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# Way of Carbon Emission Reduction in Coal Mines Based on Carbon Balance Method and B-Wilson Method

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This study is to analyze carbon balance method and B-Wilson method in carbon emission reduction in coal mines. The carbon balance method and B-Wilson method are studied in four open-pit coal mines in Yimin River, Anjialing, Heidaigou and Buzhaoba. It is found that continuous process can effectively improve the unit production capacity, and has positive effect on unit coal emission. It is also found that the production process system has certain effect on the carbon emission in open-pit coal mines. Conclusion has been drawn that the coal mining process system has certain application and research value in the research on way of carbon emission reduction in open-pit coal mines.

## 1. Introduction

As a large country of coal energy consumption, China needs to consume a large amount of coal resources every year. As the coal industry gradually perfects, how to optimize the coal energy has become the key issue to be solved. The use of coal energy will inevitably cause pollution to the surrounding environment, thus affecting people's normal life. In recent years, the low-carbon economy has gradually become a new industry, which has become a hot topic all around the world. Therefore, the researches on carbon emission reduction and low carbon have become more and more abundant. Combined with relevant research data, we can see that China is a large country of carbon dioxide emission in the world, so the task of carbon emission reduction in the international community is heavy. Carbon balance method and B-Wilson method are important means in the study of carbon emission in coal mines, which has certain research value in the application of carbon emission reduction method in unit coal mines. Based on the carbon balance method and B-Wilson method, the influence factors of carbon emission in open-pit coal mines are studied. In terms of specific research, it is necessary to construct a model of plate emission calculation and determine the influence factors by identifying coal emission sources and carbon emission research methods. Then the research results are analyzed to determine the important factors of carbon emission in coal mines, and how to reduce carbon emission in coal mines is studied.

## 2. Literature review

The development of low carbon economy has become a global consensus and research goal. A series of new scientific and technological revolution represented by low carbon economy has become the new growth point and research impetus to promote economic recovery. At present, the global research on carbon emissions is mainly focused on global climate change, greenhouse gas emission inventory and estimation methods, the relationship between greenhouse gas emissions and economic and social development.

The compilation of greenhouse inventories is considered to be the navigation and benchmark of national emission reduction policies, so many countries, regions and scholars have compiled the corresponding greenhouse gas list. At present, the more common and widely used greenhouse gas list is the IPCC Greenhouse List Guide. On this basis, Quadrelli and Peterson, by analyzing different emission inventory of the various sources, pointed out that the combustion of fossil energy was the main influence factor of climate change and the key to the improvement of human social and economic development. Kennedy and others used carbon emission coefficient to measure the greenhouse gas emission of ten international metropolises,

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and defined the calculation factor (Kennedy et al., 2010), and the research on the carbon emission in China has also achieved some achievements; Zhang and others applied the life cycle method to calculate the direct carbon emissions from rural energy combustion and the production and supply of rural energy carriers. The results showed that the direct carbon emissions of rural energy consumption turned 3 times, from 0.79 x 1 billion metric tons in 1979 to 10 billion tons in 2008. This discovery shows that rural energy consumption is an important contributor to China's overall carbon emissions, and the main spatial and temporal carbon emissions are different from regional economic and environmental conditions (Zhang et al., 2014).

In the study of the influence factors of carbon emissions, domestic scholars started earlier. Wang used the LMDI decomposition model to decompose China's carbon emissions for 1957-2000 years. In China, the most typical research representative on the impact factors of carbon emissions is Xu Guoquan. According to the empirical analysis of 1995-2004 of China's data based on LMDI decomposition, it is found that carbon emission factors can be decomposed into energy structure, energy intensity, energy efficiency and economic development, and the analysis of the influence factors of carbon emissions can be analyzed. The models used include Kaya identity, partial least squares, factor decomposition, double nested structure, STIRPAT decomposition and so on.

