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Carbon Emission Calculation for Heat Treatment Industries

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Abstract: Carbon emissions calculation in the heat treatment industry is not only a necessary measure to address climate change, but also important to promote sustainable development, enhance international competitiveness, and fulfill social responsibilities. Firstly, accurate carbon emission data is the basis for formulating reasonable carbon emission reduction policies. It not only helps the government or industry association to introduce effective measures to control or reduce carbon emissions; but also standardizes the reporting of enterprises in the industry through unified accounting methods, ensuring the accuracy and transparency of data, which is crucial for internal self-regulation and external supervision of the industry. Secondly, a verification system is established to provide a solid foundation for the start and operation of the global carbon emission trading market. This helps to ensure the authenticity and accuracy of the data of enterprises participating in the transaction. The framework of this calculation is derived from Chinese group standard T/CHTA 009-2022 "Carbon Emission Accounting Method for Heat Treatment Industry" issued by the China Heat Treatment Industry Association. In the future, as the collected data becomes more complete, scholars will use mathematical and big data methods to simulate and verify, thus correcting the mathematical formula, making the carbon emission formula more reasonable.

Key words: Carbon emission calculation, heat treatment industry, standardized carbon emission, simulation verification

1. Introduction

As the world grapples with the undeniable impact of climate change, industries are under increasing pressure to reduce their carbon footprints. In particular, the heat treatment sector has garnered attention for its significant contribution to greenhouse gas emissions. To address this, it is crucial for these industries to accurately assess their carbon footprint. This assessment serves as a roadmap for identifying areas of improvement, implementing targeted strategies, and paving the way for a more sustainable future.

To standardize the heat treatment process and set the stage for data collection, the industry saw the release of T/CHTA009-2022 "Carbon Emission Accounting Methods for Heat Treatment Industry" on Dec. 1, 2022, with implementation following on Jan. 1, 2023 by the CHTIA (China Heat Treatment Industry Association). Key players in the drafting included the Beijing Mechanical and Electrical Research Institute Co., Ltd., Guangdong Shichuang Metal Technology Co., Ltd., and Jiangsu Fengdong Thermal Technology Co. This standard, drawing on domestic and international benchmarks, such as the ISO 14064 greenhouse gas series of standards and GB/T 32150-2015 Greenhouse Gas Emission Accounting and Reporting for Industrial Enterprises General Principles, outlines the scope and reporting requirements for carbon emissions in the heat treatment sector. This systematic and concise approach aligns with global standards, positioning the heat-treatment industry for a sustainable future.

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2. Literature Review

Under the current requirements of “carbon peak and carbon neutrality”, it is necessary to account for the carbon emissions of each industrial sector and ensure the accuracy of the data through verification, and then to achieve the “elimination of the best and the worst” through evaluation, and to promote the application of low-carbon technologies to reduce carbon emissions, as well as to monitor and manage carbon emissions through the application of financial management services to realize cost reduction and efficiency in the unified carbon market across the country and the world. Through monitoring and controlling management of carbon emissions, the application of financial management services, etc., in the national and even the world’s unified carbon market, we can achieve cost reductions and efficiency gains, and ultimately achieve carbon peaks, carbon neutrality, and a beneficial environmental and economic situation. Currently, there is an urgent need to compile relevant standards for greenhouse gas emission accounting in all industries as soon as possible, conduct greenhouse gas emission accounting and monitoring, accurately and precisely map out the actual situation, account for carbon emission figures, and provide a basis for carbon emission reduction and evaluation. Therefore, the most urgent and fundamental task is to formulate greenhouse gas emission accounting standards for the heat treatment industry.

Heat treatment is a very important key process in the manufacturing process of mechanical products, as it gives full play to the potential of the material to ensure the parts and products of the intrinsic quality and service life; to improve the product grade is extremely important; at the same time, heat treatment has a high energy consumption, the environment and safety have a significant impact on the processing technology; heat treatment of electricity accounts for approximately 25% of the machinery manufacturing industry to 30%, to ensure product quality, production safety, product quality, and safe production based on realizing energy savings and emission reduction of cleaner heat treatment production, the mechanical industry product performance and quality, reduce costs, improve production efficiency, save energy, and reduce environmental pollution; all play a significant role.

