

Current Situation and Measures of Environment Affected by Mine Water in Hunan Limin Coal Mine

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Abstract: The pump drainage of mine water in Hunan Limin Coal Mine has caused various problems including huge depression cone and collapse of goaf roof, resulting in serious leakage of surface water. Therefore, a great need of measures should be conducted. In this paper, the mine water properties and the hydrogeological characteristics were studied. The results indicate that the PH value of main shaft water of Limin Well is 2.21-3.81 (average: 2.90), Fe^{2+} is 178-1,308 mg/L, Mn^{2+} is 3.93-8.65 mg/L; the PH value of auxiliary shaft water is 3.45-4.08, Fe^{2+} is 876-1,264 mg/L, Mn^{2+} is 6.27-8.71 mg/L; the PH value of Shuikoushan old pithead water is 2.33-3.91, Fe^{2+} is 1,059-2,207 mg/L and Mn^{2+} is 23.00-34.00 mg/L, which indicates that the mine water in the area is strongly acidic, and Fe^{2+} and Mn^{2+} exceed the standard seriously. Based on the characteristics of mining tunnel in the area, the wellhead of artesian water in Limin Well should be closed with shaft without pressure so as to ensure that the mine water can be discharged out in a concentrated and orderly way. The sewage treatment facilities at the main shaft of Limin Well need to be expanded, and new sewage treatment facilities should be built at Shuikoushan old pithead. Through hydrologic survey and water balance analysis, Zhoutou Reservoir can be used as a water source to construct drinking water project, which can completely solve the problem of drinking water safety in the area. The study would solve the bad situation of Limin Coal mine by providing the corresponding measures, which could provide the references for the similar mines when facing these problems.

Keywords: drinking water safety project; Hunan; Limin coal mine; mine water; sewage control

1 INTRODUCTION

According to statistics, about 2 t of mine water is produced by per ton of coal mining in China [1, 2], and the total amount of mine water in coal mines is more than 6 billion m^3 every year [3]. The mine water is characterized by high suspended matter, high salinity and acid [3-8]; the mine water in western China is characterized by high salinity and high fluoride; the mine water in a few areas contains toxic and harmful elements such as Cd, H, Pb, As, Cr (VI) and Ni [9-14], which causes ecological environment pollution. The long-term pump drainage of underground water from coal mining also causes such geological environmental problems as soil erosion, land subsidence, surface collapse, structural damage of aquiclude, leakage of surface water, cross strata pollution of underground water and fall of the water level in mining areas [3]. Many researches have already been conducted on the mining leachates affected environment [15-18], the properties of the leachates including pH [19], electric conductivity [20], composition (especially the cations such as Pb, Zn, Fe, Mn) [21] are determined to clarify the situation of the mines.

Hunan Limin Coal Mine, located in Zhadu Town, northeast of Lengshuijiang City, Hunan Province, consists of Limin Well and Libei Well, with an annual production capacity of 600 000 tons/year and 450 000 tons/year respectively. A large amount of underground water is pumped out during mining, resulting in serious leakage of surface water. After Limin Coal Mine stopped production in 2016, pump drainage of underground water was stopped and the underground water level rose, so that acid mine water with excessive heavy metals (such as Fe and Mn) gushed from the main shaft and inclined shaft, causing serious damage to the water environment in the area. Through the systematic investigation of the water environment in Limin Coal Mine, this paper reveals the current situation of water environment destruction and its influence on the drinking water safety of human and animals in the area, and puts forward suggestions on mine sewage treatment and solutions for the drinking water safety in the area, in order to provide scientific basis for

ecological restoration of geological environment in mining areas.

2 GENERAL SITUATION OF THE MINING AREA

2.1 Geology

The outcrop of Limin Coal Mine includes the quaternary strata, namely middle-upper carboniferous Hutian Group, lower carboniferous Datangjie Zimenqiao Formation, Ceshui Formation and Shidengzi Formation, and the coal seams of lower carboniferous Ceshui Formation are mainly mined. The whole mine is slightly in an arc-shaped monocline structure, and the dip angle is generally more than 25° . The fault structure in the mine is not developed. There are four main faults, namely, Zanzikou reverse fault, Muguatian reverse fault, Fuke normal fault and Fuke reverse fault, of which Muguatian reverse fault and Zanzikou reverse fault have been taken as the north-south boundary of the mine with little influence on mine mining.

Ceshui Formation is a coal-bearing formation with seven coal beds, but only three coal beds can be mined. The three coal beds are 0.67 m - 7.48 m thick with an average thickness of 2.58 m. There are five layers of siderite in the coal measure strata in the area, and the sulfur content of siderite is relatively high, which leads to acid mine water.

