Study on the industrial feasibility of adding lignite for blast furnace

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Abstract: Lignite resources in China are abundant and cheap. The application of lignite resources is one of the promising solutions for the energy crisis of industries in China. In the present work, the resources of coal mines around Kunming, Yunnan Province, P.R. China were investigated. After considering various factors, the Mile coal was selected as the supply for the lignite experiment. Conducting the industrial analysis and properties experiments on the single lignite and mixed coal of different proportions. On the basis of ensuring safety, and the coal blending structure of 60% anthracite-35% bituminous coal-5% lignite has been selected for the industrial test in no. 3 blast furnace of a steel plant. At the same time, the data of the blast furnace condition in the reference period and the test period were collected and compared. We can conclude that the blast furnace with 60% anthracite-35% bituminous coal-5% lignite injection test was stable, safe and feasible. Finally, according to the replacement ratio of lignite and bituminous coal, the economic benefits of lignite instead of bituminous coal were evaluated, and the results were more optimistic, which achieved the effect of reducing costs for the factory.

1. Introduction
Lignite has a lower metamorphic grade which between peat and bituminous coal, but the advantage is with high volatile content, high combustion efficiency[1-2] and abundant resources. Making full use of lignite resources will effectively alleviate the shortage of resources in China[3-4]. It is significant for both the environment and energy. Because of the great advantage of lignite, many domestic and foreign scholars have studied more on the properties and structure of lignite, but less on the safety and feasibility of selecting a specific proportion of mixed coal blending structure for blast furnace and conducting industrial tests. Guo, FH[5] et al. studied the co-combustion of CBPs and coal by thermogravimetric analyzer and fluidized bed. Wang, HY[6] et al. investigated the correlation between the amount of lignite added and the explosiveness and combustion of blended coal.

This paper is a specific industrial injection experiment for mixed proportion[7-8] of lignite, bituminous coal and anthracite, such as explosiveness, volatile, grindability and combustion rate. Even on the basis of using 40% of bituminous coal and 60% of anthracite for injection coal, a steel plant have used a proportion of 5% of lignite to replace bituminous coal for injection testing to maximize the benefits[9, 10] and the steel plant will gradually enlarge the proportion of lignite, which has certain reference value.
2. Laboratory experiments and results discussion

2.1 Materials
Selecting lignite from the Mile area as an experiment, samples of lignite, bituminous coal and anthracite were dried in a blast-drying oven at 105 for 2 hours before the experiment, after drying the moisture content of the dried coal sample was less than 20%, then the samples were crushed and screened, then the practical which within 0.074-0.038 mm were used.

2.2 Results
Each coal sample was mixed according to different proportions, and measured its explosiveness, volatile matter, fixed carbon, grindability and burning rate.

![Figure 1. The industrial analysis index and performance of coal blending structure](image)

In Figure 1, 2, the number 1. 2. 3. 4. 5. 6. 7. and 8 represent lignite, 40% bituminous coal -60% anthracite, 5% lignite -95% anthracite, 10% lignite-90% anthracite, 15% lignite-85% anthracite, 5% lignite -35% bituminous coal-60% anthracite, 10% lignite-30% bituminous coal-60% anthracite, 15% Lignite-25% bituminous coal-60% anthracite, respectively.

From the explosive analysis, it is noticed that as the proportion of lignite increases, its explosiveness increases. The 5% lignite -35% bituminous coal-60% anthracite coal has a weak explosiveness and a flame length of 9cm, which meets the requirements for safe production. And another proportions of flame length are not less than 9cm, this structure is the first choice during the test period. The single lignite has high volatile matter and strong explosiveness, while the bituminous coal and anthracite have low volatile content and poor combustibility. When mixed coal is burned at the fire source, lignite will be firstly burned and give off a large amount of heat. Bituminous coal and anthracite coal will consume this part of heat. However, bituminous coal and anthracite has a high ignition point, the heat released from lignite combustion is not enough to make the mixed coal reach the explosion temperature, so bituminous coal and anthracite are equivalent to explosive inhibitors of lignite, so the explosive become weaker.