3. Methods

In the standard document, experts define a formula to guide companies in the industry to calculate carbon emissions, and after collecting enough data, use big data algorithms and mathematical principles to verify the reasonableness of the formula, the formula definition and verification process of the standard document are shown in Figs. 1 and 2.

In the standard document (T/CHTA009-2022), experts define “carbon emissions” in the heat treatment industry as direct and indirect emissions of carbon dioxide during the processing and production of heat treatment units.

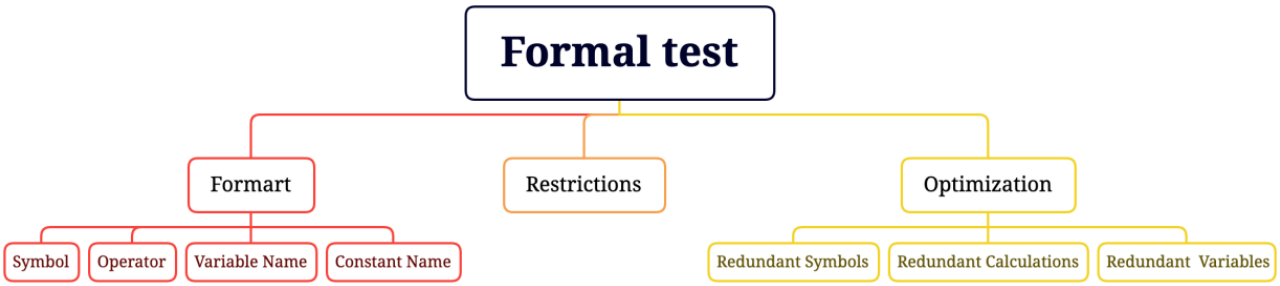

Fig. 1 Formal test components.

