemical type	Notes
Category	Number						
Well water	9	N_1^3	60.29–159.35	204–461	7.4–8.5	HCO_3–Mg.Na.Ca、HCO_3–Mg•Na	Loess
Spring	26	K_{11}	55.52–136.55	179–421	7.4–8.5	HCO_3–Mg.Na.Ca、HCO_3–Na•Mg	Pressurized
Drilling	1	J_2z	58.3	5,531	9.2	Cl–Na	water
water	2	K_{1L}	100.4–252.3	447–1,175	8.2–8.3	SO_4-Na.Mg、HCO_3–Na.Mg	
	1	J_2a	162.1	3,380	7.2	HCO_3•Cl– Ca •Na	
	2	K_{1y}	243.2–274.8	2,590–5,390	8.1	Cl.SO_4–Na、SO_4–Na	
	3	$J_{2y下}$	90.8–333.2	13,880–16,150	8.2–9.0	Cl–Na	
	2	J_{2y}	1.7–12.7	194–243	8.2–8.8	HCO_3.SO_4–Na、HCO_3.Cl-Na	

electro-catalytic oxidation, biological treatment, etc. [25], and the more developed processing technologies are the membrane and thermal method [26]. Combined with domestic and foreign research reports, the current stage of the mature high brine process mainly includes ultra-high pressure reverse osmosis (DTRO), pure ED, ED plus low pressure RO. The corresponding technological process is shown in Fig. 2, respectively.

In order to choose the treatment scheme suitable for the coal-seam gas production effluent in the researched area, to deal with the 10 m^3/h used as the calculating baseline, the above processes were analyzed and compared in terms of application features, operating pressure, return water quality, preprocessing requirements, pharmaceutical, membrane replacement fee, ton water operation fee, equipment investment, operation cost and the comprehensive comparison are shown in Table 3.

According to Table 3, the ED does not need to overcome the osmotic pressure of the inorganic salt, and is more suitable for the concentration of the high concentration inorganic salt. In dealing with high salt water, ED [27] has the advantages of low cost of water treatment, low running pressure, good water quality, high temperature resistance, corrosion resistance, strong pollution resistance, low energy consumption and medicine cost, low cost of membrane replacement, safe and reliable operation. High pressure RO running high pressure, high cost, organic matter, calcium, magnesium, silicate all concentrated will lead to subsequent evaporation of crystalline clogging, so there is a technical risk. Electrodialysis plus RO relative to pure ED can reduce the equipment but the risk of stable operation of the mechanical vapor recompression (MVR) system is increased due to the simultaneous enrichment of organic matter.

3.2. Typical case

3.2.1. Collecting and transporting scheme

The coal-seam gas mining effluent enters the well reservoir first after the well. Owing to the influence of resource distribution conditions, topography and coal-mining succession, the field distribution of CBM wells is wide and the quantity of the water collecting and conveying scheme is difficult.

In order to realize the optimum collecting, processing and resource utilization of CBM produced water in mining area, the comprehensive cost of conveying, storing, purifying and using each link should be considered synthetically. The comparison of different collecting and transporting schemes of typical projects in mining areas is shown in Fig. 3 and Table 4.

After comparison and analysis, a moderate scale centralized gathering and transportation program is recommended. For the purpose of saving investment, the gas pipeline can be installed at the same time as laying water pipes. After collected and homogenized, the water is advantageous to intensive treatment, reduce investment. The treated effluent can be centrally managed or reused, or a deep purification process could be taken based on the reuse demand to further improve the utilization of water quality. Therefore, program III is recommended as a recommendation (Fig. 4).

3.2.2. Processing technology

In the study area, the salt content of CBM produced water is in the range of 12,000–23,000 mg/L, the average concentration of 16,000 mg/L below, the salt content in the water should be lower than 1,000 mg/L. According to the characteristics of

