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Exploration and Application Practice of Energy Conservation Theory and Method in Steel Manufacturing Process System

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Abstract: This article briefly discusses the theoretical basis and overall goals of energy conservation in the steel manufacturing process system. It is proposed that in the process of implementing system energy conservation, it is necessary to fully recognize and utilize the characteristics and functional advantages of the steel manufacturing process, pay more attention to energy quality, firmly grasp the overall goal of system optimization, focus on the integrated optimization of gas, steam, and waste heat systems, and propose the idea of constructing a "steel chemical gas electricity heating cooling multi generation system". Based on practice, the main principles, models, and effects of implementing systematic energy conservation in steel enterprises have been proposed.
Keywords: steel manufacturing process; system energy-saving; system optimization; energy conservation and emission reduction; waste heat and energy generation; polygeneration

Introduction

The energy-saving work of China's steel industry has achieved tremendous results, but the energy-saving space that traditional energy-saving models can explore is becoming smaller and smaller. In the new stage of history, it is necessary to use a systematic perspective, theory, and method to promote the efficient operation of the energy system in the steel manufacturing process through the implementation of system energy conservation, and to achieve deep level energy conservation, emission reduction, cost reduction, and efficiency increase in steel enterprises.

1 Fundamentals of system energy conservation theory

The implementation of systematic energy-saving in the steel manufacturing process requires the comprehensive application of interdisciplinary theories and methods such as systems theory and system optimization theory, thermodynamics, metallurgical process engineering, and industrial ecology.

1.1 System theory and system optimization theory

1.1.1 System theory

The core idea of systems theory is the holistic concept of the system, which considers the object of study and processing as a system, analyzes the structure and function of the system, studies the interrelationships and changes of the system, elements, and environment, and studies and resolves problems from the perspective of system optimization.

The task of systems theory is not only to understand the characteristics and laws of a system, but more importantly, to use these characteristics and laws to control, manage, transform or create a system, so that its existence and development are in line with human needs.

The basic principles of systems theory include the principles of system integrity, system hierarchy, system openness, system purposefulness, system mutation, system stability, system self-organization, and system similarity [1].

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1.1.2 System optimization theory

System optimization is the progress of system evolution, which is the improvement of the organization, structure, and function of a system under certain conditions. It can achieve minimum dissipation, highest efficiency, and maximum benefits.

The principle of system optimization is to handle the relationship between parts and the whole based on the established goals and under the principle of overall optimization. Simultaneously considering local interests, in the event of a serious conflict between the two, local interests must be subordinate to the overall interests.

The theory of dissipative structure indicates some basic prerequisites for system optimization, and synergy studies focus on discussing the internal mechanisms of system optimization.

1.2 Industrial ecology

The essence of industrial ecology is to reconstruct the economic system by imitating natural ecosystems, following the laws of material circulation and energy flow, and incorporating the economic system into the material circulation process of natural ecosystems using systematic and integrated management ideas, seeking to maximize the comprehensive benefits of the environment, economy, and society.

The industrial ecosystem pursues the linkage and coupling of various production processes within the system, from raw materials, intermediate products, waste to products, in order to achieve optimal utilization of resources, energy, investment, and environmental friendliness.

Industrial metabolism analysis is an effective analytical method for establishing ecological industry. This method simulates the function of the system by analyzing its structure, and studies the metabolic mechanism of ecological industry through input-output analysis [2].

1.3 Thermodynamic laws

Mainly applying the first and second laws of thermodynamics. The first law of thermodynamics, namely the law of conservation and conversion of energy, mainly explains the equivalence between work and heat in terms of quantity. For an isolated system, the internal energy of the system is constant.

The essence of the second law of thermodynamics is the irreversibility of macroscopic systems in their development. It mainly explains the essential difference between work and heat from the qualitative aspect of energy conversion, and explains the direction, conditions, and limitations of energy transfer and transformation, thereby pointing out the differences in mass of various forms of energy. Using the second law of thermodynamics, commonly used analysis methods include exergy analysis and energy level analysis.

