Building materials production process carbon emission analysis and optimization of Low-Carbon manufacturing

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Abstract: In order to study the carbon emission characteristics of building materials production process, the material, energy consumption and carbon emission characteristics of building materials production process were analyzed, the carbon emission boundary conditions of building materials production process were proposed, and the carbon emission calculation model of building materials production process was established. Based on the data provided by a manufacturing company, we calculated and analyzed the carbon emissions of the building materials production process, identified the waste in this production line, and proposed an analysis method based on lean thinking to propose corresponding improvement measures from the production management level to address the waste problems, Reduce non-value-added carbon emissions caused by waste, thus improving the lean level of gear production lines and transforming to low carbon manufacturing.

1 Introduction

China has set the goal of striving to achieve carbon peaking by 2035 and carbon neutrality by 2060. Carbon emissions from the building materials industry account for 35% of carbon emissions from the three major industries of iron and steel, chemical and building materials. The building materials production manufacturing industry is managed in a sloppy manner, with insufficient lean control of carbon emissions. Building materials production and manufacturing industry, as the major energy consumer in China's manufacturing industry, will become the main target of emission reduction tasks (EPA, 2017). Many scholars at home and abroad have conducted a lot of research on carbon emissions in the manufacturing process of product components, and some achievements have been made, and emission reduction strategies have been formulated (Chen YL, 2011; Paju M, Heilala J, Hentula, et al., 2010). However, these studies only start from the industrial level, and the carbon emission effects of different industrial structures vary greatly, and further research and analysis on the energy consumption and carbon emission of the production process of building materials are needed.

2 Carbon emission analysis of Building materials production process

2.1 Carbon emissions from raw material preparation processes

The raw material preparation process needs to consume materials and energy, mainly gangue, shale and some auxiliary materials, crushing, screening and air separation process to consume electricity, oil and other resources. The raw material preparation process mainly has electric energy, fuel oil and other energy consumption, which will produce carbon emissions (Maksyutov S, Eggleston S, Woo J H, et al., 2019).

2.2 Building materials production process carbon emissions

In the production of building materials, various material input and output, energy conversion and consumption, waste emission and disposal generate a large amount of carbon emissions. The carbon emission boundary of the building materials production process can be set as the whole process from material input to building materials product output (Zhao ZJ, Zhang Peng, Zhao MN, et al., 2017). The production of building materials mainly relies on mechanical equipment; therefore, the higher the energy consumption of equipment in the production process of building materials, the more carbon emissions. The carbon emissions of the whole process

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of building materials production mainly include: carbon emissions from energy extraction, raw material handling, and material transportation, carbon emissions from the combustion of fossil fuels involved in each process and carbon emissions from material consumption (Liu Q, Tian Y, John W S, et al., 2015).

3 Carbon emissions of production processes

3.1 Production process production events and energy consumption classification

Production Event (PE) is an essential element to describe the production process and is an abstract description of the production activity, where the dynamics of the production system is driven by production events (Cao HJ, Li HC, Song SL, et al., 2011). In this paper, a production event is defined as a variable that affects energy consumption. According to the basic theory of lean thinking, production events are classified as Value-added Event (VAE) and No-value-added Event (NVAE) (Li HC, Cao HJ, 2015). A value-added event is defined as a production event that generates value, and a non-value-added event is defined as a production event that does not generate value, and the value of the classification criteria specifically refers to the value purchased by external customers. Non-value-added events can be divided into two categories: Necessary NVAE (N-NVAE) and Unnecessary NVAE (U-NVAE). For the purpose of bottleneck identification, non-necessary NVAEs are further divided into Internal Non-Necessary NVAE (U-NVAE) and External Non-Necessary NVAE (E-U-NVAE)6. The classification process for production events is shown in Figure 1.

