DOI: 10.54254/2755-2721/89/20241118

Pathways to Carbon Neutrality in Civil Engineering

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Abstract. With the development of the global economy and trade exchanges worldwide, urban infrastructure and industrial development have become part of the competition among countries. However, the construction industry and the production of chemical materials emit a large amount of carbon dioxide, leading to the continuous deterioration of the environment, so it is necessary to effectively reduce emissions. As a synonym for global emission reduction, carbon neutrality plays an important role in different industries, especially in civil engineering. In this paper, we start with building materials and green construction to explore the realization of carbon neutrality at the source and center of carbon emission in civil engineering. Firstly, we introduce the low-carbon production technologies of cement and steel, including calcium recycling and membrane separation technology in the cement industry, high-temperature combustion technology and carbon capture technology in steel industry. Then, we take renewable concrete as an example to discuss the emission reduction path of green building materials. Finally, it outlines how to carry out green construction, introduces assembly carbon reduction technology and energy integration system, and demonstrates the possibility of this green construction program in the case of "T&A House".

Keywords: Carbon Emissions, Carbon Capture, Building Materials, Cement, Steel.

1. Introduction

Civil engineering is a highly carbon-emitting field with an urgent need for carbon neutrality. Traditional building materials are produced with low energy efficiency, mixed production processes, and low waste utilization and recycling rates. This has led to excessive emissions from the production of traditional building materials such as cement and steel, with the cement industry, for example, accounting for a high proportion of total carbon dioxide (CO_2) emissions. Carbon capture technologies are often used in civil engineering to reduce carbon emissions. For example, sustainable concrete can be used for construction materials, and recycled materials and low-carbon materials can be utilized to help reduce carbon emissions during construction.

In construction, carbon sequestration can be considered, utilizing carbon capture and storage technologies to reduce carbon emissions from construction materials. Renewable energy sources such as solar and wind can also be used to reduce the demand for fossil fuels and lower carbon emissions. Carbon capture technology has already been applied to building materials such as steel and cement. However, overall, there is still room for improvement in the maturity of the technology. Some key technologies, such as capture efficiency, cost, and storage safety, still need improvement. The development of building materials in the field of carbon neutrality is very promising. Carbon neutrality

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has become a major industry and government focus as global concerns about climate change and environmental pollution increase. Reducing carbon emissions has become a major goal in building materials, especially in housing and infrastructure construction. Some new and emerging environmentally friendly building materials and technologies offer more possibilities for carbon neutrality. For example, the use of renewable resources or waste to manufacture building materials, the promotion of the use of carbon-neutral cement and steel, and the development of new types of energy-saving thermal insulation materials can effectively reduce the carbon emissions of building materials. In addition, carbon neutrality can be achieved by increasing the recycling rate of building materials and extending the life cycle of buildings. In the field of road construction, the use of carbon-neutral materials and technologies to reduce carbon emissions is receiving increasing attention. For example, the use of recycled rubber, recycled asphalt and other renewable materials in the production of road-building materials, as well as the adoption of technologies to extend the service life of roads and reduce energy consumption, can effectively reduce carbon emissions during the road construction and utilization phases.

Overall, as the concept of carbon neutrality continues to take hold, the future of the building materials sector will focus more on developing and applying environmentally friendly and carbon-emission-reducing technologies and materials. The use of carbon capture technology to reduce carbon emissions from producing traditional building materials and developing green building materials are particularly prominent. Therefore, this paper discusses carbon reduction technologies for the civil engineering field, building materials, and high carbon emissions during the construction phase.

2. Emission Reduction Pathways for Traditional Building Materials

Considering the excessive production emissions from traditional building materials such as cement and steel, this paper describes carbon reduction technologies in these two industries.

2.1. Optimization Technology for Emission Reduction in Cement Production

The cement industry is dominant in the building materials industry, and its high CO_2 emission is a big problem for every country. Therefore, in this paper, we first take the cement production abatement technology to elaborate the abatement path of traditional building materials.