1.4 Energy saving theory of steel process system

1.4.1 Fundamentals of system energy conservation

In the 1980s, Academician Lu Zhongwu of Northeastern University proposed the concept of "energy carrier" in his book "Fundamentals of System Energy Conservation", proposing to reduce the unit consumption of the first and second types of energy carriers in each production process, recover the energy carriers and various energies lost in each production process, and further propose inter process coordination, equipment group load distribution, and product task distribution Optimization problems such as fuel allocation [3]. On this basis, Professor Cai Jiuju's team has carried out a large amount of effective and expanding research work.

1.4.2 Metallurgical process engineering

Academician Yin Ruiyu's "Metallurgical Process Engineering" mainly studies the physical essence, structure, and overall behavior of metallurgical manufacturing (production) processes. Intended to clarify the driving forces behind the flow (and storage) of substances (and energy) involved in the metallurgical manufacturing process. A series of knowledge related to the functional structural efficiency issues involved in the research of manufacturing processes, including spatial and planar layout, time and temporal arrangement and control, control and optimization of emissions and consumption (or recycling) in the process [4].

Academician Yin Ruiyu provided the physical essence and three major functions of the dynamic operation process of steel manufacturing process, as well as the concepts and theories of energy "flow" and "energy flow network" in his book "Metallurgical Process Engineering", pointing out the direction of steel process optimization.

2 The overall goal of energy conservation in steel process systems

For the steel process, system energy conservation mainly aims to reduce consumption and increase output on the basis of improving efficiency, thereby reducing energy costs. The energy structure and cost composition characteristics of typical steel processes can be mainly achieved through the following approaches:

(1) By optimizing the energy system, the consumption of resources such as coal, coke, and electricity in the process is reduced, ultimately reflected in reducing the amount of purchased energy and lowering the cost of purchased energy;

(2) By optimizing the energy system, waste heat, residual pressure, steam, gas, etc. can be converted into power or electricity, reducing the cost of purchasing electricity and reducing the amount of purchased electricity;

(3) By optimizing the energy system, the output of energy products can be increased, such as higher value energy products such as heat, cooling, gas, chemical products, etc., which can offset the cost of purchased energy and energy.

On the basis of reducing system energy costs, the above three aspects will also reduce comprehensive energy consumption and CO_2 emissions per ton of steel.

3 Key points of energy-saving in the implementation system of steel process

3.1 Fully recognize and utilize the characteristics and functional advantages of the steel manufacturing process

The energy system of the steel process is a complex large-scale system with non steady state, non-equilibrium state, irreversibility, openness, and dissipation characteristics, which provide prerequisite conditions for system optimization. The components of complex large-scale systems have diversity and differences, which can produce rich, colorful, and non mediocre overall emergence characteristics. The more complex the system, the greater the space and potential for optimization.

The complexity of the energy system in the steel process is mainly reflected in the diversity of carriers, processes, and functions. At the same time, there are differences in time, space, energy, and energy quality. These characteristics and process functional advantages should be fully utilized. Through the construction of nonlinear relationships between multiple energy media and multiple users, optimization of supply and consumption paths, adjustment of energy structure, optimization of system goals and functions, To achieve minimum dissipation, highest efficiency, and maximum benefits.

3.2 Comprehensive application of the first and second laws of thermodynamics

To comprehensively apply the first and second laws of thermodynamics, analyze and evaluate the rationality of enterprise energy consumption from both the "quantity" and "quality" aspects of energy. With the continuous deepening of system energy-saving work, the second law of thermodynamics analysis method is often more important.

Especially when studying the recovery and utilization of waste heat resources, it is necessary to follow the second law of thermodynamics, not only to calculate the "quantity" balance of heat, but also to study the "quality" matching of heat. It is necessary to use energy level analysis methods to construct a more reasonable "energy level matching" relationship between "supply and use".

3.3 Pay attention to the "system efficiency" and "system benefits" of energy utilization

System energy conservation should firmly grasp the overall goal of system optimization. Improving system efficiency is the means, improving system efficiency and reducing system costs are fundamental, and cannot be confused or interfered with. Efficiency is the foundation, efficiency is the goal, and efficiency is often achieved through efficiency.