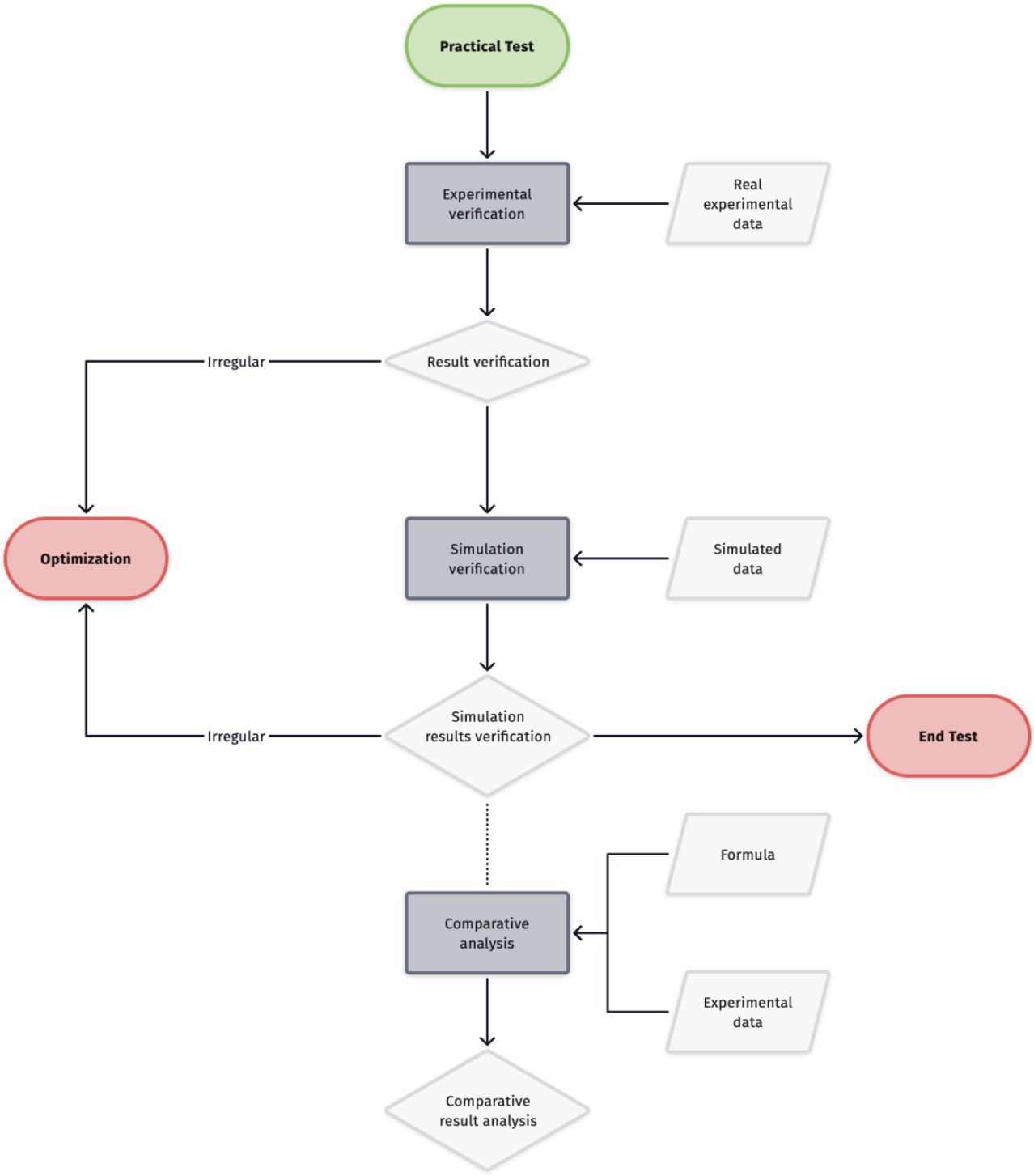

Fig. 2 Practical test process.

The standard defines “direct emissions” as carbon emissions from burning fossil fuels (e.g., natural gas) during heat treatment processes, as well as other carbon emissions resulting from chemical reactions or physical changes. China’s heat-treatment industry consumes approximately 400 million cubic meter of natural gas and liquefied petroleum gas. Natural gas is a low-carbon clean fossil energy source, with the promotion of premixed secondary combustion, oxyfuel combustion, and other advanced technologies. China’s heat

treatment industry, natural gas, and liquefied petroleum gas produce direct emissions of carbon dioxide, and there is still a certain amount of space for emission reduction. China's heat-treatment industry consumes more than 100,000 tons of quenching oil per year, strengthens quenching oil recovery and regeneration, and facilitates oil recycling and reuse.

The standard defines "indirect emissions" as carbon emissions generated by emission sources held or controlled by other units, which are caused by the heat treatment processing and production of this heat treatment unit. Here usually refers to the heat treatment production process of electricity consumption, heat treatment production process in China's average power consumption of 600 kWh/t or so, part of the above-scale enterprises heat treatment average unit power consumption of 400 kWh/t or less, according to an average of each ton of parts heat treatment to save 200 kWh of power consumption calculation; the national heat treatment industry is now the annual power savings of up to 10 billion kWh, or approximately 4 billion tons of standard coal, only to save power to reduce carbon dioxide emissions of 7 million tons per year. Annual power savings reduced carbon dioxide emissions by only 7 million tons.

The carbon emissions from heat treatment units are fell into two main categories:

(1) Direct carbon emissions per unit, which refer to carbon dioxide emissions generated by burning fossil fuels, such as natural gas, for combustion, also fall into this category, as does carbon dioxide generated by the heat treatment carburizing process, which generates carbon dioxide emissions because of the quenching and cleaning media consumed.

(2) Carbon emissions per unit of medium refer to the electricity used directly by the thermal processing unit or the carbon dioxide emissions resulting from the use of the power medium.

4. Accounting for Direct Carbon Emissions

The assessment of carbon emissions from heat treatment units should adhere to the principles of science, accuracy, and fairness and minimize bias and uncertainty in the assessment. The standard stipulates that direct carbon emissions from heat treatment units are the sum of emissions from fossil fuel use and the production process.

Table 1 summarizes two common categories of carbon emissions. The total carbon emissions of heat treatment units are the sum of those two categories, direct and indirect emissions, with direct emissions to be accounted for and evaluated individually according to the source, and indirect emissions to be accounted for and evaluated in accordance with the sum of the enterprise's purchased electricity (or other direct power sources).

The fossil fuel emissions C_e per unit of heat treatment are mainly calculated based on the fuel consumption of the fuel type Q_i, the low-level heating value of the fuel F_i, the carbon content per unit of calorific value c, and the carbon oxidation rate, which is calculated in accordance with Eq. (1):

$$C_e = \sum_{i=1}^{n} \left(Q_i * F_i * c_i * f_i * \frac{44}{12} \right) \quad (1)$$

C_e: Total carbon emissions from fossil fuels, t

Q_i: The consumption of fuel i, where i is the fuel type, t

F_i: Low-level heating value of fuel i, TJ/t

f_i: Carbon oxidation rate of fuel i, %

c_i: the carbon content per unit calorific value of fuel i, tCO_2/TJ

Table 1 Classification of carbon emission.

