

# Research on the Development of Thermal Power Engineering Based on Energy and Boilers

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**Abstract:** In the backdrop of continuously escalating global energy demands, the significance of thermal power generation as a conventional form of energy conversion in the realms of energy and boiler technology cannot be overstated. This study encompasses various energy sources and boiler types utilized in thermal power generation engineering, as well as the potential and practices of these technologies in enhancing energy efficiency and sustainability. The research also delves into the environmental and economic challenges faced by current thermal power generation, along with discussions on future development opportunities. Through case analyses of existing technologies, this paper aims to offer a comprehensive perspective, identifying key advancements and optimization pathways in thermal power generation engineering, thereby providing insights for future energy frameworks.

**Keywords:** Energy; Boilers; Thermal Power; Engineering Development.

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## 1. Introduction

Thermal power engineering, which occupies a central position in global energy production, is facing both existing challenges and new opportunities as technology advances and environmental protection is increasingly emphasized. Traditional thermal power generation relies on the combustion of fossil fuels, a process that involves the selection of energy sources and the application of boiler technology, which directly affects power generation efficiency and environmental pollution. Therefore, exploring how to ensure energy supply while improving energy efficiency and reducing environmental burden has become the focus of research in this field. This study further clarifies the possibility of realizing the double benefits of environment and economy by deeply analyzing the current situation and development of thermal power generation technology.

## 2. Research Methodology

Thermal power engineering involves a plethora of intricate physical processes and chemical reactions, rendering the prudent selection and application of research methodologies paramount. Initially, the study adopts an amalgamation of experimental analysis and numerical simulation. Experimental analysis allows for direct observation of the operational dynamics of boilers and other thermal equipment, facilitating the collection of requisite operational data. The authenticity of such data is pivotal in validating theoretical models and enhancing equipment designs. However, the limitations of experimental methods lie in their exorbitant costs and time-intensive nature, particularly during prolonged operational tests. At this juncture, numerical simulation manifests its distinctive advantages. By establishing precise computational models, it becomes feasible to simulate the thermal flow and energy conversion processes within boiler systems in a virtual environment, not only with heightened efficiency but also with the ability to regulate and modify experimental conditions, thereby addressing complex scenarios often unattainable in experiments. The study further underscores the significance of multi-scale models. Processes

within boiler systems span from microscopic chemical reactions to macroscopic heat exchange, exhibiting diverse levels and mutual influences [1]. Leveraging multi-scale models empowers researchers to intricately capture interactions across various levels, from the microscopic to the macroscopic, thereby enhancing predictive accuracy and reliability. Moreover, an innovative aspect of this research methodology lies in the reinforced role of data analysis. With the advancement of information technology, big data and machine learning techniques have begun permeating engineering research. By analyzing historical operational data, machine learning models can prognosticate system performance and even autonomously adjust operational parameters to optimize system efficiency. This approach not only enhances energy efficiency but also lays the groundwork for the intelligent management of thermal systems. In conclusion, through the amalgamation of experimentation and simulation, coupled with multi-scale analysis and advanced data processing techniques, this study erects a comprehensive and profound research methodology framework. This not only furnishes robust support for the technological advancement of thermal power engineering but also propels the close integration of theoretical inquiry and practical application. By means of these research methodologies, a deeper comprehension and optimization of boiler and related energy equipment design and operations are achievable, thereby contributing to the sustainable development of the energy sector.

## 3. Energy Sources and Boiler Technology in Thermal Power Engineering

### 3.1. Overview of Energy Sources Used in Thermal Power Generation

As one of the most widely utilized methods for energy generation globally, thermal power generation relies on fossil fuels as its fundamental raw materials, including coal, oil, and natural gas. Despite facing challenges regarding environmental sustainability, fossil fuels maintain an undeniable position within today's energy framework

worldwide. Coal, upon which thermal power generation heavily relies due to its abundant reserves and relatively low cost, continues to play a central role in energy production across numerous nations. Nevertheless, the substantial emissions of carbon dioxide and other greenhouse gases during combustion exacerbate the issue of global warming. In response, technological advancements suggest a trend towards optimizing the stages of thermal power generation through more efficient boiler technology and cleaner combustion methods. The application of supercritical and ultra-supercritical boilers notably enhances the thermal efficiency of thermal power generation while reducing adverse environmental impacts. At the core of this technology lies the ability to operate under extremely high pressure and temperature conditions, preventing the phase transition of water and steam, thus improving thermal efficiency. With increasing global attention towards environmental issues, the utilization of clean energy and the development of carbon capture technology become particularly crucial. In the future, the challenge facing thermal power generation lies in balancing the dual tasks of energy demand and environmental protection, ensuring the sustainable development of energy [2]. Despite formidable obstacles, significant progress in enhancing energy efficiency and reducing environmental impact through technological innovation and international cooperation remains foreseeable.