2.2 Mining Overview

Limin Coal Mine is mainly composed of Limin Well and Libei Well (see Fig. 1), of which Limin Well has an ore-bearing elevation of +200--300 m, a vertical height of 500 m, a strike length of nearly 7 km. The mining is conducted in two levels: +190 m and -140 m. Before the mine is closed, the shallow part has been mined to +50 m and the deep part has been to -140 m, and the goaf area is about 2.95 km^2 . The well is equipped with main shaft, auxiliary shaft and four ventilation shafts. The quasi-mining elevation of Libei Well is +680 m - ± 0 m and is in +190 m horizontal mining, the goaf area is 0.034 km^2 . It

shares the main shaft with Limin Well, and there are four ventilation shafts.

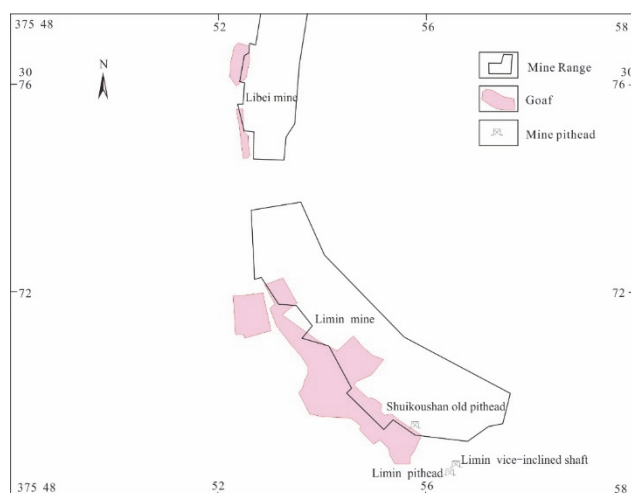


Figure 1 Diagram of the coal mine

There are more than 200 small collieries and old pitheads in the mining range of Limin Coal Mine, whose goal is directly connected with goaf of Limin Coal Mine. Even the laneway of China Resources Limin Coal Mine is used for ventilation and drainage. After Limin Coal Mine stops pump drainage, the mine water rises and flows out of the wellhead through the main shaft, auxiliary shaft and Shuikoushan old pithead (+198.0 m) with lower inlet elevation.

3 CURRENT SITUATION OF WATER ENVIRONMENT IN THE MINING AREA

In this study, the pH values and the metal cation contents of the mining solution are determined in order to clarify the effect of mining solutions on the environment. The hydrogeological characteristics of the area are also investigated for the purpose of putting forward the measures for the current situation of the mine.

Table 1 Mine inflow in Limin coal mine / m³/h

Month	2013		2014		2015		2016		2017	
	Main shaft	Auxiliary shaft	Main shaft	Auxiliary shaft	Main shaft	Auxiliary shaft	Main shaft	Auxiliary shaft	Main shaft	Auxiliary shaft
1	97	80	80	62	102	86	158	139	140	
2	92	76	76	59	97	78	132	112	138	
3	81	64	68	55	83	65	135	117	142	
4	90	71	79	61	99	81	166	132	150	
5	113	86	82	63	138	86	251	203	165	
6	162	112	122	81	205	115	299	232	394	353
7	140	94	151	97	320	238	340	256	563	476
8	135	90	180	116	183	162	243		231	214
9	124	79	149	97	176	157	185		172	148
10	88	67	133	83	164	142	149		140	131
11	85	65	121	76	167	146	110		76	70
12	83	62	135	84	189	167	127		69	64
Average	108	79	115	78	160	127	191	170	198	208