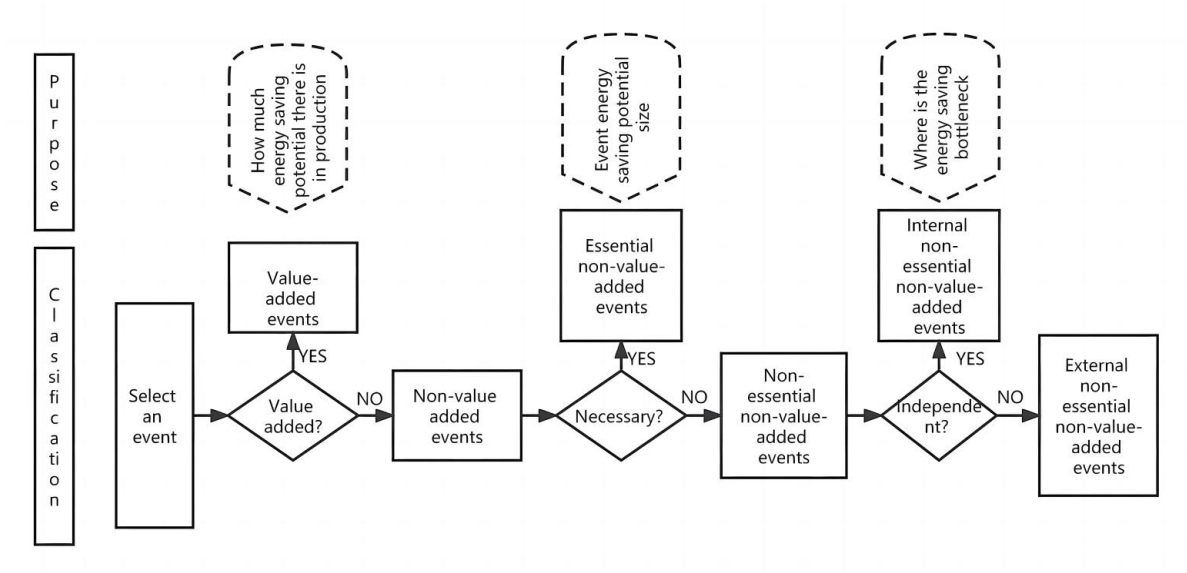

Figure 1. Classification of production events

3.2 Carbon emission calculation

There are three methods for calculating carbon emissions, which are the actual measurement method, the material balance method and the emission factor method (Hao QT, Huang MX, Bao Gang, 2011). In this paper, we use the emission factor method, which is the statistical average of the amount of greenhouse gases emitted from the production of a unit of product (Müller E, Stock T, Schillig R, 2014), and the calculation formula is as follows:

$$C = Q \times EF \tag{1}$$

Where: C is the carbon emission per unit of product produced; Q is the consumption of energy; EF is the carbon emission factor of energy. In the manufacturing industry, each energy consumption data can be obtained through process meters and combined with the corresponding carbon emission factors to obtain the total carbon emissions.

Combined with the classification of production events presented in 2.1, the carbon emissions of a manufacturing system are calculated using the formula:

$$CE_{total} = CE_{va} + CE_{nva} \tag{2}$$

Where: CE_{total} is the total carbon emissions of the product produced ($kgCO_2e$); CE_{va} is the value added carbon emissions of the product produced ($kgCO_2e$); CE_{nva} is the non-value added carbon emissions of the product produced ($kgCO_2e$).

Among them, the quantitative calculation formula of value-added carbon emission is:

$$CE_{va} = \sum_{i=1}^{N} CE_{va_i} = \sum_{i=1}^{N}\sum_{j=1}^{X}\left[Q_{mt_{ij}} \cdot CEF_{mt_{ij}}\right] + \sum_{i=1}^{N}\sum_{i=1}^{S}\left(E_{idle_{ij}} + P_{ij} \cdot t_{va_{ij}}\right) \cdot CEF_{elec} \tag{3}$$

Where: CE_{va_i} is the value-added carbon emissions of process i ($kgCO_2e$); $Q_{mt_{ij}}$ is the mass of raw material j consumed in process i (kg); $CEF_{mt_{ij}}$ is the carbon emissions of raw material j consumed in process i ($kgCO_2e/kg$); $E_{idle_{ij}}$ is the no-load energy consumption of the l-type equipment used in the i-th

process(kwh); P_{ij} is the rated power of the lth equipment used in the i-th process (kw); $t_{va_{ij}}$ is the effective working time (value-added time) of the i-th equipment used in the i-th process (h).