### **3.2. Types of Boilers Used in Thermal Power Plants**

The array of boiler types employed in thermal power plants is diverse, comprising notably subcritical, supercritical, and ultra-supercritical boilers. Each variant boasts distinct technical attributes and applicability, thereby yielding considerable discrepancies in both plant efficiency and environmental impact. Subcritical boilers have long been the conventional preference due to their comparatively mature design and operational techniques. However, in terms of efficiency, these boilers typically plateau at 38% to 42%. While stable and widely deployed, their performance in energy utilization and carbon emission reduction falls marginally short. Operating at elevated pressure and temperature conditions, supercritical boilers achieve heightened efficiency, ranging approximately from 43% to 45%. This augmented efficiency not only signifies increased electricity generation but also implies diminished carbon dioxide emissions per unit of fuel, thus making a substantial environmental contribution. As for ultra-supercritical boilers, they push the boundaries of pressure and temperature beyond supercritical limits, often surpassing the 45% efficiency threshold. Despite the higher costs and technological demands, they may emerge as the most sustainable option for the thermal power sector in the long term. In conclusion, the selection of an appropriate boiler type not only impacts the economic viability of power plants but also constitutes a pivotal consideration regarding environmental ramifications and the sustainable utilization of energy resources. With technological advancements and escalating environmental standards, future thermal power plants are likely to gravitate towards boiler technologies that offer high efficiency and low emissions.

### **3.3. Energy Efficiency and Sustainability in Thermal Power Engineering**

In the realm of thermal power generation, the paramount

considerations lie within energy efficiency and sustainability. Elevating energy efficiency not only aids in reducing the cost of electricity generation but also stands as a pivotal means to realize environmental conservation objectives. Boilers, as the core components of thermal power generation systems, exert a direct influence on the overall energy utilization of the entire plant. Taking modern ultra-supercritical and advanced ultra-supercritical boilers as illustrations, these highly efficient boiler technologies have propelled thermal power plants towards achieving heightened energy conversion efficiencies. By augmenting the pressure and temperature of inlet steam, these high-efficiency boilers conspicuously enhance thermal efficiency, thereby curtailing fuel consumption and deleterious emissions. The cultivation of such efficient technologies not only aligns with economic benefits but also resonates with the global call for decarbonization and environmental preservation. Moreover, sustainability holds undeniable significance within thermal power generation engineering. This domain is gradually integrating more hybrid power systems, amalgamating renewable energy sources with conventional ones. For instance, certain power plants are beginning to experiment with co-firing biomass with coal, a measure that not only diminishes reliance on fossil fuels but also mitigates carbon emissions to a certain extent. Additionally, the adoption of state-of-the-art waste heat recovery techniques and residual heat utilization systems stands as an effective pathway towards enhancing the sustainability of thermal power generation. The realization of efficient and sustainable electricity generation necessitates the amalgamation of modern technologies with stringent environmental policies. Only through this union can thermal power generation engineering stride towards a greener and more sustainable future while ensuring energy supply security [3].

### **3.4. Case Studies of Successful Energy and Boiler Technologies for Thermal Power Plants**

In discussing exemplary cases of successful energy sources and boiler technologies in thermal power plants, the case of Changqing Power Plant stands out. Through the adoption of ultra-supercritical boiler technology, Changqing Power Plant has significantly enhanced thermal efficiency while concurrently reducing carbon emissions during combustion. Ultra-supercritical boilers operate at higher pressures and temperatures, allowing water to transition directly to steam at supercritical conditions, thus circumventing the energy losses incurred during the separation of water and steam in traditional boilers. This technology not only elevates energy utilization efficiency but also makes a positive contribution to environmental preservation. Particularly in the face of global environmental challenges and energy crises, the application of ultra-supercritical boiler technology offers a solution for the thermal power generation industry to mitigate pollution and enhance energy efficiency. Furthermore, Changqing Power Plant has meticulously configured and managed its equipment during the implementation of this technology, ensuring operational safety and economic viability. Through continuous technological innovation and management optimization, Changqing Power Plant has set a paradigm for the thermal power generation industry, emphasizing both technological advancement and environmental benefits. This case illustrates that the future of the thermal power generation industry lies not only in the adoption of advanced