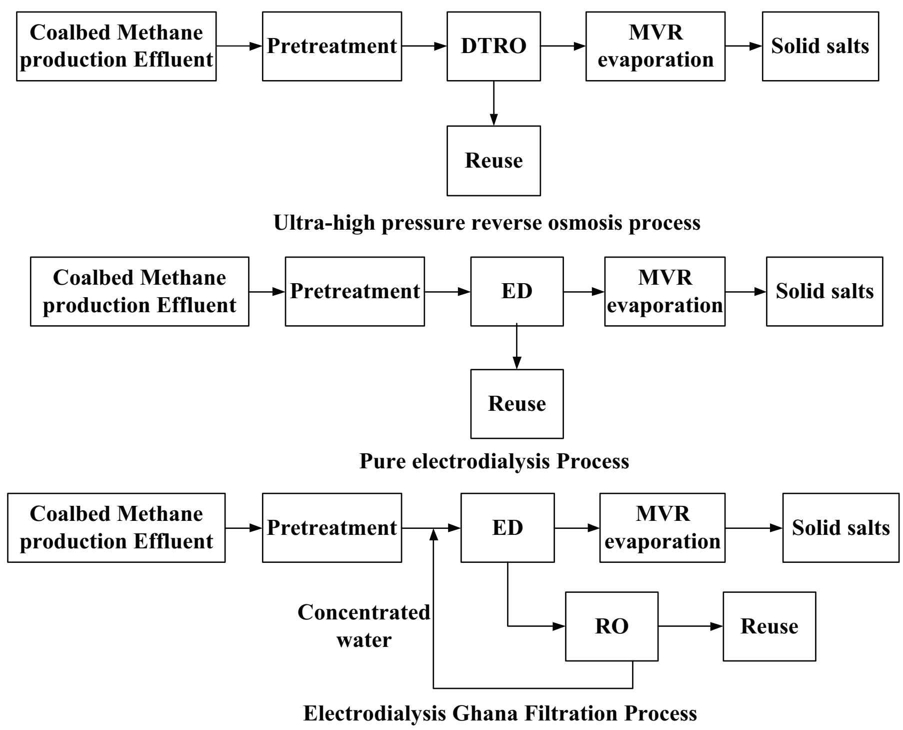

Fig. 2. Corresponding technological process.

Table 3
CBM produced water treatment alternatives

Contrast item	DTRO [26] +MVR	ED + MVR	ED+RO+MVR
Application features	Salt removal and enrichment efficiency is high, the device is simple and easy to operate, the continuous stable operation is hard to achieve, MVR system is also easily polluted	Used in inorganic salts enrichment and organic waste water to remove salt, COD with clear solution to the follow-up MVR system has protective effect	MVR system is easily polluted by the salt removal in inorganic salts concentrate and organic wastewater
Operating pressure	Maximum running pressure ≤12 MPa	≤0.2 MPa	≤0.2 MPa
Return water quality	≤1,000 mg/L	≤900 mg/L	≤300 mg/L
Preprocessing requirements	High requirements for intake of calcium, magnesium, silicon and cod	Frequent inverted pole, optimized process parameters, low requirements for intake of calcium, silicon and COD	Frequent inverted pole, the operation process parameter optimization, to the water intake of calcium, silicon and other content requirements lower, high COD
Pharmaceutical	Scale inhibitor, insecticide, acid, alkali, enzyme detergent, ton water medicament charge ≥¥4.5 ($0.6532)	No need to add scale inhibitors and fungicides, using 0.1% acid or 0.1% alkali washing, tons of water reagent fee ≥¥0.05 ($0.0072)	Do not need to add scale inhibitor, use 0.1% acid or 0.1% alkali washing, ton water medicament fee ≥¥1.2 ($1,742)
Membrane replacement fee	Import film, ton water membrane replacement fee ≥¥3 ($0.4354)	Domestic production, ton water membrane replacement fee ≥¥1.22 ($0.1771)	Ton water membrane replacement fee ≥¥2.56 ($0.3716)
Ton water operation fee (0.6 yuan/kwh m)	≥¥18/t ($2.61/t)	Approx. ¥12/t ($1.74/t)	Approx. ¥15.6/t ($2.26/t)
Investment estimation of equipment	≥¥12 million ($1,741,832)	≤¥8.5 million ($1,233,797)	≥¥10.5 million ($1,524,058)

water quality, processing requirements and the current technological level [28], the use of ED technology and on the basis of further optimization, the optimized scheme is as follows.

In order to meet the requirements of the subsequent ED water intake, the CBM effluent is subjected to a pretreatment system such as softening, coagulation, sedimentation and filtration, to remove suspended solids, hexavalent chromium, BOD, etc. By ED desalination after the water-soluble total solid ≤1,000 mg/L, resource utilization can be fully achieved. Concentrated water enters the concentrated salt pond, carries on the MVR crystallization treatment (zero emission), to be disposed of as a useful chemical raw material in a solid form, to achieve zero water discharge [29]. The process flow is shown in Fig. 5, and the main construction is involved in Table 5.

Process features:

- Simple process: the use of three-stage treatment, greatly simplifying the water treatment process;
- High reliability: the use of softening, coagulation, and chromium removal integrated device, both phase ED and energy-saving MVR technology, which can effectively ensure the follow-up equipment reliable operation;
- Using PLC control, high degree of automation, simple management.

3.2.3. Use of water resources

- Complying with standards and discharging into the surface water;
- Meeting the agricultural irrigation standards and using for irrigation or green water;
- Meeting the renewable use of industrial water quality standards and achieving zero liquid discharge;
- Selecting the target recharge area, recharging the underground, but with technical difficulties.