In recent years, the research on coal consumption of carbon emissions is mainly from the global scale to the medium scale and then to the product consumption side. In 1988, IPCC was established, which represented the birth of a research organization that specialized in climate change. In 2006, the IPCC list guide law was further revised to focus on the method of emission and the default value. Since then, each country has carried out the research on the calculation method of greenhouse gas emission in China according to the guide. For example, the methodology used in the United States is based on the 1996 guide, excellent practice and the latest 2006 guide, using a "bottom-up" approach to assess fossil fuel carbon emissions. On the basis of coal types and energy statistics, Yu and others combined traditional IPCC guidelines with coal classification, grade classification at facilities and energy emission factors to formulate carbon emissions inventory (Yu et al., 2014), which are in accordance with the conditions of Australia. For China, since 1990s, the Chinese government and experts have carried out a number of studies on greenhouse gases in China. On the meso scale, some provinces and megacities are also calculating the greenhouse gas emissions based on the traditional greenhouse gas inventory guidelines, and the urban climate protection action (CCP) initiated by the Local Government Environmental Action Council (ICLEI) has formulated a standardized calculation for the compilation of urban and regional greenhouse gas inventories. Davis's team and Mózner and so on studied greenhouse gas inventories of regional energy consumption in cities in northwest England, China, Beijing and Shanghai, respectively. After that, the carbon emission inventory of energy consumption gradually developed from the middle view level to the product consumption side angle (Davis and Caldeira, 2010; Mózner, 2013). This research method originated from the life cycle method of the calculation of greenhouse gas emission, and the typical representative was the estimation of the CO2 emission coefficient at each stage of the coal life cycle.

The main source of carbon emissions from coal mining is carbon emissions from coal-bed methane. At present, there are two main types of methods to calculate the emission of coal bed gas. The first is the IPCC list guide method. This method is the method of combining coal gas and coal production, and coal production as the medium to estimate the emission. The other research method is the measurement method, mainly including gas content - depth relation method analogy method and so on. In addition, the mine measurement method and the source method are also included. In the field of coal transportation, Zhou and others, as the leader of the bottom - up estimation method, calculated the carbon emissions produced in China for 2005-2009 years. In the study, the uncertainty was analyzed (Zhou et al., 2015). Three methods are used to estimate the carbon emission of coal and other energy consumption, including the measurement method, the material balance algorithm and the emission coefficient method. In the macro level, the carbon emission models are mainly ERM-AIM, Logistic, MARKAL, SD model and so on. In the micro level, the carbon emission model is typical of the boiler carbon emission model. Some scholars deduced the calculation formula of the carbon emission of the boiler and the way to reduce the CO2 emission of the boiler. After understanding and mastering the coal carbon emissions, Li and others studied how to slow down the carbon emissions. The research found that carbon capture and storage technology in development is now recognized as a high tech that may promote global climate change mitigation (Li et al., 2015). Yu and so on, based on LCA, achieved carbon emissions of a CCS study. The results showed that carbon dioxide capture technology could reduce carbon dioxide emissions by about 80% during the whole generation life cycle (Fisk et al., 2013).

To sum up, there are many research achievements on carbon emissions, but the research on carbon emissions includes three aspects: carbon emission inventory estimation, carbon emission and socioeconomic relationship research, and carbon footprint research. However, there are few studies on carbon reduction methods based on carbon balance method and B-Wilson method. Therefore, based on the above research situation, in accordance with the basic principle of explosive, the calculation method of carbon emission factor of explosive is put forward in view of the way of carbon arrangement in open pit coal mine: carbon balance method and B-Wilson method, and the carbon emission factor of common explosive in open pit coal mine is calculated.

## 3. Methods

### 3.1 Construction of preliminary calculation model of carbon emission in open-pit coal mines

Based on the preliminary estimation method of carbon emission in open-pit coal mines and combined with the carbon emission sources in the production process of open-pit coal mines, a preliminary calculation model of carbon emission in open-pit coal mines is constructed as follows: E=ZE+JE

The specific value is determined by the power supply mode of open-pit coal mines. If it comes from a power grid, i=1, then the carbon emission factor of the power grid is adopted; if the power is a combination of self-generating electricity and purchased electricity, i=2, then the carbon emission factor of self-generating electricity is calculated. The carbon emission calculation method of open-pit coal mines based on production links is analyzed around the main production links. The production is divided into seven links: perforation, blasting, mining and loading, crushing, transportation, dumping and assisting. The results obtained by this method and the preliminary carbon emission estimation method of open-pit coal mines should be kept closed, so other carbon emission sources other than these seven production links need to be added. Figure 1 is the comparison of the two methods. As can be seen from Figure 1, other carbon emission sources include effusion and autoignition. Therefore, the model divided the coal emission in open-pit coal mines into nine links for accounting.