Note: Unit of water inflow is m³/h

Table 2 Analysis results of mine water quality

Date	PH			Fe ²⁺ / mg/L			Mn ²⁺ / mg/L		
	Main shaft	Auxiliary shaft	Shuikoushan old pithead	Main shaft	Auxiliary shaft	Shuikoushan old pithead	Main shaft	Auxiliary shaft	Shuikoushan old pithead
7.17	3.81	3.84	3.11	1308	1264	1781	8.65	8.43	25.90
7.18	3.78	3.91	2.33	1092	986	1752	8.33	8.19	25.50
7.19	2.94	3.93	2.36	236	936	2207	5.11	7.00	24.80
7.20	3.12	3.85	2.56	225	925	1790	6.09	8.33	26.60
7.21	2.80	3.96	2.92	251	1015	1616	5.82	8.16	24.00
7.22	3.07	4.08	2.60	285	1046	1703	5.82	8.00	23.60
7.23	2.45	3.54	3.35	304	1234	1716	5.8	8.05	34.00
7.24	2.21	3.45	3.70	312	955	1360	5.68	7.90	23.00
7.25	2.53	3.68	3.83	239	1095	1482	5.78	8.71	25.60
7.26	2.89	3.97	3.87	249	979	1059	5.26	7.67	24.00
7.27	2.52	3.72	3.84	229	943	1212	5.04	7.64	24.30
7.28	2.95	3.98	3.75	246	1089	1725	5.21	7.46	26.90
7.29	2.88	3.98	3.91	208	1083	1519	5.04	7.29	26.20
7.30	2.62	3.85	3.70	210	992	1431	4.83	6.56	26.60
7.31	2.86	3.90	3.61	178	876	1310	3.93	6.27	25.70
Average	2.90	3.84	3.30	372	1028	1578	5.76	7.71	25.78

3.1 Leakage of Surface Water and Drying up of Spring Wells

Coal mining in the area has caused leakage of surface water in local sections, mainly located in the shallow part of coal bed or near the cropline, belonging to the old goaf of Limin Coal Mine. The collapse of roof has led to the development of vertical cracks. Some cracks go straight to the surface, forming ground fracturing and land subsidence

on the surface. Surface water leaks along the weathering zone and mining subsidence zone. In the area, leakage of surface water from Lijiang stream is serious, which is mainly distributed in the upper stream of Lijiang stream, namely Zhushan Bay, Yanshan Bay, Jiulishui and the lower stream of Zifang Village. There is no water in irrigation canals and ditches, and the water storage capacity of mountain ponds and paddy fields is poor. In rainy season, rainwater leaks rapidly, resulting in no guarantee

of drinking water for people and livestock in the mining area.

3.2 Current Situation of Mine Drainage and Water Pollution

According to the statistics of multi-year water inflow of Limin Well (Tab. 1), the water inflow of Limin Well was approximately 200 m³/h before 2015; however, after 2015, small collieries around Limin Well were closed successively, and the water inflow of Limin Well increased. Since May 2017, the artesian water has appeared in the main wellhead of Limin Well, the auxiliary inclined shaft of Limin Well and Shuikoushan old pithead. According to the statistics of water inflow (Fig. 2), the water inflow increases significantly from May to August each year, indicating that the atmospheric precipitation is the main factor affecting the mine inflow. In addition, in Shuikoushan old pithead, the average water inflow of the artesian water is 30.8 m³/h in rainy season.

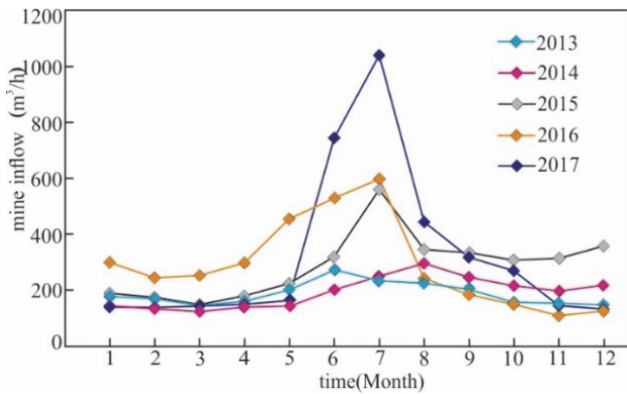


Figure 2 Changes of water inflow of Limin coal mine

There are five layers of siderite in the coal measure strata in the area, with relatively high sulfur content, which leads to acid mine water. The quality of mine water collected from the main shaft and auxiliary shaft of Limin Well and Shuikoushan old pithead is tested and analyzed, and the results are shown in Tab. 2. The PH value of main shaft water of Limin Well is 2.21-3.81 (average: 2.90), Fe²⁺ is 178-1,308 mg/L (average: 372 mg/L), Mn²⁺ is 3.93-8.65 mg/L (average: 5.76 mg/L); the PH value of auxiliary shaft water is 3.45-4.08 (average: 3.84), Fe²⁺ is 876-1264 mg/L (average: 1208 mg/L), Mn²⁺ is 6.27-8.71 mg/L (average: 7.71 mg/L); the PH value of Shuikoushan old pithead water is 2.33-3.91 (average: 3.30), Fe²⁺ is 1,059-2207 mg/L (average: 1578 mg/L) and Mn²⁺ is 23.00-34.00 mg/L (average: 25.78 mg/L). The above data show that the artesian mine water from the three places is acidic and the content of iron and manganese exceeds the standard. The comparison of pollutant concentrations (Fig. 3) shows that the acidity and Fe²⁺ and Mn²⁺ concentration of the main shaft with relatively higher elevation are higher than those of the auxiliary shaft (+191.0 m) and Shuikoushan old pithead (+198.0 m). It should be related to the enlargement of the submerged goaf after the mine water rises. The underground water level rises after Limin Coal Mine stops pump drainage, but the water pollution under the mine is serious and cannot be directly used as production and domestic water.

