Discrimination of bursting water source by hydrochemical and stable isotope method

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Abstract Take a typical coal field in north China as an example, the chemical characters of water in each aquifer were founded according to the standard water samples. Compared the chemical characters between bursting water and standard water, the source of water inrush can be judged. Some disputed sample results need judging again by the indexes of hydrogeological conditions and water burst characters. Based on this method, 491 samples were analyzed. The accuracy was 80 %. This method provides a way to identify the source of bursting water in the mine.

Keywords hydrochemical, piper diagram, stable isotope, water bursting source, karst water-filling coal field

Introduction

Hebi coal mine district is located in alluvial plain of the Taihang Mountain in Henan province. It is a typical karst water-filling coal field in North China coal basin, in which the coal deposits were mainly formed in the Carboniferous to Permian periods (Han and Yang 1984). In Hebi coal mine district, there were 392 times water burst in the history. The water source of the biggest water burst was the groundwater from the Middle Ordovician carbonate aquifer, the water yield was 13,507 m^3/h and the mine was flooded (Zhao 2007). Water disasters seriously threaten the safety of coal production. From bottom to top, the main aquifers in this coalfield are Middle Ordovician carbonate aquifer (O_2), the second thin-bedded limestone aquifer of Carboniferous Taiyuan group (L_2); the eighth thin-bedded limestone aquifer of Carboniferous Taiyuan group (L_8), the coal seam roof and floor sandstone aquifer of Permian Shanxi group (S) and the Neogene conglomerate aquifer (N). The groundwater occurrence in these aquifers is the main source of mine water bursting. Due to the difference of hydrogeochemical environment during groundwater formation process in different aquifer, the hydrochemical composition and stable isotopes content of groundwater are different. The hydrochemical composition and stable isotopes content of bursting water were sampled and assayed. Bases on the characters of hydrogeochemical, the source of water bursting cloud be ascertained (Wang 1990, Hu *et al.* 2010). It is the basis for rescue and water disaster control.

The Hydrogeological Background

In hebi coal mine district, the O_2 aquifer, which thickness is 400 m and the karst fissure is well-developed. According to pumping test data, the minimum value of water discharge rate per unit drawdown is 0.67 L/s/m and the maximum value is 83.91 L/s/m, the average value is 14.02 L/s/m. The middle Ordovician carbonate is widely outcropped in the Taihang Mountain area, and it accepts the recharge of precipitation infiltration. In addition, the river leakage recharges the groundwater through the karst fissure. After accepted the recharge in mountain area, the water runoff to the piedmont from west to east, and discharges by karst spring and mine drainage. Generally, if the mine water bursting which source is O_2 karst water, the water yield is greater than 100 m^3/h.

The L2 aquifer with an average thickness of 7 m has a stably distributed, but the karst fissure is poor-developed and inhomogeneous, and the water abundance is greatly different in spatial. According to the pumping test data, the water discharge rate per unit drawdown is about 0.012-2.619 L/s/m, the hydraulic conductivity is about 0.392-28.84 m/d. Because of the L_2 aquifer has limited outcrop area and no recharge source, the karst water is static reserves and easy to drainage. The water yield which comes from the L_2 aquifer is usually less than 100 m^3/h. Once O_2 water and L_2 water has hydraulic connection in some area by the faults, water yield can reach to hundreds of cubic meters per hour.

The L8 aquifer with an average thickness of 3–5 m has a stably distributed, but the karst fissure is poor-developed. It has little recharge source and the occurrence of water is limited. And water yield usually less than 50 m^3/h, it is 13.2–48.8 m^3/h.

The Shanxi group coal seam roof and floor is sandstone aquifer, in which the fracture is poor-developed and the groundwater is limited. During the mining, the fracture water in sandstone aquifer can discharge into the mine through natural fracture, mining fracture and fault, but the water yield is very small.

Neogene conglomerate aquifer is distributed in the southern part of hebi coal mine district with the thickness is 30 – 80 m. In this aquifer, the pore and fracture well developed, the precipitation and surface water are the main recharge sources. It is an important water-filling source of mining for the shallow coal seam.