Starting from the cement industry, we find the key technology paths for several types of carbon capture in cement according to the process characteristics [1]: Chemical absorption, Oxy-fuel combustion, Calcium cycle process, Indirect heat transfer decomposition, and Membrane separation. The process principles and characteristics of each technology are summarized below.

2.1.1. Calcium recycling technologies

Calcium recycling is a new type of recycling method, which is based on the principle that in the reverse reaction of $CaO+CO_2 \rightarrow CaCO_3$, CaO is used as an absorbent to carbonize and then decarbonized at high temperature, thus realizing the recovery of CaO. The CaO decarburizing agent in this process can meet the raw material requirement for cement clinker forging without wasting resources. The calcium recycling process adopts a gooseneck high-temperature carbonization furnace, in which more than 80% of CO_2 reacts with calcium oxide in the carbonization furnace to produce $CaCO_3$. In terms of process control, the flue gas from the rotary kiln is cooled by heat transfer through a secondary preheater to realize the solid-gas mixing of raw materials and flue gas, so as to achieve the purpose of controlling the temperature of pulverized coal entering the carbonizer. Secondly, a set of cooling equipment was set up beside the carbonization tube furnace to discharge the CaO at 920°C from the forging furnace and then mix and cool it to 600°C with 20% CO_2 from the third air and flue gas carbonization to reach the temperature requirement of CaO particles into the carbonization tube furnace. O_2 obtained from the oxygen system, then add the appropriate amount of CO_2, sent to the forging furnace, and then the raw materials of the conventional preheater, the raw materials of the preheater of the carbonization system and the $CaCO_3$ three kinds of raw materials are heated separately and decomposed at high temperatures, to achieve the separation of the flue gas of the cement kiln containing CO_2 [2].

Various countries have taken carbon emission reduction measures for cement plants. In 2020, Italy's CLENKER plan began to start the commercial transformation of carbon capture scale of $130×10^4$ t/a.A Spanish institute has established a CO_2 capture test platform based on the calcium cycle, and the efficiency of capturing CO_2 is up to 70% ~ 90% [3].

2.1.2. Membrane Separation Technology

Membrane separation technology can be used in a number of applications in the cement industry, one of the main applications being carbon capture in the clinker firing process of cement production.

In this process, membrane separation technology can be utilized to capture CO_2 from high temperature flue gases and prevent it from being emitted directly into the atmosphere. This reduces environmental pollution and allows the CO_2 to be used for other purposes, such as carbon capture and storage (CCS) or in other industrial processes. The basic principle of membrane separation is to utilize the difference in diffusion coefficients of the components within the membrane to achieve selective separation of the components under pressure, temperature, concentration, etc. This process is mainly determined by the molecular weight and diffusion coefficient of the polymer. The general membrane materials are sensitive to sulfur and cannot withstand high temperatures, so before entering the membrane separation equipment, they must undergo a pretreatment similar to that of chemical absorption. A similar study was conducted by the CEMCAP carbon capture program in 2020 [4]. It was found that CO_2 was highly selective to nitrogen, which indicates that the two gases can be easily separated; however, H2O was difficult to remove, which affected the final captured CO_2 concentration. The project proposes using typical secondary membrane filtration and low-temperature liquefaction dehydration equipment to capture high-concentration targets efficiently.

2.2. Carbon Capture and Utilization in the Iron and Steel Industry

The iron and steel industry is an important source of carbon emissions, the main sources of which are the combustion of coal, coke and other fuels, as well as carbon monoxide and CO_2 generated during the reduction of iron ore.

In this process, iron and steel industry carbon emissions come mainly from fuel combustion and reduction reactions. Therefore, the steel industry not only puts enormous pressure on the environment, but is also an important source of CO_2 emissions. The iron and steel industry's contribution to carbon emissions has led it to increase its investment in environmentally friendly technologies and equipment, thereby improving energy efficiency and reducing carbon emissions.