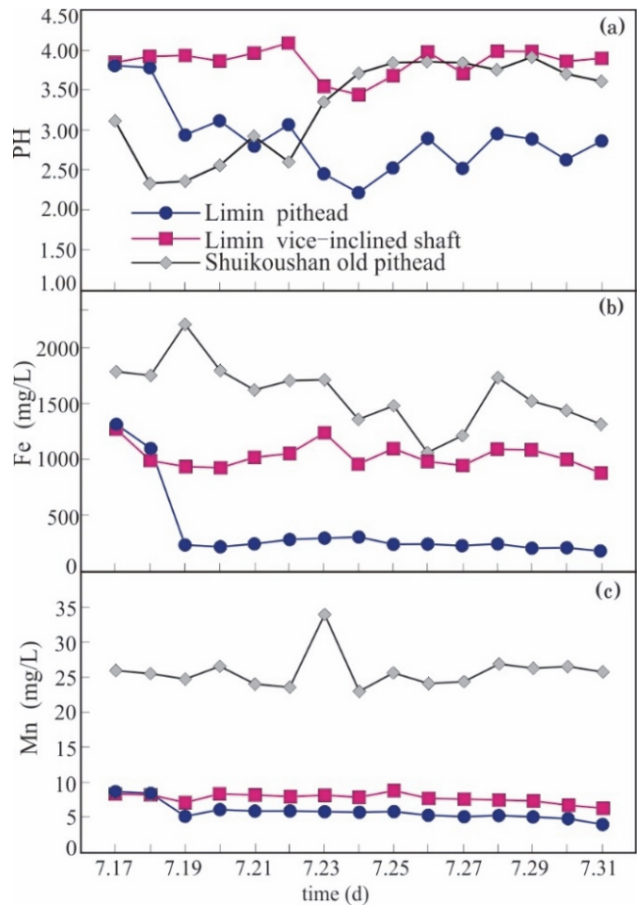


Figure 3 Comparison of pollutants in two mine mines and old pithead

4 MEASURES

4.1 Prevention and Control of Mine Water Pollution

Limin Well is closed with shaft under pressure, so the mine water level will continue to rise, the maximum static water level of Ceshui Formation will reach +265.07 m, more siderite layers in goaf will be submerged and soaked, the scope of pollution sources will be expanded, and the concentration of pollutants in mine water will increase again [8]. In addition, there are more than 200 abandoned shafts in small collieries in the area, 17 shafts with wellhead elevation lower than +265.7 m, and 15 shafts connecting with the goaf or laneway of Limin Well. If the mine water level rises, the mine sewage will overflow the surface through abandoned unsealed shafts (such as Shuikoushan old pithead), sealed shafts that cannot bear pressure, spring holes and mining fissure zones. As a result, there are many effluent points and scattered pollution points, so the management is very difficult. Therefore, Limin Well cannot be effectively prevented and controlled by the measures of underground sealing or source blocking. The mine sewage should be treated passively, that is, perfect sewage treatment facilities should be built in artesian wellhead.

According to the sewage treatment capacity of existing sewage treatment facilities and mine water inflow, the treatment capacity for Limin Coal Mine shall be increased by 600 m³/h, so that the total treatment capacity can reach 800-900 m³/h. The newly-added treatment station can be built at the existing emergency pool in the industrial plaza. Shuikoushan old pithead also has the phenomenon of artesian mine water, and the average water inflow is about

30.8 m³/h in rainy season. A new sewage treatment station should be built near the wellhead, with a sewage treatment capacity of 35 m³/h. In addition, long-term monitoring of mine water inflow, water quality and water quality treated by sewage treatment facilities should be carried out to provide basis for scientific management and control of mine water.

4.2 Drinking Water Safety Project

According to the current situation of water resources in the mining area, there is a shortage of underground water, the mine water pollution is serious, and the guaranteed rate of water supply is generally low. To guarantee drinking water safety of 16 800 residents in the area, it is necessary to construct a drinking water safety project.

