Coal quality characteristics and coal accumulation patterns of seam No.4 at medium depth in Longting mining area, Weibei P-C Coalfield

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Abstract. On the basis of collecting the latest exploration data of the study area, the authors made the research of the coal quality characteristics and coal accumulation patterns of seam No.4 at medium depth, which provided geological basis of the construction of high production and efficiency coal mine and the next coal resources exploration. The results show that the seam No.4 is black - brown-black, semi bright coal type, at the Ⅶ phase of the medium rank coal, high calorific value, easy to grind, nonagglutinating, noncoking and at the relatively high - high softening temperature gray level. The raw coal of seam No.4 generally belongs to middle ash coal, ash yield gets higher from south to north. It’s given priority to a low ash coal in the south and middle ash yield coal in the north. The seam No.4 belongs to low-sulfur coal, and shows "dumbbell" type in sulfur contour map, with the basic characteristics of low in the middle, high on both east and west sides and higher in southwest, lower in northeast. The thickness and deposition range of the seam were controlled by ancient fluvial erosion after the coal-accumulating period around the Qiao8-11 holes in the south of study area and in the other area, during the coal-accumulating period were controlled by syndepositional structures.

1. Introduction
The Carboniferous Permian coalfield in the north of Wei River in Shaanxi Province is famous for its abundant coal resources, known as the "black belt" in the north of Wei River. Many coalfield geological researches involve this area [1-5]. The study area is located in the south of Hancheng mining area, adjacent to Xiangshan coal mine in Hancheng mining area in the north, and naturally connected with Chenghe mining area in the south, covering an area of about 170km². The latest exploration results show that there are generally three minable coal seams in the area, among which coal seam 4 is one of the main minable coal seams [6-8]. Therefore, it is necessary to discuss and study the coal quality characteristics and coal accumulation rules of No. 4 coal seam, so as to provide geological basis for the construction of high-yield and high-efficiency coal mine and the exploration of coal resources in the next step.
2. Occurrence of coal seam 4
No. 4 coal seam is located at the top of Taiyuan formation, and its relative buried depth is 280-1340m. The thickness of the coal seam is 0-5.70m, with an average thickness of 1.65m, mainly medium thick coal seam. The thickness of coal seam is generally thick in the South and thin in the north. Although the thickness of coal seam in the south is thick, the thickness changes greatly (0-5.70m), especially in the restricted area of borehole Qiao 7 (0m), Qiao 11 (0m), Qiao 12 (0.95), Qiao 14 (5.70m). The thickness of coal seam in the southwest corner is obviously different. The erosion of coal seam is completely caused by ancient river erosion, and the thickness of coal seam in other sections in the South changes little (2.05-2.90 m). The thickness of coal seam in the north is relatively thin, but it is stable with small change (1.15-2.20 m), with the trend of thickness change in the middle thin and east-west sides (Figure 1).

![Figure 1. The thickness isoline map of seam No.4](image)

3. Coal quality characteristics

3.1. Physical properties and characteristics of coal

1. Physical properties of coal

No. 4 coal in the study area is black brown black, dyed with asphalt luster; angular fracture, a small amount of shell fracture is found in mirror coal, with small hardness, brittleness, slippery surface, poor block, mostly in granular or powder shape; the combustion flame is medium length, less flammable, basically non melting and non expansion, or slightly melting and expansion, and the ignition point is about 380-400 °C according to a small amount of data.

2. Coal rock characteristics

No. 4 coal is mainly composed of broken grain structure, fine to medium strip structure, with horizontal bedding structure. There are pyrite film and network calcite veinlets on the fracture surface. The macroscopic coal rock type is mainly of semi bright coal type, followed by semi dark coal or dim coal type, and occasionally bright coal type.

According to the micro coal rock data of l0-1, 11-3 and 18-4 boreholes, the total organic content of coal seam 4 is 87.2-96%, mainly vitrinite, accounting for 68.8-76.4%, inertinite, accounting for 18.4-
21.9%, inorganic macerals are mainly clay minerals, accounting for 3.2-10.8%, followed by carbonate minerals, accounting for 0.6-2%, which are micro vitrinite inert coal (Table 1). The average maximum reflectance ($R_{\text{max}}$) of No. 4 coal seam is more than 2.08% and less than 2.25%. The degree of coalification belongs to the seventh stage of medium rank coal.

| Table 1. The test result of maceral content and reflectivity of No. 4 coal seam |
|----------------------------------|----------------|------------------|-----------|--------------|-----------------|-----------------|
| Coal seam number | Drill hole number | Micro quantitative results of coal and rock (%) | Average maximum reflectivity (%) |
| | | Vitrinite group | Inert group | Chitin group | Total organic matter | Clay type | Sulfides | Carbonate type | Oxide | Total inorganic content | |
| L1-3 | 74.1 | | 74.1 | 21.9 | / | 96 | 3.2 | / | 0.8 | / | 4.0 | | 2.18 |
| 4# | L0-1 | 68.8 | | 68.8 | 18.4 | / | 87.2 | 10.8 | / | 2 | / | 12.8 | | 2.25 |
| L8-4 | 76.4 | | 76.4 | 19.6 | / | 96 | 3.4 | / | 0.6 | / | 4.0 | | 2.12 |

3.2. Chemical properties of coal

1. Industrial analysis

The raw coal ash content (AD) of No. 4 coal is 10.45-34.04%, with an average of 20.46%. It is generally medium ash coal. The ash content of coal seam 4 changes from low to high from south to north, with the characteristics of high in the north and low in the south. In the south, low ash coal is the main coal, in the north, medium ash coal is the main coal, and in some sections, medium high ash coal.