Hydrochemical characteristics of the groundwater from each aquifer

In order to set up the hydrochemistry identification standard of each aquifer, multiple water quality surveys were carried out in Hebi coal mine district. The 491 groundwater were sampled for water quality analysis. The index include: HCO_3^-, Cl^-, SO_4^{2-}, K^+, Na^+, Ca^{2+}, Mg^{2+}, hardness, total dissolved solid (TDS), and pH. The groundwater hydrochemical characteristics of each aquifer are as follows (tab.1, fig. 1).

O_2 Karst water

The hydrochemical composition of Ordovician limestone karst water is controlled by water-

Groundwater type (Number of samples)		Major cation			Major anion			PH	Hardness	TDS
		Na^++K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}			
O_2 karst water (184)	average	12.34	79.69	20.99	13.19	298.79	31.71	7.78	281.56	330.16
	SD	4.14	22.36	5.59	5.58	53.96	17.28	0.25	61.33	87.88
L_2 karst water (54)	average	22.05	162.45	28.51	15.00	350.65	233.64	7.39	526.36	655.28
	SD	6.87	35.12	7.40	4.81	76.37	60.10	0.27	80.04	96.75
L_8 karst water (62)	average	117.93	73.77	25.90	25.20	467.73	76.62	8.20	290.84	533.52
	SD	37.67	22.49	8.05	11.34	89.04	26.51	0.39	60.47	125.60
Sandstone fissure water (106)	average	281.81	17.88	7.84	53.97	592.87	42.56	8.54	76.59	737.54
	SD	78.89	9.67	4.84	22.64	156.26	14.12	0.45	23.49	231.49
Conglomerate pore-fissure water(42)	average	35.21	83.49	22.00	31.78	289.84	44.99	7.98	299.04	442.37
	SD	12.36	25.01	5.33	8.42	35.95	15.20	0.30	86.95	94.08
Goaf water (43)	average	283.77	262.85	92.66	52.04	421.77	1101.95	7.98	1037.92	2066.85
	SD	58.08	64.00	24.09	13.69	107.58	244.29	0.40	243.60	428.55