technologies but also in the integration of these technologies into specific production practices to achieve the dual objectives of economic profitability and environmental protection. The success of Changqing Power Plant vividly demonstrates the fusion of technological innovation and environmental responsibility, providing valuable experience and insights for the sustainable development of the global energy sector.

## **4. Challenges and Opportunities in Thermal Power Generation Engineering**

### **4.1. Environmental Impacts of Thermal Power Generation**

Electricity generation from fossil fuels is a pivotal pillar in the global energy supply. Yet, the environmental ramifications of this mode of energy production have perpetually remained a focal point of scientific inquiry and policy deliberation. Power plants primarily rely on the combustion of fossil fuels such as coal, oil, and natural gas to generate electricity, inevitably resulting in the release of copious amounts of greenhouse gases and other pollutants. Foremost among these emissions is the release of carbon dioxide, a principal driver of global warming. Whenever coal or oil is combusted, power plants discharge vast quantities of carbon dioxide into the atmosphere. Statistically, thermal power generation stands as one of the major contributors to global carbon dioxide emissions. Furthermore, these plants also emit sulfur compounds and nitrogen oxides, which, upon reacting with other atmospheric constituents, give rise to acid rain, inflicting harm upon soil, water bodies, and biodiversity. Interestingly, despite the adverse environmental impacts of thermal power generation, it plays an indispensable role in ensuring energy security and economic stability. Until renewable energy sources such as wind and solar power can entirely supplant conventional sources, thermal power generation remains a cornerstone in the energy portfolios of many nations. Balancing this dichotomy poses a challenge that necessitates wisdom and innovation. Consequently, future thermal power engineering endeavors must not only prioritize enhancing the efficiency of fuel combustion but also intensify research investment in clean energy technologies. This encompasses the development of advanced emission control technologies, such as carbon capture and storage (CCS), to mitigate environmental impacts. Simultaneously, expanding the proportion of renewable energy usage and progressively transitioning towards green energy production can be construed as an effective avenue for combating environmental pollution. The future of thermal power generation presents formidable challenges, yet it also holds abundant opportunities. Through technological advancement and policy adjustments, there is hope to chart a sustainable path that safeguards energy needs while preserving the Earth's environment [4].

### **4.2. Economic Factors Affecting the Development of Thermal Power Plants**

Fuel price fluctuations constitute one of the most conspicuous economic factors affecting this sector. Thermal power plants, relying heavily on coal as their fuel, have operational costs intricately tied to the coal market's supply and demand dynamics. As coal prices ascend, so do the costs

of electricity generation, directly constricting the economic viability of these plants. The tightening of environmental policies also effectively escalates the operational costs of thermal power plants. With global emphasis increasingly shifting towards environmental conservation, various governments have sequentially introduced a series of emission reduction measures and standards. As a traditional high-emission industry, the thermal power generation sector has been compelled to invest significantly in upgrading desulfurization, denitrification, and dust removal facilities. While these environmental investments contribute to pollution reduction and enhance social image, they undeniably escalate the financial burden on enterprises in the short term. Furthermore, the challenges and opportunities brought about by technological advancements coexist. The application of new technologies such as supercritical and ultra-supercritical technologies, while capable of substantially enhancing power generation efficiency and reducing the consumption of standard coal, entails exorbitant initial costs in terms of technology development and equipment investment. Only through long-term operation can these costs be absorbed, realizing an elevation in economic benefits. The impact of economic factors on thermal power plants is multifaceted, encompassing not only direct cost expenditures but also indirect effects stemming from policy orientation and technological updates. In such a volatile economic environment, how thermal power plants balance costs and benefits, and how they adopt effective measures to address economic challenges, are pivotal in determining their future sustainable development. Under the dual pressures of market and policy, the continuous optimization of operational strategies and the innovative application of technology are indispensable pathways for the thermal power generation industry when confronting economic challenges [5].

