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Efficiency Optimization and Emission Control of Industrial Combustion Systems under Multiple Operating Conditions

Industrial combustion systems are critical thermal energy sources widely used in metallurgy, chemical processing, power generation, and building materials industries. However, during practical operation, these systems face multiple operating conditions, including fluctuating loads, diverse fuel types, and varying environmental factors. These challenges often lead to reduced combustion efficiency, increased energy waste, and elevated emissions of pollutants such as NOx, CO, and particulate matter, which impact environmental sustainability and energy utilization. Therefore, optimizing combustion efficiency and controlling emissions under multiple operating conditions is a crucial area of industrial energy and environmental research.

The efficiency and emissions of combustion systems are influenced by various factors, including fuel properties, air-to-fuel ratio, burner design, flue gas temperature, and flow field distribution. Under multi-condition operation, these factors change dynamically, rendering traditional empirical control methods insufficient to meet the dual objectives of energy conservation and environmental compliance. To effectively enhance system performance, engineering models that simulate the dynamic characteristics of the combustion process are needed, integrating thermodynamics, fluid mechanics, and chemical reaction mechanisms to analyze the relationship between combustion efficiency and pollutant formation.

This study presents a methodology for efficiency optimization and emission control of industrial combustion systems under multiple operating conditions. A dynamic model of the combustion system is developed to simulate the combustion process and flue gas emissions under varying loads, fuel types, and environmental conditions, enabling the evaluation of system energy efficiency and pollutant levels. Based on simulation results, optimization algorithms are applied to adjust combustion parameters, including air-fuel ratio, burner configuration, and fuel blending strategies, aiming to maximize combustion efficiency while minimizing emissions. The approach provides engineering guidance for operational management, energy-saving retrofits, and environmental compliance planning.

The findings offer industrial enterprises a systematic strategy for energy optimization and pollutant reduction, supporting high-efficiency operation of combustion systems under multiple operating conditions. Additionally, the study provides a theoretical and engineering basis for intelligent control and sustainable development of industrial combustion technology, promoting the synergistic improvement of energy utilization efficiency and environmental protection.