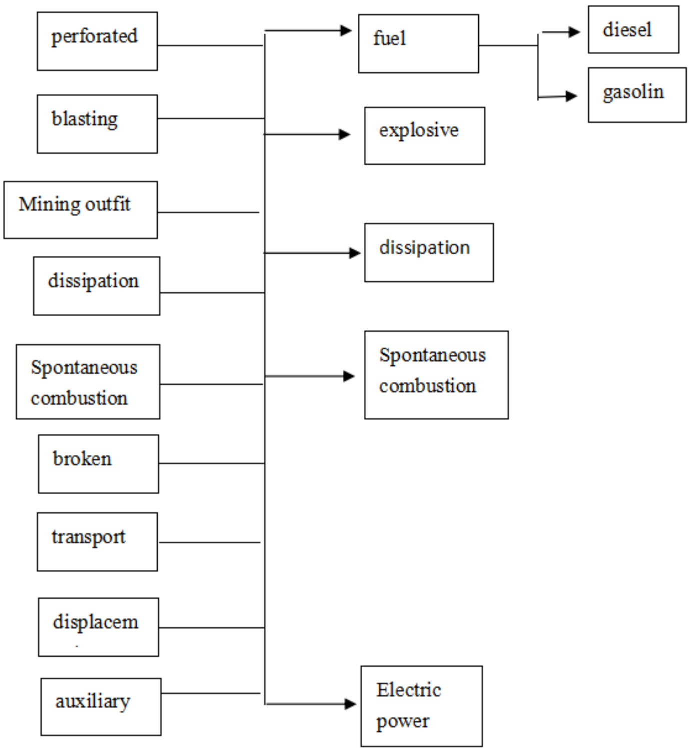


*Figure 1: A closed graph of carbon emission sources in two open-pit carbon emission accounting methods*

The energy consumption of the steel rope impact perforator is electric power. The drive of down-the-hole drill is divided into electric down-the-hole drill and pneumatic down-the-hole drill. The energy consumption is respectively electric power and diesel oil. The energy consumption of rotary drill is electric power and the energy consumption of cone drill is electric power or diesel oil, of which electric power prevails. (Carbon emission source identification of perforation link is shown in Table 1)

*Table 1: Carbon emission source identification of perforation*

| Rig type | Carbon source | Direct source/indirect source |
|---|---|---|
| Steel cord percussion punch | Electric power | indirect |
| Electric submersible drill | Electric power | indirect |
| Pneumatic diving drill | diesel | directly |
| Rotary drill | diesel | directly |
| Rotary drill | Electric power | indirect |
| Rotary drilling rig | diesel | directly |
| Rotary drilling rig | Electric power | indirect |

**3.2 Carbon emission source identification in open-pit coal mines**

The research on carbon emission calculation in open-pit coal mines should start from the analysis of carbon emission source. Carbon emission sources are generally divided into direct emission sources, indirect emission sources and other indirect emission sources. For open-pit coal mines, the direct carbon emission source refers to the carbon emission caused by each production link of open-pit coal mines. The indirect carbon emission source refers to some emission sources owned or controlled by other companies, such as outsourced electric power so as to satisfy the operation of open-pit coal mines. Other indirect emission source refers to employees' commuting. In this study, only direct and indirect carbon emission sources in open-pit coal mines are counted. From analyzing the production process of open-pit coal mines, the source of greenhouse gas in open-pit coal mines mainly has five aspects: 1. carbon emission caused by fuel consumption, such as consumption of diesel oil and gasoline; 2. greenhouse gas released by the chemical reaction of explosive in the blasting link; 3. effusion of some greenhouse gases in the mining process of open-pit coal mines; 4. carbon emission caused by uncontrolled autoignition in open-pit coal mines; 5. carbon emission caused by indirect carbon emission source—electric power. The carbon emission sources in open-pit coal mines are summarized as five aspects, such as carbon emission caused by fuel oil (especially diesel oil, gasoline), carbon emission caused by explosive explosion, carbon emission caused by effusion during mining, carbon emission caused by uncontrolled autoignition and carbon emission caused by electric power. Five carbon emission sources are referred to as fuel, explosive, effusion, autoignition and electric power.

**3.3 Determination of carbon emission factors in open-pit coal mines**

The explosive blasting in the blasting link in open-pit coal mines belongs to chemical explosion. The chemical components of explosives are mainly carbon, hydrogen, oxygen and nitrogen. Among them, carbon and hydrogen are combustible elements, oxygen is a combustion-supporting element, and nitrogen is an oxygen carrier. The process of explosive explosion is a rapid oxidation-reduction process between combustible element and combustion-supporting element. The composition and quantity of explosive products are affected by many factors, including type and chemical composition of explosives; explosive explosion reaction conditions, such as temperature, pressure, charge conditions, detonation conditions and density; mixing uniformity of mixed explosives. Therefore, it is extremely complex and difficult to accurately determine the explosive reaction equation or the composition of explosive products. There are two ways to calculate the carbon emission factors of explosives. The first way is that carbon elements in explosives are oxidized to carbon dioxide after primary and secondary reaction. The carbon dioxide emission can be calculated by the carbon element as long as the general chemical formula of the explosive is written, and it is named as the carbon balance calculation method.