Classification of carbon emissions		Examples of emissions
Direct emissions	Emissions from fossil fuel use	Emissions from combustion of fossil fuels such as natural gas
	Production process emissions	Emissions from consumed quenching and cleaning media
Indirect emissions		Emissions resulting from the direct use of electricity in the heat treatment unit or from the use of power media (e.g. industrial gases, circulating media, etc.)

Table 2 Fossil fuel use is calculated on the basis of actual calorific value.

Fuel type	Low calorific value (TJ/t)	Carbon content per unit calorific value (tC/TJ)	Carbon oxidation rate
Liquefied natural gas	0.051435	17.2	99%
Gasoline	0.04307	18.9	98%
Diesel	0.042652	20.2	98%
Anthracite	0.026344	27.4	85%

The gaseous fuels were measured using a flow meter and converted to volumetric weight in a standardized state according to the pressure and temperature. Liquid fuels are converted into weight by a container or volumetric flow, whereas solid fuels are weighed on a scale. The fuel consumption can be read by the heat treatment unit metering device, and the accuracy of the meter should generally be 0.1%-0.5% (or equivalent accuracy level).

The low-level heating values, carbon content per unit calorific value, and carbon oxidation rates of fuels commonly used in heat treatment units are listed in Table 2. Heat treatment enterprises shall, in accordance with GB/T384, GB/T11062, GB/T213, and other relevant standards, perform actual measurements of the low-level heat content of the fossil fuels used. Enterprises that do not have these conditions may use the measured data provided by suppliers in line with the above standards or adopt the recommended values in Table 2.

The standard production process emissions C_d is mainly based on the carburization process emissions C_c and quenching and cleaning process quenching and cleaning media consumed in the emission C_j calculated according to Eq. (2).

$$C_d = C_c + C_j \tag{2}$$

C_d: Emissions from production processes, t

C_c: Emissions from the carburization process, t

C_j: Emissions from quenching and cleaning media consumed during quenching and cleaning processes, t

To further calculate carbon emissions, it is important to study the emissions generated by the carburization process and the emissions generated by the quenching and cleaning media consumed during the quenching and cleaning processes.

Emissions C_c from carburization processes are mainly based on the carbon dioxide produced by the consumption of carbon-containing atmospheres in certain processes (e.g., carburization and carbon-containing atmosphere protection gas) and are calculated according to Eq. (3).

$$C_c = Q_S * S * \frac{44}{12} \tag{3}$$

Q_s: Carbonaceous atmosphere consumption, t

C_c: Emissions from the carburization process, t

S: Carbonaceous atmosphere carbon content, %

The carbon-containing atmosphere consumption with a flow meter and according to the pressure, the temperature converted to a standard state of the volume of the weight can be read by the heat treatment unit metering device, and the accuracy of the meter should generally reach 0.1%-0.5% (or equivalent accuracy level).

The emissions C_j from the quenching and cleaning media consumed during the quenching and cleaning processes were calculated based on the actual consumption Q_j and the carbon emissions c_j per unit mass of the corresponding media, calculated according to Eq. (4).

$$C_j = Q_j * c_j \tag{4}$$

C_j: Emissions from quenching and cleaning media consumed during quenching and cleaning processes, t;

Q_j: Actual consumption of quenching and cleaning media, t;

c_j: Carbon emissions per unit mass of the corresponding medium, %.

In the future, the actual consumption will be determined by the heat treatment unit itself, and the carbon emissions per unit mass of the corresponding medium will adopt relevant data from domestic and

foreign literature standards. If there are no clear data for reference, the manufacturer can provide reference values through production or the principle of conservation of elements.

For heat treatment, commonly used fuel liquefied natural gas as an example, usually liquefied natural gas with a low heating value *F* natural gas of 0.051435 TJ/t, unit calorific value of carbon content c natural gas for 17.2 tCO_2/TJ, carbon oxidation rate f natural gas for 99%, and calculated heat treatment consumption of 1 kg of liquefied natural gas directly emits carbon dioxide amount of 3.2 kg.