Table 1 *The statistics characteristic of hydrochemical components*

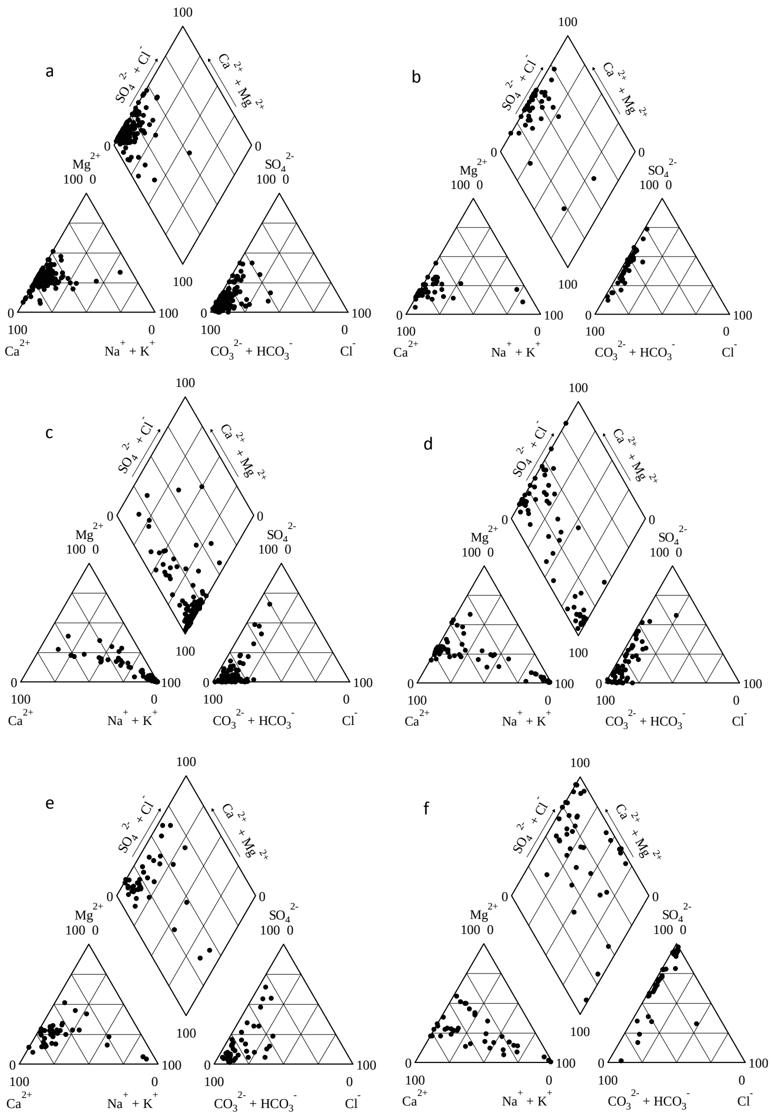

Fig. 1 *The piper diagram of groundwater a-O_2 karst water; b-L_2 karst water; c-L8 karst water; d-Sandstone fissure water; e-Conglomerate pore-fissure water; f-Goaf water*

rock interaction. In the groundwater, the cations are dominated by Ca^{2+} and Mg^{2+}, and the anion is HCO^{3-}. The O_2 karst water has some typical characters as follows. The hydrochemical type is $HCO_3^-Ca{\cdot}Mg$ (fig. 1-a). The TDS are at a low level, ranging from 200 to 400 mg/L. The total hardness is very low, ranging from 200 to 350 mg/L. The concentration of Cl^- is less than 25 mg/L. The concentrations of Ca^{2+} and Mg^{2+} vary from 60 to 90 and 15 to 30 mg/L. The percent meq/L of (Ca^{2+}+Mg^{2+}) is more than 90 %, and the percent meq/L of HCO_3^- is more than 80 %.

L_2 karst water

Affected by the natural in sediments and water-rock reaction, the ions of the water are dominated by HCO_3^-, SO_4^{2-}, Ca^{2+} and Mg^{2+} in L_2 aquifer. The hydrochemical type of L_2 water are $HCO_3{\cdot}SO_4$-$Ca{\cdot}Mg$ and $SO_4{\cdot}HCO_3$-$Ca{\cdot}Mg$ (fig. 1-b). The TDS are at a higher level, ranging from 500 to 700 mg/L, the average value is 655.28 mg/L. The concentration of SO_4^{2-} is range from 150 to 700 mg/L, the average value is 233.6 mg/L, and the percent meq/L is range from 30 % to 55 %. The concentrations of Ca^{2+} and Mg^{2+} in L_2 water are higher than O_2 water.

In L_2 water, the concentrations of Ca^{2+} and Mg^{2+} vary from 100 to 200 and 24 to 36 mg/L.

L_8 karst water

L8 aquifer is closed to sandstone aquifer and coal seam that the hydrochemical characters of L8 water are very complex. The concentration of SO_4^{2-} is higher when sulfide which comes from the coal seam dissolves into L8 aquifer. The mainly hydrochemical type of L8 water are HCO_3-Na•Ca•Mg, HCO_3•SO_4-Ca•Na•Mg and HCO_3-Ca•Mg. There also have a kind of water (HCO_3-Na) when lots of sandstone water flow in to L_8 aquifer (fig. 1-c).

Sandstone fissure water

The albite and potassium feldspar content are higher in sandstone stratum. Under the effect of weathering, hydrolysis and ion exchange function, Na+ and k+ are leached into the groundwater, while Ca^{2+}, Mg^{2+} in the groundwater precipitate with the forms of $CaCO_3$ and $MgCO_3$. This process leads to the cations are dominated by K+ and Na+ in the sandstone water. The hydrochemical characteristics of typical sandstone water are: (1) The hydrochemical type is HCO_3-Na, and the percent meq/L of ($Na^+ + K^+$) is more than 85 %, the percent meq/L of (Ca^{2+} +Mg^{2+}) is less than 15 %; (2) The total hardness is low, ranging from 40 to 90 mg/L; (3) The concentrations of HCO_3^-, CO_3^{2-} are high, ranging from 400 to 700 mg/L and 10 to 50 mg/L, respectively; (4) The percent meq/L of ($HCO_3^- + CO_3^{2-}$) which is higher than (Ca^{2+} +Mg^{2+}) is ranging from 75 % to 90 %; (5) The pH is 8.0-9.0, and the water is alkaline (fig. 1-d).