3.2.4. Crystallization salt disposal

Due to the high salinity characteristics of CBM effluent, the concentrated brine part will produce a large amount of evaporated crystalline salt. Under the conditions of technical conditions and cost control, the mixed-salt [30] produced by the crystallization of concentrated brine is difficult to be fully utilized. It is suggested to further study the crystallization and concentration of the crystalline salt before crystallization.

4. Conclusions and outlook

The water quality of CBM in the Western mining area is influenced by the formation and mining technology, which

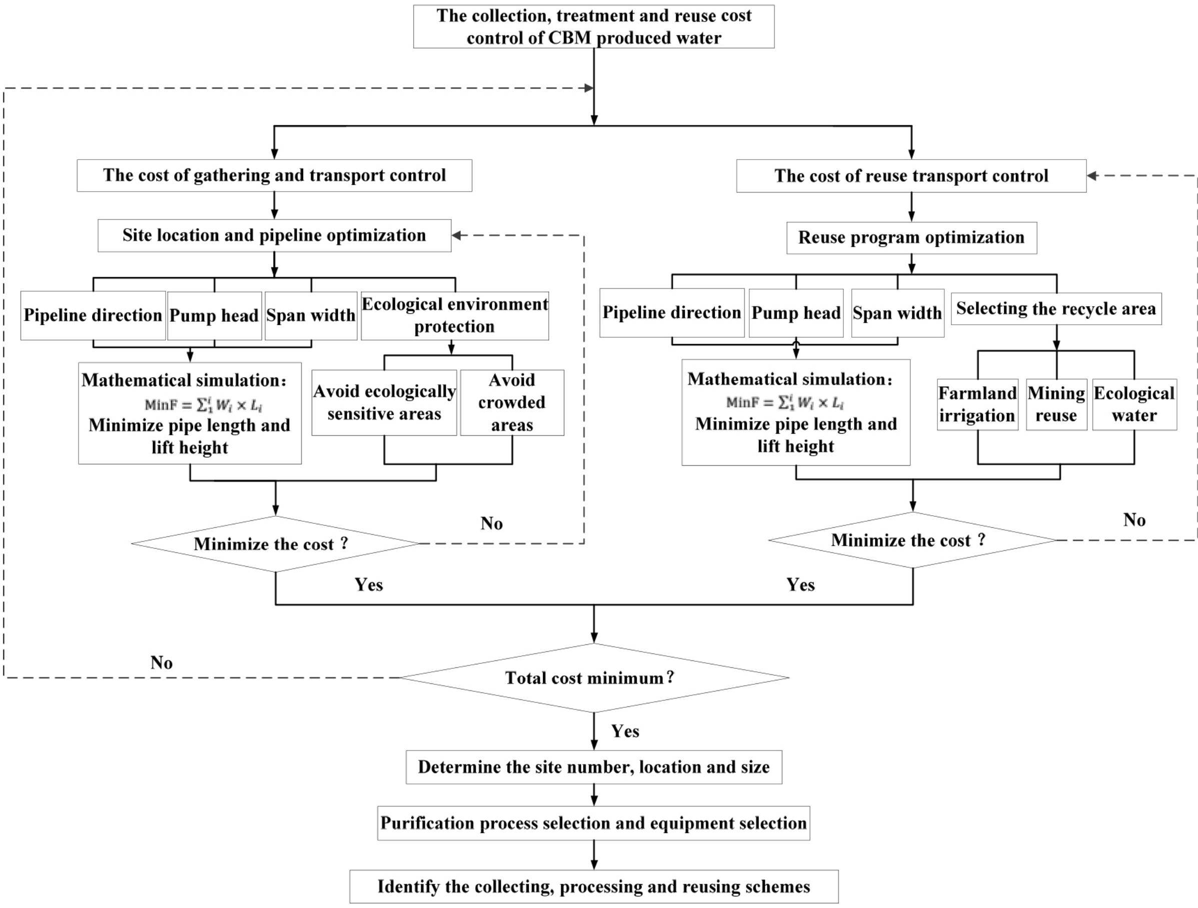

Fig. 3. Process flow diagram for determination of the collecting and reusing programs.