The Brinkley-Wilson method, abbreviated as B-W method, is a method often used to determine the reaction equation. The principle of product determination is energy first. H is generated into H2O first, the remaining O is generated into CO first, if O is still remaining, CO is then produced into CO2. And N is presented in molecular state N2 (i.e. H2O-CO-CO2).

In addition, for the mixed explosives containing the metal elements K, Na, Ca, Mg, and Al, it is determined that the metal element generates metallic oxide first, and the remaining O is distributed to C, H, O, and N according to the B-W method. If explosives still contain strong oxidizing elements such as F and Cl, they are first oxidized to metal chlorine (fluorine) or chlorine (fluorine) hydrogen, and the remaining O is treated in the same manner as the metal element. For the first type of explosive which belongs to normal oxygen equilibrium or zero oxygen equilibrium, the carbon element is oxidized to carbon dioxide, and the calculation method is consistent with the carbon balance method. For the second kind of explosive that belongs to negative oxygen balance, the priority order of oxygen distribution is different, and the calculation results are different by different methods. (The carbon emission factors of some commonly used explosives in open-pit coal mines are shown in Table 2)

*Table 2: Carbon emission factors of some commonly used explosives in open-pit coal mines*

| Explosive name | Oxygen balance | Types of explosive | $EF_b$(t/t) method of carbon balance | B-Wilson |
|---|---|---|---|---|
| Ammonium nitrate explosive | Oxygen | A class | 0.2629 | 0.2629 |
| Rock ammonium nitrate explosive | Oxygen | A class | 0.2335 | 0.2335 |
| No.2 rock ammonium nitrate explosive | Oxygen | The second | 0.2222 | 0.2222 |
| Anfo explosives | Negative oxygen | | 0.1986 | 0.1986 |
| Anti - ammonium oil explosive | Oxygen | A class | 0.1854 | 0.1854 |
| Open ammonium oil explosive | Negative oxygen | The second | 0.2269 | 0.2269 |
| Ammonium-leached explosive | Oxygen | A class | 0.2105 | 0.2105 |

## 4. Results and Discussion

### 4.1 Preliminary calculation of carbon emission in open-pit coal mines with different production process systems

In order to study the differences of carbon emission in open-pit coal mines with different production process systems, a representative open-pit coal mine is selected as the research object. In conclusion, four open-pit coal mines in Anjialing, Yimin River, Heidaigou and Buzhaoba are selected as the research objects in this section. Table 3 shows the basic information of the four open-pit coal mines. The preliminary carbon emission estimation model of the open-pit coal mines is used for accounting and analysis. Combined with the basic statistical data of three open-pit mines, the carbon emission of open-pit coal mines with different production processes since 2000 is taken as the research object. Then the carbon emission in different open-pit coal mines is quantitatively compared so as to explore the advantage interval of different mining process systems. (Representative open-pit coal mines with different process systems are shown in Table 3)

*Table 3: Representative open-pit coal mines of different process systems*

| Open pit mine | Design production scale (Mt/a) | Stripping process | Coal mining process |
|---|---|---|---|
| The min river | 11 | intermittent | semi-continuous |
| AnGuLing | 20 | intermittent | semi-continuous |
| Black adai ditch | 21 | Continuous/semicontinuous/inverted heap | semi-continuous |
| Cloth bog dam | 13 | intermittent | semi-continuous |

### 4.2 Comparison of carbon emission of different production processes

The analysis of open-pit coal mines with different production processes is mainly based on the comparison of optimal, worst and overall levels of carbon emission. (Table 4 shows the carbon emission levels in different open-pit mines)

*Table 4: Carbon emission levels of different open pits*

| Open-pit coal mines | Unit stripping carbon emission($10^{-4}$t/m$^3$) | | | Tons of coal carbon emissions($10^{-4}$t/t) | | |
|---|---|---|---|---|---|---|
| | The optimal level | The worst level | Total level | The optimal level | The worst level | Total level |
| AnGuLing | 24.04 | 36.96 | 29.09 | 76.21 | 166.24 | 123.03 |
| The min river 1 | 28.87 | 72.37 | 42.07 | 75.24 | 203.13 | 111.64 |
| The min river 2 | 18.87 | 27.53 | 21.74 | 65.59 | 76.75 | 70.41 |
| Black adai channel 1 | 14.43 | 19.78 | 17.70 | 71.14 | 131.38 | 88.16 |
| Black adai channel 2 | 20.37 | 20.83 | 20.68 | 83.14 | 98.47 | 91.72 |
| Cloth bog dam | 22.22 | 22.22 | 22.22 | 58.32 | 58.32 | 58.32 |