Non-value-added carbon emissions are quantified as follows:

$$CE_{nva} = \sum_{i=1}^{N} CE_{nva_i} = \sum_{i=1}^{N}\sum_{j=1}^{X}\left[Q_{mt_{ij}} \cdot EF_{mt_{ij}}\right] + \sum_{i=1}^{N}\sum_{i=1}^{S}\left(E_{idle_{ij}} + P_{ij} \cdot t_{nva_{ij}}\right) \cdot EF_{elec} + \left[\sum_{w=1}^{R} E_{tr_w} + \sum_{z=1}^{U} E_{in_z}\right] \cdot EF_{elec} \quad (4)$$

Where: CE_{nva_i} is the non-value-added carbon emissions of the i-th process (kgCO_2e); $t_{nva_{ij}}$ is the inefficient working time (non-value-added time) of the lth piece of equipment used in the i-th process (h); E_{tr_w} is the energy consumption of the product transported over the wth distance (kw); E_{in_z} is the energy consumption of the product stored in the z-th process (kw).

4 Case Study

4.1 Engineering Background

This paper takes the production process of coal gangue sintered bricks of an enterprise as the research object, the sintered brick production line according to the working time of 300 days per year for two-shift production, the working time of the production line is 8h/shift. The daily production of coal gangue sintered bricks can reach 260,000, with an annual output of 80 million standard bricks. Power data is obtained through direct or indirect measurements, technical specifications, etc., and time data is obtained through production reports, maintenance records, equipment logs, etc. The rest of the production data is obtained through production planning, bill of materials, scheduling lists and production reports.

4.2 Carbon emission modeling of sintered b ricks

The raw material of sintered bricks is solid waste gangue, and the fuel used in roasting process is coal sludge winded from gangue, so the carbon emission of material and fuel is zero. The production process is the traditional process layout, a total of sawing, crushing, homogenization, mixing, pressing, cutting, drying, sintering, inspection of nine key processes, the production process is shown in Figure 2.

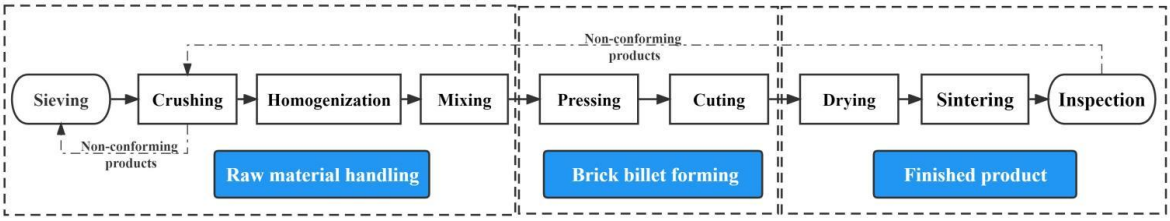

Figure 2. Sintered brick process flow

According to the brick making process, the power consumption of the whole plant is divided into two main parts, value-added power consumption and non-value-added power consumption. The value-added energy consumption mainly includes the operation of the molding process and the drying fan, while the non-value-added energy consumption includes the raw material preparation and other parts (such as the lighting of the plant). After research and reference to the empirical values of literature (Ng R, Low J S C, Song B, 2015), the carbon emission factor of electrical energy is 0.974 KgCO_2e/kWh and the carbon emission factor of diesel fuel is 3.168 KgCO_2e/kg.

The energy consumption of coal gangue sintered brick production is shown in Table 1.

