ABSTRACT

It is well-known that karst water inrush in coal mines of China is frequent and is very large in amount. In order to prevent disasters of inrush, we have used various methods, according to different natural environmental, economical and technological situations, to reduce the damage caused by inrush, strengthen prevention capability, save drainage cost and protect the ecological environment of coal mines.

(1) THE HARMFULNESS OF KARST WATER INRUSH IN COAL MINES

China is one of the major coal-producing countries in the world, with the most complicated hydrogeological conditions.

In the process of sedimentation of coal seams, alternating limestones were deposited both on the roof or at the bottom of coal seams. Sometimes, the limestones with a great thickness become strong aquifers. Because limestone aquifers are the main water-charging sources and threat in the mining of coals, this kind of mines are called karst water-charged deposits, which are found to occur in 30 coalfields in North China and 20 coalfields in South China, respectively.

In karst water-charged coalfields, the inrush of more than $1 \text{ m}^3/\text{min}$ has occurred for more than 1000 times. The inflow is usually several or even tens of times larger than the drainage capability, which threatens the
safety of the mines. According to incomplete statistics, karst inrush of 10-50 m³/min has occurred for 100 times, that of 50-100 m³/min, for 20 times, and that of larger than 101 m³/min, for 17 times. The largest inrush in the world occurred in the Fangezhuang Mine of Kailuan Bureau, North China in 1984, with the inflow being as large as 2053 m³/min. Once inrush occurs, accidental economic loss, sometimes even life loss, is caused.

In the respect of harnessing karst water, hydrogeologists and mine technicians have coordinated to do practical research, and a series of methods suitable to our hydrological conditions and the existing situation of the country have been gradually developed. From the point of range and extent of suffering from or destruction by karst water, as compared with the similar European mines, our conditions are more complicated. It is believed that the mine hydrogeology will develop at a still higher speed in China. The recent decrease of inrush disasters is just the result of this effort.

(2) THE ENVIRONMENT AND NATURE OF KARST WATER INRUSH IN MINES

The inrush of water from thick limestones may fall into two types: the northern China-type and the southern China-type. The boundary line between them stretches approximately from Nanjing through Wuhan to Chengdu (Figure 1). In northern part, there exists the Middle Ordovician limestone, as thick as 300-800 m, beneath the Carboniferous strata. The limestone is heavily karstified, so it becomes a threatening strong aquifer in many mines in North China. Under natural conditions, karst water discharges through karst spring. Generally, the nearer to the discharging zone, the more concentrated the karst water. The coal mines in the discharging zone or in the strong runoff zone are more likely to be charged by water and the threat extent is more serious. When excavation is deeper or close to the Ordovician limestone aquifer, the possibility of karst water inrush is greater.

In northern China, the coal measures usually contain several or more than ten thin layers of limestones. The
thickness of single layer ranges from 2 m to 10 m. These thin limestones are the direct or indirect roofs and bottoms of the coal seams, as shown in Figure 2. In some mines, there are one or two aquifers charged with relatively abundant water. When they have connection with the Ordovician limestone beneath them, or the Quaternary loose aquifer above them, the charging water is more abundant. So the inrush of karst water into pits has two ways, one is the inrush directly from the Ordovician limestone, the other is the inrush indirectly from it through thin limestone aquifers.

The existence of water-bearing aquifers is the material basis for inrush. It is very common that karst water rushes into pits through weak zones, for example, the inrush through fault zones accounts for 80%. A typical inrush through fault occurred in North Shaft in Zibo Mine, Shandong Province, with water inflow being as large as 443 m³/min. Another inrush occurred in No.1 Shaft of Fengfeng Mine in 1960, as shown in Figure 3. The collapsed column are another passageway of inrush. When thick-bedded limestones are heavily karstified, large caves are formed. The strata above the caves would collapse into cylindroid pipes by gravity, which are called the collapsed column. The collapsed column often act as weak zones in normal strata. There are case histories in which high-pressure water rushed into pits through the collapsed column. In the Tongyie Mine, karst water rushed into pit through a collapsed column at an inflow of 23.3 m³/min, and in the Fengfeng Mine in 1967, the inflow was 120 m³/min, and the inrush in the Fangezhuang Shaft of the Kailuan Mine in 1984, the largest inrush in the world, also occurred through a collapsed column. When the mining is deep, high-pressure water can burst into pits by breaking out thin aquitards. This inrush, once occurred in No.3 Shaft of the Jingxing Mine, is uncommon.

In southern China, including Hunan, Jiangxi and Sichuan Provinces and Guangxi Zhuang Autonomous Region, generally the Late Permian Longtan coal measures are mined. Beneath the coal measures, there exists the thick Maokou Limestone, usually 200-300 m thick, which is
heavily karstified and water-bearing. Above the coal measures, there exists the Changxing Limestone, 100-700 m thick. In the Heshan Mine, the thickness of the Changxing Limestone is 700 m. In southern China, these thick limestones have hydraulic connection with atmospheric precipitation and surface streams. In the history of mining, karst-water inrush was also common. In the Zhushantang Mine, the inflow of an inrush from the Maokou Limestone was 48 m$^3$/min and in No.2 Shaft, Enkou Mine, the inflow was 38.3 m$^3$/min. The limestone above the coal measures is different from that beneath them in respect of their threat to the mining. In some coalfields, as the coal seams and the Changxing Limestone are close to each other, between which there is no effective aquifuge, the possibility of inrush does exist. In the Yunzhuang Mine, the inflow of an inrush was 324.7 m$^3$/min, forming a disaster. Since there are thick limestones above and beneath the coal measures, and the exposure area is large, the precipitation can recharge the pits during the rainy season, especially during the torrential rain. In the Hongyan Mine, there once occurred a precipitation pour of 466 m$^3$/min and in the Jangbei Mine, 1500 m$^3$/min. Another source charging the mines is water from underground rivers. In the Shuohe Mine, water from river into pits was 23.3 m$^3$/min, even bringing in 250 kg of living fish. So, it can be seen that a lot of disasters and losses have been caused by inflow of karst water into mines. In addition to complex natural conditions, the technological and management problems may also serve reasons causing the inrushes.