From the grindability index, it can be see that when the coal is mixed, the grindability index of the
reference period 2 is 82, and the grindability index of experimental scheme 6 is 80, which slightly decrease, and it may cause the lower yield.

From the analysis of volatile matter, the high volatile coal rapidly warms up after entering the combustion zone, releasing a large amount of volatiles which can make the coal burn quickly. Therefore, the combustion efficiency of high volatile coal is correspondingly high, but the high volatile coal may cause the threat of spontaneous combustion during the accumulation process. In figure1, during the reference period 2, the Volatile matter is shown 12%, and the experimental scheme 6 is 13%. The difference is small, which has a slight impacts on safety.

The calorific value is mainly generated by the combustion of fixed carbon, so the higher the fixed carbon, the more the calorific value. After the 5% bituminous coal in the reference period is replaced by lignite, the fixed carbon content of the experimental scheme 6 is reduced by 1% comparing with the reference period 2, factories can increase their heat by expanding the amount of brown coal.

![Figure 2. The combustion ratio of different coal blending structure](image)

Figure 2. The combustion ratio of different coal blending structure

The combustion rate is related to the volatile and maceral, Figure 2 shows that there are a large number of vitrinite groups by polarized light microscopy, which are active components. Even its SEM image shows that the surface is loose and porous. That is because of the combustion performance performs perfect. As can be seen from the figure 2 that the combustion rate of 40% bituminous coal-60% anthracite is 69.9, and the burning rate in experimental scheme 6 is 79.19, the combustion rate improves a lot. Under the premise of ensuring safety, using the good combustion characteristics of lignite to improve the combustibility of coal blending is also the key to the injection of lignite in the blast furnace.

In a word, in order to ensure the safe operation of the furnace condition during the test phase, the experimental results of selecting the coal blending structure has a slight change with the measurement results of the reference period. From these main factors analysis, the coal blending structure of 5% lignite-35% bituminous coal-60% anthracite coal was almost consistent with the reference period 2 in terms of safety and performance.

3. Industrial experiment on Blast furnace
On the basis of ensuring safety, the project leader organized staff to conduct industrial experiments on the No. 3 blast furnace at 1080m³. they were respectively 20 days on the reference period and trial period, and ① and ② were used to respective the two period in the following data table.
This test stipulates that the oxygen content of the mill inlet does not exceed 4% and of mill outlet does not exceed 8%, the inlet temperature of the mill is below 280℃, and the outlet temperature is below 80℃. The size of coal sample that smaller than 200 mesh accounts for 63.71%.

1) Coal mill index

| blast furnace | Inlet temperature (°C) | Outlet temperature (°C) | Wind pressure (MPa) | Oxygen content (%) | <20 mesh (%) | Coal grinding (t/d) |
|---------------|------------------------|-------------------------|--------------------|-------------------|--------------|--------------------|
| ①            | 262.52                 | 75.26                   | 10.47              | 6.28              | 64.29        | 487.95             |
| ②            | 264.85                 | 75.80                   | 10.56              | 6.30              | 63.57        | 483.19             |
| difference   |                        |                         |                    |                   | -0.72        | -4.76              |

Comparing with the reference period, the mill temperature rised by 2.33℃ and the outlet temperature rised by 0.54℃. The wind pressure and the oxygen content of the mill were stable and normal, the reduction of <200 mesh was 0.72%, and the amount of coal grinding was reduced by 4.76 t/d.

In general, the mill control parameters met the pre-test regulations during the above test period. While the amount of grinding coal decreased, which was related to the lignite` s high water content and the low grindability index. In the later stage, the production could be increased by increasing the number of mills.