Table 4
A column table for comparison of different sets of transport schemes in the mining area

Project content	Program I	Program II	Program III
Site	Select a suitable site, centralized processing	Select the appropriate 2 sites to deal with	Select the appropriate 2 sites to deal with
Acquisition	With the gas pipeline construction, the pipeline concentrated to the processing station	With the gas pipeline construction, the pipeline concentrated to the processing station	With the gas pipeline construction, the pipeline concentrated to the processing station
Processing station scale	Set up a large processing station	Set up two small processing stations	Set up two small processing stations
Content	According to the whole process of construction	1 station with the whole process of construction, 1 station with no evaporation equipment, small quantities of dense water tankers transport, concentrated evaporation	2 seats in accordance with the complete construction of the process
Processing station investment	Low	Moderate	High
Operating costs	Low	Higher	Moderate
Management	Centralized, easy to manage	Scattered, partially needed transport	Decentralized, better management
Waste water utilization	Comprehensive utilization in adjacent areas	Can be used for industrial reuse or irrigation	Can be used for industrial reuse or irrigation

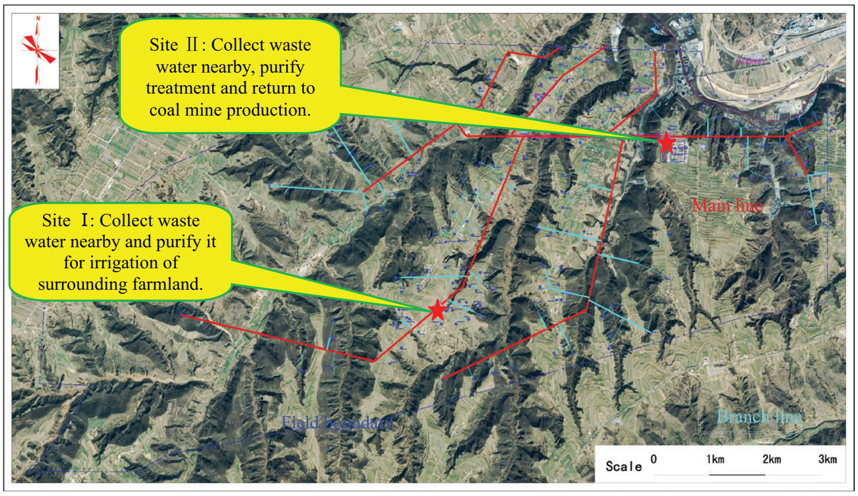

Fig. 4. General layout of the ground.

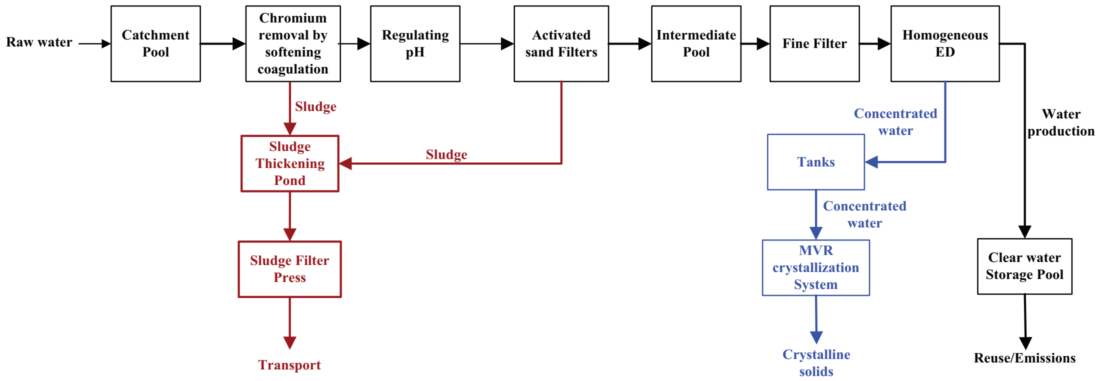

Fig. 5. Process flow diagram.

Table 5
Main equipment and statistics of architectural structures

Ordinal	Facilities/equipment	Parameters
1	Catchment pool	60 m^3
2	Softening, coagulation, and chromium removal integrated device	1 set
3	pH regulator	1 set
4	Activated sand filters	1 set
5	Intermediate pool	20 m^3
6	Sludge pond	20 m^3
7	Sludge pressure filtration equipment	1 set
8	Precision filter	1 set
9	ED processing system	1 set
10	Clear water storage pool	20 m^3
11	Concentrated water tanks	5 m^3
12	MVR evaporation crystallization system	1 set
13	Steel structure workshop	1 set

has high hardness, salinity and chloride characteristics. Owing to the dispersion of wells, wide range and large quantities, it is difficult to collect, dispose and utilize the effluent. In this paper, we propose to adopt a moderate-scale centralized gathering and transportation scheme and combine the ED process to deal with it. The concentrated brine is evaporated by MVR, which can achieve the standard treatment and resource utilization of CBM water in the studied area. Since the salt produced by the brine treatment is difficult to be integrated, the separation technology before divalent cationic crystallization is the next step in the field.

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