2.2.1. High-Temperature Combustion Technology

High-temperature blast furnaces are the core equipment for ironmaking and smelting in the iron and steel industry. In this high-temperature environment, the control of combustion is particularly important, as it requires both high efficiency and good stability and safety. In this case, the fuel is very easy to explode or incomplete combustion, seriously affecting the device's service life. Therefore, developing a new efficient combustion control method to ensure its controlled and stable operation under high-temperature conditions is a very challenging technology. Therefore, under the condition of ensuring proper oxygen supply and maintaining high temperature, insufficient combustion and exhaust gases are minimized as much as possible. At the same time, advanced sensing and monitoring technology is used to monitor the temperature, gas composition and combustion process in real time to achieve real-time regulation and optimization of the combustion process.

For the Blast Furnace Basic Oxygen Furnace (BF-BOF) production route: The BF-BOF route produces steel from raw materials such as iron ore, coal, limestone, and steel scrap. About 75% of the steel is produced by the BF-BOF route. First, iron ore is reduced to metallic iron using carbon monoxide as the main reducing agent, which is formed by the reaction of coke with oxygen. The effluent gas leaving the blast furnace consists of 22 mol% CO, 22 mol% CO_2 , 5 mol% H_2 and 51 mol% N_2 [5]. 2.5-3.5 t of blast furnace gas is formed per ton of steel. Due to the presence of CO and H_2, the blast furnace gas still contains calorific values, which are recovered by combustion to produce energy, resulting in higher CO_2 emissions, and then the iron produced from the blast furnace, also known as hot metal or pig iron, is converted to steel in the blast furnace.

2.2.2. Carbon Capture Technology

CCS is an important carbon reduction technology that aims to capture and sequester CO_2 underground to avoid its emission into the atmosphere, which causes global warming.

The method is to separate CO_2 from the combustion source, collect, purify and compress it to reduce the emission of CO_2 in the plant, and thus reduce the amount of CO_2 in the atmosphere. The technology mainly consists of pre-combustion capture technology, oxygen-enriched combustion capture technology and post-combustion capture technology [6]. In the iron and steel industry, CCS technology can treat blast furnace flue gas. Firstly, the main concentration point of CO_2 emissions from the blast furnace flue gas is identified, which is usually the blast furnace exhaust flue or chimney outlet. The selected CCS equipment is installed at the blast furnace flue or chimney outlet and captures CO_2 from the flue gas through absorption and separation processes. The captured CO_2 is further processed and converted into a stable form, such as compressed into liquid form, transported underground or injected into an underground storage layer. For the successful implementation of CCS technology, it is necessary to have a favorable geological environment and a confined environment to ensure that the sequestered CO2 does not escape into the atmosphere.

3. Emission Reduction Pathways for Green Building Materials

With the increasing awareness of environmental protection and the demand for sustainable development, green building materials have gained widespread attention and pursuit. Green building materials can not only reduce carbon emissions and resource consumption but also reduce environmental pollution, which is in line with people's pursuit of a healthy, comfortable, and sustainable lifestyle. The rapid development of urbanization and the continuous growth of the construction industry have increased the demand for energy efficiency, environmental friendliness and sustainability of buildings. Green building materials have great potential in the market because of their excellent performance and environmentally friendly features, which can meet the needs of new buildings and renovate existing buildings. The following is an example of renewable concrete to discuss low-carbon building materials.

With the rapid economic development of various countries, infrastructure is increasing rapidly, resulting in a large amount of waste concrete. Secondary recycling of waste concrete can effectively solve the problem of construction waste storage and is important for reducing carbon emissions in the construction industry, reducing energy consumption and achieving carbon neutrality.

Compared with ordinary concrete, the proportion of carbon emissions in the transportation phase of recycled concrete materials decreases, while the proportion of carbon emissions in the production phase of materials increases. The reason is that the addition of recycled aggregates to concrete can reduce the amount of natural aggregates and reduce CO_2 emissions in the process of material transportation; since the strength of recycled aggregates is much smaller than that of natural aggregates, the cement content mixed into them is increasing in order to ensure their strength, resulting in increasing carbon emissions in the preparation process.

Taking a project in Shanghai as an example, the carbon emission of recycled concrete with C30 strength grade was calculated and compared with that of ordinary concrete with the same functional unit. Under the boundary conditions, the total equivalent carbon emission under the functional unit of ordinary concrete is 122.8 kg. In comparison, the total equivalent carbon emission under the functional unit of recycled concrete with 40% recycled aggregate is 120.2 kg, with a decrease of 2.3% in carbon emission [7].

