

# Research on the Mechanism and Preventive Measures of Heat Transfer and Coking in Boilers

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**Abstract:** Boilers are one of the most important power supply sources in the chemical industry. The irreplaceable nature of its products requires boilers to maintain stable long-cycle operation during the production process. However, boiler failures occur from time to time and necessary measures need to be taken to reduce the chances of failure. Among these failures, metal corrosion and tube failures are particularly prominent. Due to the fact that the thermal calculation results do not match the actual; the coefficients in the design are not reasonably selected, and the hearth and boiler shape are not properly selected; the structural design of the superheater system and the arrangement of the heated surface are not reasonable; and the wall temperature calculation method is not perfect, which leads to the improper selection of materials and so on. These will make the fire-side heat exchange system produce wall temperature super-high, tube bundle burst and other failure phenomena. These phenomena cause a certain degree of hidden danger to the safe production of the boiler.

**Keywords:** Heat Transfer; Coking; Prevention and Control.

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## 1. Introduction

Boilers are commonly used in industrial production to produce steam or heat water. Heat transfer and coking are two important problems during the boiler operation. Heat transfer refers to the process in which energy is transferred from the heat generated by fuel combustion to the water in the boiler, and coking is the solid residue formed by the deposition of ash and other substances in the fuel on the inner wall or pipe of the boiler after combustion.

In order to effectively avoid the impact of boiler heat transfer resistance and coking problems, in-depth research and corresponding preventive measures are needed. For heat transfer problems, we can optimize the boiler structure design, improve water treatment, and clean the heat exchange surface regularly. For coking problems, the fuel selection optimization, control combustion parameters, and strengthen boiler cleaning and maintenance can be considered to reduce coking generation.

In the process of boiler installation and repair, each step of the work has strict specification requirements, so the implementation is often difficult to do everything [1-3]. The influence of these factors such as poor welding quality, incomplete welding of the intermediate partition of the coupling box, defective weld of the coupling box tube seat, welding of dissimilar steel tubes, welding quality of ordinary welds, substandard oval degree of the tube elbow, thinning of the elbow, clogging of foreign objects, quality problems of the tubes, wrong steel, and the quality of the installation is bound to have a certain effect on the normal use of the bundles of tubes, and even provoke the phenomenon of tube bursting. After analysing the problems existing in the boiler water-side system, the scheme of injecting EWPT water treatment agent into the boiler water was proposed[4-7]. This water treatment agent effectively reduces the adverse effects of corrosion and scaling of the water-side system on boiler operation. It also improves steam quality, reduces boiler water discharge, achieves energy saving and emission reduction, and fulfils social and environmental liability. As a boiler used for power

generation, the failure of the heat exchange system is an important troubling factor that affects the safe, stable, and continuous operation of the boiler, so all managers attach great importance to the failure of the heat exchange system.

## 2. Current Status of the Boiler Plant

### 2.1. Technology Upgrading

Combustion technology is one of the key concerns of boiler plants. The new generation of boilers adopts advanced combustion technologies, such as fluidised bed combustion, supercritical combustion, etc., which can achieve higher combustion efficiency, lower emission level and higher operational stability. Boiler plants pay more and more attention to energy-saving and emission reduction, and adopt various energy-saving and emission reduction technologies. For example, flue gas waste heat recovery technology, desulphurisation, denitrification and decarbonisation technology can effectively reduce energy consumption and environmental pollution and improve resource utilisation. The level of digitalisation and intelligence of the boiler plant has been continuously upgraded. Advanced digital monitoring system, intelligent control system and remote monitoring technology have been introduced, which can realise real-time monitoring, data analysis and remote control of boiler equipment and operation status, improving operation efficiency and management level. Boiler plants are gradually shifting to diversified fuel supply and clean energy. In addition to traditional coal-fired boilers, more and more boiler plants are using clean energy sources such as natural gas, biomass energy, solar and wind power to reduce dependence on fossil fuels and lower emissions. Boiler plants are constantly making process improvements and equipment renewals by introducing advanced production equipment and manufacturing processes. The new generation of boiler equipment has higher thermal efficiency, lower energy consumption and less emission, which can better meet the market demand and environmental protection requirements.

## 2.2. Clean Energy Transition

Many boiler plants are converting their coal boilers to natural gas. The combustion of natural gas produces lower carbon emissions than coal and is a cleaner burning process, making it a relatively cleaner energy option. The stability of natural gas supply and relatively low emissions also make it a preferred alternative fuel for many boiler plants.