4.2.1 Selection of Water Source and Estimation of Water Supply

Zhoutou Reservoir, about 7.0 km to the south of Limin Well (outside the influence range of mining), is a medium-sized water conservancy project with comprehensive utilization of flood control, water supply and irrigation, and the water quality meets the Class II standard of surface water. The dam site of the reservoir boasts a controlled rainfall collecting area of 14.34 km², the length of the main stream above the dam site is 7.58 km, and the slope of the main stream is 12.8%. The maximum flood level of the reservoir is 357.12 m, the total storage capacity is 10.37 million m³, the normal pool level is 356.15 m, the normal storage capacity is 8.18 million m³, the dead water level is 333.55 m, and the dead storage capacity is 138 000 m³. The multi-year average annual precipitation is 1423.6 mm, the multi-year average annual runoff coefficient is 0.562 [22, 23], and the multi-year average annual runoff depth is 626.38 mm. According to Eq. (1), the multi-year average runoff of Zhoutou Reservoir watershed is 11.473 million m³. The above shows that the reservoir has strong regulation and storage capacity and high water level topography. It can completely rely on gravity flow to realize water supply, and the water production cost is low, so it is an ideal water source for water diversion project of Limin mining area.

$$Q = S \times C \times P \quad (1)$$

where, Q is average annual runoff; S is water-collecting area; C is annual average runoff coefficient; P is annual average rainfall.

4.2.2 Water Demand and Water Balance Analysis

The total water supply scale of Zhoutou Reservoir is 100 million t/d, and the annual water demand is W_1 3.65 million m³. According to the estimation of 30% of the multi-year average flow in the watershed, the ecological water quantity W_2 that Zhoutou Reservoir needs to replenish regularly to the downstream is 3.442 million m³. 90% of the annual water demand in the irrigation area of Zhoutou Reservoir is 11.915 million m³. It is worth noting that there are some available small reservoirs and mountain

ponds in the irrigation area of Zhoutou Reservoir, and the rainfall collecting area is about 11.0 km². Based on Eq. (1), the total water supply of both is about 8.801 million m³. Therefore, the actual irrigation water demand W_3 is 3.114 million m³.

If Zhoutou Reservoir is selected as the water supply source of residents in Limin mining area, it should solve the problem of shortage of drinking water for 16 800 residents in the area. For rural residents with centralized water supply, the domestic water quota is 100 L/person/d, and the domestic water consumption is 1680 t/d. Considering the leakage loss of 10%, the daily total water demand is 1848 t/d, and the annual water demand is W_4 675 000 m³. Estimated according to Eq. (2), the annual total water demand W is 10.881 million m³.

$$W = W_1 + W_2 + W_3 + W_4 \quad (2)$$

where, W is total water demand; W_1 is water demand of the existing water plant of Zhoutou Reservoir; W_2 is ecological water demand of the downstream of Zhoutou Reservoir; W_3 is the actual irrigation water demand in the irrigation area of Zhoutou reservoir; W_4 is domestic water demand of residents in Limin mining area.

Thus, the water supply (11.473 million m³) and water demand (10.881 million m³) of Zhoutou Reservoir can be balanced. Choosing Zhoutou Reservoir as the water supply source for the drinking water safety project for the benefit of the people can avoid the worry of water quantity and quality.

5 CONCLUSIONS

(1) The PH value of the main shaft water of Limin Coal Mine is 2.21-3.81 (average: 2.90), Fe²⁺ is 178-1308 mg/L, Mn²⁺ is 3.93-8.65 mg/L; the PH value of the auxiliary shaft water is 3.45-4.08, Fe²⁺ is 876-1264 mg/L, Mn²⁺ is 6.27-8.71 mg/L, which indicates that the mine water in the area is strongly acidic. The PH value of Shuikoushan old pithead water is 2.33-3.91, Fe²⁺ is 1059-2207 mg/L and Mn²⁺ is 23.00-34.00 mg/L, which indicates that the mine water in the area is strongly acidic, and Fe²⁺ and Mn²⁺ exceed the standard seriously, and the problem of drinking water safety in the area is prominent.

(2) Limin Well should be closed with shaft without pressure so as to ensure that the mine water can be discharged out in a concentrated and orderly way. Sewage treatment facilities with a treatment capacity of 600 m³/h should be added to the main wellhead of Limin Well, so that the total treatment capacity reaches 800-900 m³/h; sewage treatment facilities with a treatment capacity of 35 m³/h should be newly built at Shuikoushan old pithead. Zhoutou Reservoir on the south of the mining area owns good water quality and sufficient water quantity, which can be used as a water source for drinking water safety project.

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