According to the holistic principle of systems theory, it emphasizes measuring the energy efficiency of the system as a whole. For steel enterprises, system energy conservation should firmly focus on reducing overall energy costs, reducing overall energy consumption, and improving overall energy efficiency.

3.4 Focusing on the integrated optimization of gas, steam, and waste heat systems

The core of energy flow in the steel manufacturing process is the conversion of coal and the recovery and utilization of secondary energy. The efficient recovery and utilization of gas resources and waste heat resources is the key to improving the energy efficiency of the steel manufacturing process system. According to model analysis, a large amount of coal input into the steel process is converted into coke oven gas, blast furnace gas, and converter gas, which contain approximately 47% of the chemical energy of the input coal; The amount of waste heat resources generated per 1 ton of steel production accounts for approximately 52% of the coal resource consumption [5].

When steel enterprises implement system energy conservation, they should focus on the integrated optimization of gas, steam, and waste heat systems, and achieve system goals by building a more reasonable and efficient energy flow network. There are mainly two optimization routes.

3.4.1 Efficient power generation

At present, improving the recovery and utilization efficiency of gas, steam, and waste heat to improve the level of waste heat energy generation and reduce the cost of purchasing electricity is an important way to enhance the energy efficiency and competitiveness of steel enterprises.

A single technology or project is difficult to significantly improve the level of self generation of waste heat and energy in steel enterprises. It is necessary to apply system energy-saving theories and methods, implement system diagnosis, optimization, and top-level design, and plan the continuous progress of the project in order to significantly

improve the level of waste heat and energy generation.

The author conducted a model study on efficient power generation in steel processes and designed a long-term large-scale steel enterprise model with an annual output of 6.5 million tons of crude steel. The energy system of this model enterprise has been optimized and designed according to the principle of system optimization. The gas, steam, waste heat and other systems are fully matched and applied with advanced and mature technologies in the current industry. The main energy consumption indicators refer to the values of advanced enterprise indicators in the industry. Research has found that the installed capacity of the enterprise's waste heat and energy spontaneous system can reach about 530MW, and the net power generation per ton of steel can reach about 527.9 kWh, as shown in Table 1, can basically achieve self-sufficiency in electricity consumption for enterprises [6].

In recent years, the author has organized and completed energy system optimization work for more than 30 domestic steel enterprises. The proportion of waste heat and energy self generation in these enterprises has significantly increased. The self generation proportion of some enterprises before and after optimization is shown in Table 2.

3.4.2 Building a "Steel-Chemical-Gas-Electricity-Heating-Cooling" multi generation system

According to the principles of systems science, by implementing system optimization, the energy system of the steel manufacturing process can add new functions on the existing basis. By fully utilizing the characteristics and functional advantages of the steel manufacturing process, we can deeply develop energy conversion functions. Through the intersection and coupling of material flow, energy flow, information flow, and value flow, we can construct a "steel chemical gas electricity heating cooling" multi generation coupling system.

Through model research, it was found that a steel enterprise with an annual output of 6.5 million tons of crude steel can construct a multi-objective energy system using system optimization methods. While producing 6.2 million tons of steel, it can also produce about 370000 tons of methanol, or about 300000 tons of ethylene glycol, or supply about 10% of COG 700 million cubic meters, or 2 900 million cubic meters, or approximately 340000 tons of liquefied natural gas, or approximately 340000 tons of power generation 300 million kWh, or heating about 12.6 million m^2, or supplying 580 tons/h of medium and low temperature steam, or cooling about 48 70000 kW [5]. There is a certain correlation and constraint between outputs other than steel, and it is not possible to achieve all of the above outputs simultaneously. Different enterprises can optimize and choose different operating modes based on their different operating conditions.

3.5 The main principles and models of implementing system energy conservation in steel enterprises

3.5.1 The main principles of system energy conservation

Under the new situation, the implementation of systematic energy conservation in steel enterprises requires a shift from local, single process, and individual technology focused energy conservation to the direction of integrated optimization of the entire process, system, multi energy medium system, and energy flow network.