Table 1. Production status of the workshop

Indicators	Numerical value	Unit
Total production time	22.6	h
Total value-added production time	2.8	h
Total non- value added time	19.8	h
Comprehensive energy consumption	17160	h
Total value-added energy consumption	12355.2	kWh
Total non-value-added energy consumption	4804.8	kWh
	218.4	kWh

According to the production energy consumption in Table 1, the carbon emission stream data can be derived based on equation (2)(3)(4) and the corresponding carbon emission factors, and the total carbon emission is calculated as 16,942 kgCO_2e, of which non-value-added carbon emission is 5,242 kgCO_2e, and the non-value-added carbon emission accounts for one-third, which indicates that there is more serious production waste and carbon emission impact in this production line.

4.3 Carbon emission analysis of sintered br ick production process

Combined with the lean production management idea of eliminating the seven types of waste, tsintered brick production process can be analyzed to specifically find waste problems and eliminate the impact of carbon emissions caused by waste (Herrmann C, Thiede S, Stehr J, et al., 2008).

① There is overproduction. The production line calculates the planned production quantity based on the market demand forecast and work-in-process inventory for a certain period, resulting in production exceeding the customer's demand, causing waste such as inventory occupancy and raw material consumption.

② Excessive work-in-process inventory. Excessive WIP leads to the accumulation of WIP inventory between processes and the prolongation of production cycle. More than 90% of the non-value-added time is caused by excessive WIP inventory, and there is inventory waste.

③ There is unnecessary turnaround transportation. Products are transported longer distances and more times in the logistics turnaround process, which wastes a lot of personnel and resources.

In summary, this gangue sintered brick production line has manufacturing excess waste, inventory waste, transportation waste, processing waste.

4.4 Carbon emission optimization of sintere d brick production line

The following implementation countermeasures are taken for the waste existing in the above analysis:

① Determine the production tempo of sintered bricks and determine the fixed beat process. The production rhythm is grasped by customer demand, and the drying-roasting unit controls the sintered brick value stream production process as the last continuous flow unit downstream according to the rules for the selection of the fixed beat process.

② Establish an inventory supermarket. Establish a raw material supermarket and rely on extraction kanban to pull production between processes. At the same time, the finished goods supermarket is set up after the drying-roasting unit to closely connect the front and back operations.

③ Combining inspection processes. The establishment of sieving-crushing-aging and drying-baking production units allows operators to better control the quality of sintered bricks and to inspect them directly within the unit, and the inspection processes can be combined in a continuous flow unit to reduce unnecessary handling and the accumulation of in-process products.

The comparative effect before and after improvement is shown in Table 2.

Table 2. Comparison of metrics before and after sintere d brick production improvement

Indicator	Before Improvement	After Improvement
Value-added time(h)	2.8	4.4
Non-value-added time (h)	19.8	10.8
Value-added carbon emi ssions($kgCO_2e$)	11700	10642
Non-value-added carbon emissions($kgCO_2e$)	5242	3047
Total Carbon Emissions ($kgCO_2e$)	16942	13589

As shown in Table 2, the combination of inventory supermarket and Kanban not only eliminates overproduction products and work-in-process inventory, but also greatly reduces the time of work-in-process inventory, greatly reduces production lead time, eliminates 572$kgCO_2e$ carbon emissions caused by inventory waste; eliminates 1623$kgCO_2e$ carbon emissions generated by transportation between processes; reduces non-value-added carbon emissions from 5242$kgCO_2e$ to 3047$kgCO_2e$.

5 Conclusion

(1) Through the analysis of the carbon emission of the production process of building materials, it can be seen that the carbon emission of the production process of building materials mainly comes from the consumption of materials and energy in the production process, and the carbon emission of the production process of building materials can be reduced by avoiding overproduction and reducing handling.

(2) A carbon emission model was developed. From the perspective of non-value-added characteristics, a carbon emission reduction method is proposed, and waste is analyzed using lean thinking to provide a basis for eliminating waste and improving environmental efficiency from the production management level.

(3) A carbon emission optimization method based on lean production ideas is proposed. It reduces the material and energy consumption and processing cost of building materials production, and the production environment is clean and protects the safety and health of operators.

Disclosure statement

The author declares no conflict of interest.

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