### 4.3 Comparison of carbon emission levels for the same production process system

According to statistics, about 90% of the stripping technology in China's open-pit coal mines adopts single bucket-truck intermittent technology, and about 70% of the mining technology adopts semi-continuous technology. When the production process system of open-pit coal mines is different, the equipment used in perforation, mining, crushing, transportation, dumping and auxiliary links in different, which results in different energy consumption. Table 5 shows energy consumption types according to different links of the process system. Compared with other process systems, draglines stripping technology combines mining, and transportation with dumping so as to improve the electric power utilization rate. It can be seen from Table 5 that the continuous process reduces the crushing link with good continuity, large unit production capacity and high energy use efficiency compared with the discontinuous process and the semi-continuous process.

*Table 5: Energy consumption table of open-pit coal mining process*

| process | perforated | Mining outfit | broken | transport | displacement | auxiliary |
|---|---|---|---|---|---|---|
| Continuous process | electricity | Electric/diesel | - | diesel | diesel | Diesel/gasoline/electricity |
| Semicontinuous process | electricity | Electric/diesel | electricity | Electric/diesel | diesel | Diesel/gasoline/electricity |
| Continuous process | electricity | electricity | - | electricity | electricity | Diesel/gasoline/electricity |
| Pull bucket shovel dump process | electricity | electricity | - | electricity | electricity | Diesel/gasoline/electricity |

## 5. Conclusions

Based on the case study of open-pit mine, the application of carbon balance method and B-Wilson method in carbon emission reduction is analyzed. This study finds that there is a close relationship between carbon emission and stripping technology and coal mining system. When the stripping technology of open-pit coal mines is superior, the carbon emission is relatively good. If different mining process systems of open-pit coal mines are the same, the unit carbon emission will decrease accordingly when the coal mining quantity and stripping quantity increase gradually. In terms of coal production characteristics, indirect and direct carbon emission sources are the main carbon emission sources in open-pit coal mines. In the production process of open-pit coal mines, the carbon emission control of crushing station must be strengthened, and the carbon emission calculation model is used to analyze the way of carbon emission reduction of coal mines. In the course of this study, part of research results are discussed due to the limited length of the literature and the rest of the data isn't conducted in-depth study. Through this study, it can be concluded that the carbon balance method and B-Wilson method have certain research value in way of carbon emission reduction of coal mines.

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### Reference

Davis S.J., Caldeira K., 2010, Consumption-based accounting of co2 emissions, Proceedings of the National Academy of Sciences of the United States of America, 107(12), 5687-92, DOI: 10.1073/pnas.0906974107

Fisk J.P., Hurtt G.C., Chambers J.Q., Zeng H., Dolan K.A., Negrónjuárez R.I., 2013, The impacts of tropical cyclones on the net carbon balance of eastern us forests (1851-2000), Environmental Research Letters, 8(4), 925-932, DOI: 10.1088/1748-9326/8/4/045017

Kennedy C., Steinberger J., Gasson B., Hansen Y., Hillman T., Havránek M., 2010, Methodology for inventorying greenhouse gas emissions from global cities, Energy Policy, 38(9), 4828-4837, DOI: 10.1016/j.enpol.2009.08.050

Li W., Younger P.L., Cheng Y., Zhang B., Zhou H., Liu Q., 2015, Addressing the co 2, emissions of the world's largest coal producer and consumer: lessons from the haishiwan coalfield, china, Energy, 80(C), 400-413, DOI: 10.1016/j.energy.2014.11.081

Mózner Z.V., 2013, A consumption-based approach to carbon emission accounting – sectoral differences and environmental benefits, Journal of Cleaner Production, 42(3), 83-95, DOI: 10.1016/j.jclepro.2012.10.014

Yu S., Wei Y.M., Guo H., Ding L., 2014, Carbon emission coefficient measurement of the coal-to-power energy chain in china, Applied Energy, 114(2), 290-300, DOI: 10.1016/j.apenergy.2013.09.062

Zhang L.X., Wang C.B., Bahaj A.S., 2014, Carbon emissions by rural energy in china, Renewable Energy, 66(3), 641-649, DOI: 10.1016/j.renene.2014.01.005

Zhou Y., Li Y.P., Huang G.H., 2015, Planning sustainable electric-power system with carbon emission abatement through cdm under uncertainty, Applied Energy, 140, 350-364, DOI: 10.1016/j.apenergy.2014.11.057