(3) EFFECTIVE MEASURES REDUCING THE INRUSH PROBABILITY AND DISASTERS

In order to reduce the inrush probability of karst water effectively, the first thing is to investigate the occurrence, storage and runoff of karst water, predict the passage way through which water flows into pits, as well as the positions where inrush will occur. The geological structure and hydrogeological and engineering geological characteristics must be known to prospect the water pressure or water table, initial place of confined
water entering aquitards. The techniques adopted include mapping, water injection or releasing and hydraulic connection tests, and groundwater regime monitoring. In order to delineate the dangerous area of inrush, we have successfully used the underground logging, seam waves, radar and radioactive measurements. Based on the knowledge of the hydrological environment, concrete and effective schemes to prevent karst water inrush can be worked out.

Drainage of karst water is an active method. It needs a lot of money to drain water away. It is applicable only to the mines with little water, or to the areas with relatively simple hydrogeological conditions in the hydrogeologically complicated regions, or provinces short of coals. In southern China, the drainage is as much as 100 m³ or more per ton of coal mined, but it is desirable to use drainage method. The Meitanba Mine is the exact example. However, it is obvious that the method may bring about ecological destruction. Springs and surface streams may be dried and collapse of the surface may be caused in some mines. In some regions with complicated hydrogeological conditions a lot of scientific tests have shown that coal can be mined by use of aquifers that can support certain water-pressure. At certain depth, the mining with water-pressure has a practical value. Coal would be mined even under the water-pressure of 24 kg/cm². Up to now, we have mined about 10,000,000 tons of coal by the method of mining with water-pressure. This method has been widely used in China. The coefficient of judgement in determining whether karst water inrush would occurs, and the lower limit of mining is obtained on the basis of hundreds of practical inrush data. The mining with water-pressure includes a complete set of techniques for preventing karst water inrush.

As far as old mines with complicated hydrogeological conditions are concerned, a comprehensive prevention and control method against karst water inrush is valid. We have applied the method to the mines in Hebei and Jiangsu provinces and satisfactory results have been obtained. For instance, on the basis of clarifying hydrological conditions, sluice gate have been established to isolate...
different mining areas from one another; and by checking up on the existence of karst water in advance, predicting the amount of water through hydrogeological parameters and judging the water source through hydrochemical features, we can make a detour or block up the dangerous segments to avoid inrush. Some coal mines are in the runoff zones of high pressure, an inrush of $85 \text{ m}^3/\text{min}$ once occurred and the mine was flooded. By using this method, 10,000,000 tons of coals has been mined safely. In the mines with abundant karst water, the most important thing is to prevent the recharge from precipitation and surface streams to thick limestone aquifers to reduce the amount of charging water into pits. To do so, we should cut or block up the charge passageways in the outcrop areas or change the channels for the surface streams. After we used it in provinces, a lot of benefits has been gained. In the Xuzhou Mines, since the blocking construction was established, the charge of precipitation has decreased by 10 times. In the Enkou Mine, after the river bed has been concreted, the water inrush probability is nearly zero. In the Nantong Mine, when a stream course crossing the outcrop of limestone was transformed, the amount of water flowing into pits has decreased greatly.

In the last 20 years, we have used the method of establishing underground heavy curtains to block up the karst water flow. We drilled holes and poured blocking material in the form of injecting mud into them to make underground dams. The key of this method is to change the runoff of karst water or reduce the amount of water flowing into the pits, in the end, to prevent the inrush of karst water. This method has been repeatedly used. Practice has shown that shallow (<100 m) blockage is more effective. Heavy curtains can also interrupt the way connecting the production mines with the flooded ones and the passageway of "skylight" through which a strong aquifer recharges the mines. In addition, they can cut off the aquifers recharged by surface streams and reduce the amount of karst water flowing into the pits and rejuvenate the dried springs. According to the data from seven projects, an inflow of $137.9 \text{ m}^3/\text{min}$ to pits has been eliminated. It is believed that the blockage
projects can reduce the threat of inrush, strengthen the capability of preventing the water inflow and save a lot of money on water drainage.

In some mines, many efforts have been made to combine the mine drainage with water supply and turn the disastrous water into usable water resources.

Fig. 1 A sketch map showing the distribution of karstic coal mines in China.
Fig. 2 The relationship between aquifers and coal seams of karstic coal mines.

Fig. 3 Sketch map of inrush through fault.

Fig. 4 The relationship between aquifers and coal seams of karstic coal mines in South China (exemplified by Hunan and Guangxi).