Through practice, the following system optimization principles have been summarized and formed: the comprehensive application of the first and second laws of thermodynamics; Following the principles of "matching supply and demand, equivalent substitution, maximizing utilization, coordinated and orderly, and efficient transformation, " we strive to maximize system energy efficiency; The overall optimization of energy flow generation and recovery systems, intermediate buffering and transmission systems, and end-user systems; Reasonable matching of priority usage order and users of different secondary energy sources; Reconstruction of energy flow

Table 1 Situation of waste heat and energy generation in model enterprises

Generator Set	Installed capacity/ MW	Annual energy output/10^4kWh
CCPP generator set	50 × 4	160 000
Ultra high pressure steam generator set	65 × 3	126 500
Dry quenching power generation	25 × 2	31 487
Sintering waste heat power generation	25 × 1	16 200
TRT power generation	25 × 2	32 000
Saturated steam power generation	10 × 1	7 200
summation	530	373 387

Table 2 The proportion of self generated waste heat and energy before and after optimizing the energy system of some enterprises %

Enterprise	Before optimization	After optimization
a	56	95
b	65	93
c	23	90
d	51	86
e	50	80
f	32	69

function and construction of a multi-objective energy system; Comprehensive application of optimization measures in management, process/technology, equipment/equipment, operation/operation, automation/intelligence, etc.

3.5.2 Implementation mode of system energy conservation

The implementation of system energy-saving models in steel enterprises includes the following content.

(1) Top level design, comprehensive consideration. We need to stand at the height of the chairman and general manager, from a global perspective, and carry out top-level design with the goal of optimizing the system, maximizing energy efficiency, and minimizing costs; Coordinate various links such as energy procurement, processing, transportation, storage and distribution, use, conversion, recycling, reuse, and export; Taking into account various aspects such as "supply demand", "economy safety environmental protection", "conceptual concepts, management, process technology, equipment, information technology", etc.

(2) Professional leadership and systematic planning. It should include various professional systems such as coal coke, gas, steam heat, water, electricity, oxygen nitrogen argon, compressed air, etc., and develop a 3-5 year medium to long-term systematic planning plan.

(3) Advance step by step from top to bottom. The leading project is led by the company level supervisory department and strongly promoted from top to bottom; Overall planning, unified leadership - division of labor and responsibility, step-by-step implementation, and establishment of a continuous promotion mechanism.

(4) Widely participate and borrow external forces. Extensive participation from senior management, functional departments, various factories, processes, and related positions is required; If external forces are effectively utilized, it will be more professional, focused, and objective.

4 Energy saving practices in steel enterprise systems

Based on the theory and methods of system energy conservation, utilizing new ideas, methods, and achievements in energy flow network research, a comprehensive and systematic review, diagnosis, analysis, and optimization of the energy system in steel enterprises can be carried out. Through the implementation of planning measures, the operational level of the enterprise's energy system can be significantly improved and energy costs can be significantly reduced.

This model has been implemented in more than 30 steel enterprises in China, and the energy consumption and cost of each enterprise's energy system have been significantly reduced, fully confirming the effectiveness of the system's energy-saving methods.

5 Conclusion

Under the new situation, the energy system of the steel manufacturing process is facing new development requirements such as energy conservation and environmental protection, cost reduction and efficiency improvement, and enhancing the sustainable development ability of enterprises. This system urgently needs to be upgraded to a better system through innovation and evolution.

For such a complex artificial large-scale system, applying external influences through system optimization methods can further achieve the adjustment and optimization of the physical side structure and function of the system. In the process of implementing system optimization, it is necessary to further strengthen the overall concept of the energy system and handle the relationship between local and overall aspects well; To balance the overall, hierarchical, open, stable, and self-organizing nature of the system; To analyze the structure and function of the system, study the interrelationships and changing patterns of the system, elements, and environment, and make good use of collaborative mechanisms; To further build and form a new self-organizing mechanism, through the synergistic effect of information flow, gradually achieve intelligent control of the system, and promote the optimization and upgrading of the energy system in the steel manufacturing process.

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