2) Blast furnace operation

| blast furnace | Air volume (m³/min) | Wind temperature (°C) | Wind pressure (KPa) | Smelting strength (t/m³·d) | Top pressure (KPa) | Pressure difference (KPa) |
|---------------|---------------------|-----------------------|---------------------|-----------------------------|-------------------|--------------------------|
| ①            | 2630                | 1180                  | 309                 | 1.27                        | 154               | 156                      |
| ②            | 2602                | 1180                  | 311                 | 1.32                        | 155               | 155                      |
| difference   | -28                 | 0                     | 2                   | 0.05                        | 1                 | -1                       |

When the blast furnace was running smoothly, the hot air pressure and the furnace top pressure were correspondingly stable. Therefore the pressure difference was controlled within a small range. According to the data in the table, the furnace condition fluctuated slightly because of the improper operation of the blast furnace and fuel changes. Meanwhile, the coal ratio increased by 2kg/t and the coke ratio decreased by 1kg/t, so the result was considerable.

3) Blast furnace molten iron quality

| blast furnace | Temperature (°C) | Si   | Mn   | S    | P    | V    | Ti   | Output (t/d) |
|---------------|-----------------|------|------|------|------|------|------|--------------|
| ①            | 1473.6          | 0.248| 0.632| 0.027| 0.090| 0.064| 0.116| 3961         |
| ②            | 1477.9          | 0.260| 0.675| 0.026| 0.089| 0.113| 0.197| 3954         |
| difference   | 4.3             | 0.012| 0.043|-0.001|-0.001| 0.049| 0.081| -7           |

When the temperature of molten iron is suitable and the chemical composition is relatively stable, it indicates indirectly that the furnace condition is operating normally. The elemental silicon content will affect the fluidity of molten iron, if the content is too high, the
steel and iron will be hot brittleness. When in the process of the rolling and forging, the steel is prone to cracks, which affects the quality of the product. The trial period of Si and S content had a little change comparing with the reference period. Even another components of molten iron were relatively stable, so the whole process of spraying 5% lignite had little effect on the quality of molten iron.

4. Economic evaluation
The price of bituminous coal is 1004.97 RMB/t (dry basis without considering tax price), and the anthracite is 1043.49 RMB/t, lignite is 256 RMB/t. In order to compare the economy of blast furnace lignite injection in a reasonable way, based on the low calorific value then calculate the price of two coals when the bituminous coal and the lignite have the same calorific value.

The replacement ratio can be expressed as:
\[ A = \frac{Q_1}{Q_2} \]

Q1: low calorific value of injecting pulverized coal
Q2: Low calorific value of tested coal
A: the replacement ratio of tested coal

So the replacement ratio of lignite and bituminous coal is 31257/22028=1.42. In other words, when take the calorific value of a ton of bituminous coal and make the calorific value of lignite equal to it. At this time, the amount of lignite is used 1.42 tons. So after the lignite price is converted, it is 256*1.42=363.52 RMB/t equivalently. The processing charge and freight of raw coal are 290 RMB/t, and the processing fee of coal powder in the test period is calculated at 120 RMB/t. Finally the cost of lignite is about 773.5 RMB/t, which is 231.47 RMB/t Spread from the price of bituminous coal. If the usage of lignite is 60 t per day, 13888.2RMB will be saved. In the later stage, if the proportion of lignite added is expanded, the benefits will be more significant, which achieve the goal of energy saving and consumption reduction.

5. Conclusion
Based on laboratory data and factory coal injection tests, the following conclusions can be drawn:

Industrial analysis and various performance tests were carried out for different proportions of coal blending structures. The 60% anthracite-35% bituminous coal-5% lignite coal blending structure was safety and feasibility which was selected for industrial test; After the injection of 5% lignite, the furnace condition is normal, and the quality and output of molten iron had not caused much impact. The goal of replacing 5% bituminous coal with lignite can be achieved; From the perspective of budget, the cost of injecting lignite is much lower than that of bituminous coal when at the same amount of heat. From the perspective of mass production, its economic benefits were considerable.

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