### **4.3. Regulatory and Policy Implications of Thermal Power Projects**

The role of thermal power engineering is pivotal in the global energy production landscape. However, amidst the strengthening environmental consciousness and the increasingly stringent regulatory framework, this domain encounters myriad regulatory challenges. Policy fluctuations directly impact the construction and operational costs of thermal power plants, profoundly shaping industry development trends. The tightening environmental regulations stand as a significant challenge that the thermal power sector cannot evade. Many nations and regions are progressively elevating standards for sulfur, nitrogen oxides, and particulate matter emissions from thermal power plants. This necessitates greater capital investment by enterprises in the research and application of clean technologies, such as flue gas desulfurization and denitrification technologies. While this imposes additional economic burdens on enterprises, it also propels the development and application of clean technologies, driving advancements in environmental protection. On the other hand, government subsidies and incentive policies also present new opportunities for the development of thermal power engineering. For instance, certain countries provide tax breaks or financial subsidies for thermal power projects employing advanced environmental technologies. This not only alleviates some economic pressures on enterprises but also incentivizes more investments in higher standards of pollution control technologies. However, policy uncertainty remains a

challenge. Frequent policy fluctuations may lead to instability in long-term project investment plans, increasing enterprise risks. Therefore, when formulating future development strategies, thermal power enterprises need to meticulously analyze and forecast the policy environment. In conclusion, the regulation and policy impacts on thermal power engineering are complex and multidimensional. Enterprises must strike a delicate balance between complying with stringent environmental requirements and seizing opportunities provided by policies, deftly navigating regulatory challenges. This requires not only the adaptability of enterprises but also necessitates policymakers to provide a rational and stable policy environment.

#### 4.4. Future Trends and Prospects of the Industry

As a longstanding mainstream method of electricity generation, thermal power faces increasingly stringent environmental standards and simultaneously embraces vast potential for technological innovation. Environmental pressures stand as a primary challenge that the thermal power sector must confront. With heightened global attention to climate change, reducing carbon emissions has become a consensus on a global scale. This necessitates a transformation and upgrade in the thermal power industry, specifically in how to mitigate adverse environmental impacts while ensuring energy supply. Technological advancement emerges as a crucial avenue to address this challenge. For instance, the application of supercritical and ultra-supercritical technologies significantly enhances the efficiency of thermal power generation, thereby reducing energy losses in the process of converting heat from coal combustion into electricity. Furthermore, the development of Integrated Gasification Combined Cycle (IGCC) technology enables cleaner and more efficient utilization of coal, aiding in alleviating environmental pressures. In the future, as the costs of renewable energy technologies such as wind and solar power continue to decline, along with advancements in energy storage technology, thermal power must seek new positioning in this evolving energy market. On one hand, thermal power plants must fully utilize their peak-shaving capabilities to complement the intermittent and unstable nature of renewable energy generation. On the other hand, exploration is needed on how to further reduce pollutant emissions through technological innovation to comply with increasingly stringent environmental regulations. Despite numerous challenges, the outlook for the entire industry is not without hope. Innovation is the key driving force behind progress in any industry, and the thermal power sector relies on technological breakthroughs to seek renewed vitality. Therefore, the future direction of thermal power development will place greater emphasis on the dual optimization of

environmental and economic benefits. The integration of intelligent and automated technologies to enhance operational efficiency while reducing human errors will play a crucial role in future development. Looking ahead, while the path of thermal power generation is fraught with challenges, each step forward validates innovation and progress. If continual exploration and optimization on the path of green transformation persist, thermal power technology can still carve out a place in the global energy landscape.

## 5. Conclusion

In conclusion, thermal power generation engineering maintains a significant position within the global energy framework. With increasing energy demands and heightened environmental considerations, the challenges confronting thermal power generation are steadily mounting. Research indicates that by embracing more efficient boiler technologies and adopting sustainable energy alternatives, the environmental performance and economic viability of thermal power generation can be effectively enhanced. Furthermore, adapting to policy regulations and fostering technological innovation will serve as pivotal factors propelling the future development of this domain. Looking ahead, the optimization and innovation of thermal power generation technologies will constitute crucial pathways to ensuring energy security, economic sustainability, and environmental stewardship. Through this study, it is hoped that theoretical underpinnings and practical guidance provided will contribute to the continuous advancement within the realm of thermal power generation.

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