5. Accounting for Indirect Carbon Emissions

The standard specifies that indirect emissions from heat treatment units are carbon dioxide emissions from purchased electricity, calculated using Eq. (5).

$$C_w = E * k \quad (5)$$

C_w: Indirect emissions from purchased electricity, t

E: Purchased electricity, 104 kWh

k: Indirect carbon emission factor for purchased electricity, 9.86 tCO_2/104 kWh

Taking the electricity consumption of a heat treatment resistance furnace as an example, it was calculated that the indirect carbon dioxide emission from the heat treatment consumption of 1 kWh of electricity was 0.986 kg.

6. Carbon Emissions Assessment

Carbon emission assessment shall be carried out under normal working conditions of the heat treatment unit, statistics shall be made on a monthly, quarterly, and annual basis, and carbon emission *C* shall be calculated according to Eq. (6).

$$C = C_e + C_d + C_w \quad (6)$$

C: Amount of carbon emission, t;

C_e*:* CO_2 emissions from burning fossil fuel, t;

C_d*:* Emissions from production processes, t;

C_w*:* Indirect emissions from purchased electricity, t.

A competent carbon assessment report should contain the following elements:

- Overview of the heat treatment unit: basic information, production processes, energy consumption, changes from the previous assessment cycle;
- Identification of emission sources;
- Accounting for emissions: direct emissions, indirect emissions, data sources, summaries;
- Carbon emission findings: emission information tables, analysis and suggestions for improvement;
- Assessment unit, reporter, reviewer (signature).

7. Discussion

One of the main hurdles faced by heat-treatment industries when calculating their carbon footprint is the lack of consistent methodologies for measuring emissions. While guidelines such as the Greenhouse Gas Protocol offer a general framework for emission calculations, the specific requirements for measuring emissions from heat treatment processes can vary significantly based on factors such as the industry sector and location. This variability can make it challenging for companies to compare their carbon footprints with industry benchmarks or identify areas for improvement.

In recent years, there has been a noticeable shift towards the importance of reporting and disclosing carbon emission data. Various international governments and regulatory bodies have mandated that companies disclose their greenhouse gas emissions in their annual reports. Furthermore, both investors and consumers increasingly seek transparency in terms of environmental performance. By calculating and disclosing their carbon footprints, heat-treatment industries can showcase their dedication to sustainability, appeal to environmentally conscious clients, and stand out in a competitive market.

The newly developed “Carbon Emission Accounting Methods for Heat Treatment Industry” standard integrates the requirements of national “carbon peak” and “carbon neutral” policies. It presents practical carbon emission accounting methods specifically tailored to the current development status of China’s heat treatment industry. These methods have been field

tested, proving their effectiveness and operability. By setting a clear framework, this standard provides guidance for heat treatment enterprises in China to conduct systematic carbon emission assessments. Based on previous research work and applications, the algorithm and usage framework of "Carbon Emission Accounting Methods" would be more accurate by validating and updating the data. Because of the correctness and rationality of the formula verification, the algorithm can be used for more requirements through iterative updating.

Implementing this standard not only provides a benchmark for domestic heat treatment enterprises in terms of carbon emissions accounting and reporting but also enables a thorough assessment of current carbon emission levels. This, in turn, facilitates the optimization of industrial structures and adjustments in energy usage, and promotes the adoption of green and low-carbon technologies within the heat treatment industry. The ultimate goal is for the heat-treatment industry in China to reach its carbon peak by 2030 and achieve carbon neutrality by 2060, thereby contributing significantly to the broader effort to reduce carbon emissions.

Calculating the carbon footprint of the heat treatment industries is a critical step in reducing greenhouse gas emissions and combating climate change. By accurately quantifying their emissions, companies can identify areas for improvement, implement targeted strategies to reduce their carbon footprints, and showcase their dedication to sustainability. Although the process of calculating carbon emissions may be complex and demanding, the long-term benefits of a comprehensive approach to carbon footprint calculation far outweigh any initial challenges. By proactively measuring and reducing their carbon footprint, heat treatment industries can play a pivotal role in building a more sustainable future for future generations.

8. Conclusion

Although the carbon emission formula is not perfect yet, with the completion of data, the carbon emission calculation formula will become more accurate. Through unified accounting methods and standardized reports, the heat treatment industry can more effectively participate in the global low-carbon development process, and ultimately help achieve the global dual carbon goal together with other industries.

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