2. Harmful components

The total sulfur (st, d) content of coal seam 4 is 0.37-3.07%, with an average of 0.95%. It belongs to low sulfur coal. The sulfur isoline of coal seam 4 is "dumbbell" type, with the basic characteristics of low in the middle, high in the East and West, high in the southwest and low in the northeast.

3. Process performance of coal

According to the results of this and previous coal quality analysis, the average dry high calorific value of raw coal in coal seam 4 is 28.14MJ/kg, and the dry base low calorific value ($q_{\text{net}, d}$) is 27.48MJ/kg, which belongs to high calorific value coal (Table 2).

The grindability of No. 4 coal seam is 88-90%, which is easily grinded (eg). The caking indexes are all 0, and the characteristics of coke slag are generally 2-4, with an average of 3, without caking and coking. The softening temperature (st) of coal ash is relatively high, ranging from 1435 °C to > 1500 °C, which belongs to the ash grade of high to high softening temperature.

| Table 2. The average calorific value of seam No. 4 |
|----------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Coal seam number | | $Q_{\text{h, ad mean}}$ value/( MJ/kg) | $Q_{\text{gr, ad mean}}$ value/( MJ/kg) | $Q_{\text{gr, d mean}}$ value/( MJ/kg) | $Q_{\text{net, ad mean}}$ value/( MJ/kg) | $Q_{\text{net, d mean}}$ value/( MJ/kg) |
| 4 | Raw coal | 26.94 | 27.34 | 28.14 | 26.14 | 27.48 |
| | Float coal | 33.70 | 34.65 | 35.42 | 34.66 |

4. Study on the rule of coal accumulation

There are more than 10 coal seams (lines) in the Carboniferous Permian coal bearing rock series of Ordos Basin. Coal seam 4-11 is located in Taiyuan formation [6-8]. According to the drilling data, the overall change characteristics of coal seam thickness are thick in the South and thin in the north. The thickness changes greatly in the South (0-5.70m), the coal seam 4 in Qiao 8-qiao 11 hole is thin, and the coal seam 4 in Qiao 14-15 hole is thick. The thickness of the coal seam in the north is stable (1.15-2.20m), with the change trend of thin in the middle and thick in the East and West (Figure 1).
According to drilling data, the pseudo roof of coal seam 4 is fine-grained sediments such as mudstone and siltstone mudstone of delta flood basin facies, and the basic roof is sandstone (K4 marker bed) at the bottom of Shanxi formation. The results of lithofacies analysis of K4 sandstone show that the roof of No. 4 coal seam of well Qiao 11 and Qiao 8 in the south of the study area is K4 sandstone, the lithology is mainly medium grained sandstone, the granularity of sandstone is coarse, and generally contains coal inclusions, with trough cross bedding developed, forming upward thinning sedimentary sequence, which belongs to channel facies. Among other boreholes, No. 4 coal seam and K4 sandstone are fine sandstone, siltstone with silty mudstone deposit, small cross layer and horizontal bedding are developed in sandstone, and horizontal bedding is developed in mudstone, which belongs to floodplain facies. It shows that the thin seam 4 near Qiao 8-11 in the south of the area is caused by the strong erosion of the ancient river.

The thickness of coal seam in the north is stable (1.15-2.20 m), with the change trend of the thickness of the middle part thin in the East and West. It shows that the middle part is the paleogeographic uplift part, the swamp is covered with shallow water, and the swamp surface is in a dry and oxygen rich environment, which results in partial decomposition of plant remains or intermittent peat accumulation due to peat exposed to the marsh surface, thus reducing the thickness of coal seam; the secondary depression in the East and west sides In the subsidence area, peat swamp develops continuously and is well preserved, and the thickness of coal seam increases accordingly. Therefore, the secondary uplift and depression of the synsedimentary structure in the peat accumulation process is one of the main reasons for the thickness change of No. 4 coal seam in the north of the area.

To sum up, the thickness change of coal seam 4 in the study area is closely related to the overlying K4 sandstone, and the two are in a scour contact relationship near hole Qiao 8-qiao 11 in the south of the study area. The strength of ancient river erosion after coal accumulation period controls the thickness and sedimentary range of the coal seam; there are mudstone and silty mudstone between the overlying K4 sandstone in other areas, and the thickness change amplitude of the coal seam is small, and the coal accumulation period is controlled by the sedimentary structure Thickness of coal seam and sedimentary range.

5. Conclusion
No. 4 coal is black brown black, mainly of semi bright coal type. It is the seventh stage of medium coal grade. It has high calorific value, is easy to grind, does not have cohesiveness and coking, and belongs to high to high softening temperature ash grade;

No. 4 coal belongs to ultra-low total moisture coal, and the raw coal belongs to medium ash coal in general. The ash content gradually increases from south to north. In the south, low ash coal is the main coal, in the north, medium ash coal is the main coal, and in some sections, medium high ash coal is the main coal;

The raw coal of No. 4 coal seam belongs to low sulfur coal. The sulfur isoline is "dumbbell" type, with the basic characteristics of low in the middle, high in the East and West, high in the southwest and low in the northeast;

In the south of the study area, the thickness and sedimentary range of the coal seam are controlled by the erosion of the ancient river after the coal accumulation period near the Qiao 8-qiao 11 hole, and the thickness and sedimentary range of the coal seam are controlled by the synsedimentary structure during the coal accumulation period in other areas.

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