Conglomerate pore-fissure water

The hydrochemical type of conglomerate pore-fissure water are HCO_3-Ca•Mg, HCO_3•SO_4-Ca•Mg and HCO_3•Cl-Na•Ca•Mg (fig. 1-e). When the hydrochemical type is HCO_3-Ca•Mg, it is difficult to distinguish the conglomerate pore-fissure water and O_2 water. Because of the aquifer is shallow, the water quality is affect easily by human activity. In the conglomerate pore-fissure water, the concentrations of Na^+, Cl^-, SO_4^{2-} and TDS are higher than those in O_2 water.

Goaf water

The goaf water is the groundwater which exists in the worked-out section and the goaf. Because of the distribution and quantity are difficult to distinct, the goaf water bursting is emergency, unpredictability, and disaster. Generally, goaf water is well sealed, that the effect of water-rock interaction leads to the higher concentrations of SO_4^{2-} and TDS. And the concentration of SO_4^2 is greater than 400 mg/L. The TDS is range from 900 to 8000 mg/L. The hydrochemical type mainly are SO_4-Ca•Mg•Na and SO_4•HCO_3^--Ca•Mg•Na (fig. 1-f). It can be distinguishes with other groundwater according to the concentrations of SO_4^{2-} and TDS.

Distinguish the source of water burst by hydrochemical characters

The obvious differences of hydrochemical characters between different groundwater in different aquifers provide a way to distinguish the source of bursting water. For example, the hydrochemical type of groundwater in O_2 aquifer is HCO_3-Ca•Mg. The type in sandstone aquifer is HCO_3-Na, Na^+ and CO_3^{2-} are higher and the total hardness is low in this kind of water. The type in L_2 aquifer is HCO_3•SO_4-Ca•Mg or SO_4•HCO_3-Ca•Mg. The type in L_8 aquifer is the mixture of sandstone water and O_2 water. The goaf water is difference with other kinds of water because of the obviously higher in TDS and SO_4^{2-}. The source of burst water can be distinguished by the difference of hydrochemical composition and stable isotopes content of groundwater in different aquifer. However, when the difference is not apparent, this method is infeasible. For instance, conglomerate water has the same hydrochemical type with O_2 water that is HCO_3-Ca•Mg. Thus, it is difficult to make a distinction between these two kinds of water only by hydrochemical method. Under this circumstance, the effective way to solve this problem is combining with the formation condition and character of water burst. The implementation steps of distinguishing water source by hydrochemical are as follows.

Step one, the water source were analyzed according to the major ions or the hydrochemical type. For example, the percent meq/L of Na+ is more than 80 %, it must be sandstone water. If the percent meq/L of SO_4^{2-} is higher than HCO_3^-, which means this kind of groundwater is goaf water.

Step two, the water samples were identified in detail according to water quality index that are ion content, molar concentration, pH, hardness, alkalinity, TDS, the ratio between different ion and so on.

Step three, the results need revising and confirming by hydrogeological conditions, the location and characteristics of bursting water.

491 water samples were analyzed based on this method. The results show that 345 samples can be distinguished correctly by hydrochemical type and water quality index, and the accuracy rate is 70 %. 395 samples can be distinguished correctly combined with the hydrogeological condition, and the accuracy rate is 80 %. The remaining samples are L_8 water and O_2 water. Because of the two kinds of water has the similar hydrochemical type, and the water quality index are also the same, it is difficult to distinguish. But the water yield of L_8 and O_2 are different. It is abundant if the bursting water comes from O_2 aquifer, and the time of duration is long, the water yield is stable. On the contrary, it is L_8 water which instantaneous water yield is only 50 m^3/h, and the water yield reduced fast.