Moreover, the waste concrete has excellent carbon sequestration capacity. The composition of waste concrete was analyzed by X-ray fluorescence spectrometer, and the components of waste concrete were mainly CaO, SiO_2, MgO and Al2O3. Among them, CaO and MgO accounted for more than 50% of the composition, and CaO and MgO reacted with CO2 to form carbonates with more stable morphology and structure, realizing the efficient capture and green fixation of CO_2, which had the advantages of stable products and no risk of CO_2 leakage, indicating that the waste concrete had excellent carbon sequestration potentials [8].

4. Emission Reduction Pathways for Low-Carbon Construction

Traditional building construction, whether it is from the choice of building materials or the layout of the construction of a large amount of CO_2 emissions, the reason for this is to consider the economic reasons for the burning of fossil fuels to do not low-carbon environmental protection and the energy system of carbon emissions system is not perfect. Low-carbon construction is now a common goal to pursue. Its features mainly include efficient energy use, reduced waste generation, and low-carbon materials. The adverse impact of construction on the environment can be effectively mitigated through the introduction of advanced technology, reduction of energy consumption, rational management of construction waste, and selection of low-carbon materials in construction [9]. Two carbon-neutral solutions are described below.

4.1. Assembled Carbon Reduction Technologies

Assembled carbon reduction technology is a method of unitized combination and disassembly of building functions under one or several sets of modules to achieve high efficiency, low carbon and sustainability of buildings [10]. This method focuses on the unitization of modules and the integration of components, realizes the industrialized assembly of components, shortens the construction cycle, improves the construction efficiency, reduces the construction cost of the site, and reduces the carbon emission of the storage and transportation of building materials. Therefore, in the construction field, combined carbon reduction technology is a technology with great potential for development.

Taking the design of "T&A House" as an example, the design is based on a steel frame and subdivided into nine functional modules, such as auxiliary space, public space and recreational space, using three scales as units. The modularized design allows each module to maintain a certain scale to a certain extent, and a variety of functional combinations can be realized to adapt to different needs. The project adopts a homogeneous layout in the layout of house types to realize the flexible integration of multiple functional spaces, which meets users' needs while avoiding the carbon emissions generated in the renewal of the old city.

4.2. Energy Integration Technologies

Energy integration and carbon reduction technology is a way to maximize carbon emissions in the energy system through the comprehensive use of various energy sources and technological means. This technology focuses on the diversified use of energy, and because of the characteristics of various energy sources, through the device system, various energy resources can be effectively combined to achieve mutual efficiency and reduce the dependence on traditional energy sources.

"T&A House" utilizes the photovoltaic effect of the solar panels on the roof for carbon offsetting and reduction, and utilizes solar thermal energy for heat storage through tubular collectors to supply hot water for domestic use instead of energy consumption. In addition, in the thermal system, the water source heat pump utilizes the physical change of refrigerant (ethylene glycol) to absorb and release heat to heat and cool the water supply. It conducts radiant heat transfer with indoor air through the roof piping and buried pipes, thus realizing energy savings and emission reduction. "T&A House" utilizes the above energy-saving and emission-reduction technologies and has obtained full scores in the test items such as hot water in the competition, showing the excellent performance of energy-saving and emission-reduction technologies in energy-saving and emission reduction [10].

5. Conclusions

In the context of low-carbon civil engineering, green building materials and green construction are particularly important. Production process decarbonization technology represented by calcium cycle and membrane separation technology in the cement industry plays an important role in the carbon neutralization of building materials. Green assembly construction and energy integration systems are

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aimed at reducing carbon emissions from the storage and transportation of building materials during the construction process and improving energy efficiency, thus achieving the goal of carbon neutrality. From these two perspectives, the introduction of carbon neutrality has, to a large extent, prompted the civil engineering industry to accelerate the promotion of new technologies and materials, and to continuously explore more environmentally friendly and efficient construction methods, thereby promoting the innovative development of the industry and enhancing its overall competitiveness and sustainability.

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