Distinguish the source of water burst by stable isotope

The altitude of karst water recharge area distribute within the scope of 500-1200m, which is 300-800m higher than piedmont plain. $\delta^{18}O$ of precipitation in mountainous area is -9.42 – -11.75 ‰, δD is -71.9 – -81.7 ‰. Meanwhile, $\delta^{18}O$ of precipitation in Hebi city is -8.40 – -8.95 ‰, δD is -59.5 – -65.2 ‰. The stable isotope in O_2 karst water has the relationship with the mountainous area precipitation and surface water caused by runoff process. $\delta^{18}O$ of O_2 water is -9.18 – -9.76‰, δD is -67.1 ‰ – -71.4 ‰. Conglomerate aquifer distributes at piedmont, and the groundwater accepts the recharge of precipitation that its stable isotope is similar with precipitation in plain terrain. $\delta^{18}O$ of conglomerate water is -8.53 – -8.76‰, δD is -63.9 – -71.4 ‰. Sandstone aquifer is occurrence in coal measure strata. Most of the sandstone water is paleogroundwater, which is due to their low velocities and long flow paths, and with a little bit modern precipitation. $\delta^{18}O$ of sandstone water is 9.8 – -10.4‰, δD is -70.1 – -73.1‰. The outcrop of L8 and L2 aquifers banded distribute at piedmont and the recharge source is local precipitation. It also has the relationship with O_2 water. $\delta^{18}O$ of L_8 water is -9.36 – -9.55‰, δD is -66.5 – -68.9 ‰. $\delta^{18}O$ of L_2 water is -9.25 – -9.98‰, δD is-65.9 – -72.1‰.

δD and $\delta^{18}O$ are different in different aquifer in Hebi mine. There have some obvious subareas in the Fig. 2. Different source of groundwater has its distribution area. We established a simple model based on the characters of isotope to analyze the source of water burst. The conglomerate water and sandstone water cloud be easy distinguish from karst water as shown the figure. The stable isotope method improves and complements the accuracy of hydrochemical method.

Conclusion

Due to the difference of hydrogeochemical environment in groundwater formation process in different aquifer, the hydrochemical composition and stable isotopes content are different. Once the mine water burst, the source of bursting water canbe ascertained by the hydrochemical composition and stable isotopes content. The results must be correct by the characteristics of water burst and geological conditions. Based on this method, 491 samples were analyzed. 395 identified results are accu-

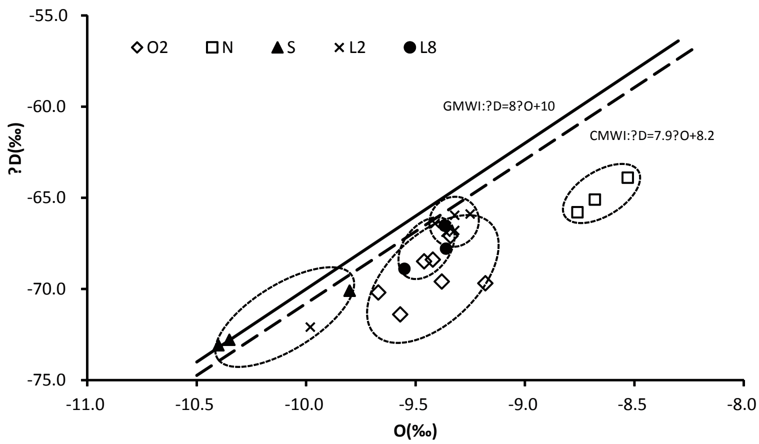

Fig. 2 *The relationship between δD andδ*^{18}*O*

rate, and the accuracy is 80 %. In addition, the stable isotope of different groundwater has obvious distribution area, this method proved a way to distinguish the source of groundwater.

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References

Han D, Yang Q (1984) China Coal Geology, 2nd edn. Publishing House of Coal Industry, Beijing

Zhao T (2007) Comprehensive Prevention and Control Technology of Ordovician limestone water in North China. Publishing House of Coal Industry, Beijing

Wang Y (1990). The application of hydrochemistry method on the prevention of mine sudden flooding. Jo Shandong University of Science and Technology, (1):11-17

Hu W, Ma Z and Cao H (2010) Application of Isotope and Hydrogeochemical Methods in Distinguishing Mine Bursting Water Source. J Earth Sciences and Environ, 32(2), 268–271