Biomass energy sources such as wood, waste and crop residues are widely used to fuel boiler plants. The combustion process of biomass energy is virtually emission free and it is a renewable energy source, hence it is attracting a lot of attention. Many boiler plants are upgrading their equipment to accommodate the use of biomass or increasing the proportion of biomass blending.

Some boiler plants are considering renewable energy sources such as solar and wind to partially or fully power their boilers. These clean energy sources are zero-emission and infinitely renewable, making them particularly suitable for hot water boilers and small boiler systems.

Heat recovery technology is widely used in boiler plants to recover waste heat, such as flue gas and waste heat, for use in heating, hot water production and industrial production. This not only reduces energy consumption and carbon emissions, but also improves energy efficiency.

Some boiler manufacturers are also actively developing Carbon Capture and Storage (CCS) technology to reduce carbon dioxide emissions from boiler combustion processes. This technology captures and separates the carbon dioxide produced during the combustion process and sequesters it or uses it for other industrial purposes, thereby reducing emissions to the atmosphere.

## 2.3. Digitalisation and Intelligence

The boiler plant adopts an advanced intelligent monitoring system, which monitors the operating status and performance parameters of the boiler equipment in real time, including temperature, pressure, flow rate, etc., through sensors and data acquisition devices, to realise all-round monitoring and data acquisition of the whole production process.

The boiler plant utilises internet and IoT technology to establish a remote monitoring and control system to achieve remote monitoring, operation and adjustment of the boiler equipment. Operators can monitor the operating status of the boiler anytime, anywhere through mobile phones, tablet PCs and other remote devices, and control and adjust accordingly, improving the flexibility and efficiency of the operation.

Boiler plants use big data analytics to conduct in-depth analysis and mining of boiler equipment operating data to identify potential problems and room for optimisation. Through data analysis, equipment failure prediction, performance optimisation, energy consumption analysis, etc. can be achieved, providing data support for operational decision-making, improving productivity and reducing costs.

The boiler plant introduces an advanced intelligent control system to achieve intelligent control of the boiler combustion process and equipment operation. The intelligent control system can automatically adjust key parameters such as fuel supply and air supply according to real-time data and preset parameters to maintain combustion stability and high efficiency, which improves the operational efficiency and safety of the equipment.

Boiler plants are also beginning to apply artificial intelligence technologies, such as machine learning and deep learning, to intelligently manage and optimise equipment

operation. By learning and analysing a large amount of historical data through AI algorithms, boiler plants can achieve intelligent diagnosis of equipment, predictive maintenance, etc., improving equipment reliability and operational efficiency.

## 2.4. Increased Market Competition

With globalisation and the deepening of market openness, boiler plants are facing fierce price competition from domestic and foreign counterparts. In order to compete for market share, boiler manufacturers often adopt price strategies to compress product prices in order to attract customers and increase sales.

The technological competition among boiler factories is also becoming more and more intense. With the advancement of science and technology, new technologies keep emerging, boiler plants need to innovate, introduce advanced production technology and techniques, improve product quality and technical content to meet the market demand for high-performance, high-quality products.

The service level between boiler plants has also become an important aspect of competition. In addition to product quality and price, boiler manufacturers also need to provide a full range of after-sales service, including installation and commissioning, training, maintenance, etc., in order to enhance customer satisfaction and loyalty.

With the intensification of market competition, brand influence is more and more important for the competitive advantage of boiler plant. Some well-known brands of boiler plant with its good quality and reputation, occupy a certain advantage in the market, while some emerging brands need to enhance competitiveness through brand building and marketing.

Boiler plants need to actively explore new markets and find growth points in the face of increased market competition. On the one hand, it can develop new applications to meet the needs of different industries by expanding the domestic market; on the other hand, it can also expand overseas business by exploring the international market to find a broader space for development.

## 2.5. Policy Support and Regulation

Many countries and regions have enacted stringent environmental protection policies and emission standards that require boiler plants to control emissions and reduce pollutant emission levels. The government strictly regulates the emissions of boiler plants and penalises those that do not meet the standards, while providing incentives and rewards for those that do.

Many countries and regions have introduced clean energy policies to encourage boiler plants to use clean energy sources, such as natural gas, biomass, solar and wind, to reduce dependence on traditional fossil fuels and lower carbon emissions. The government provides support for the development and utilisation of clean energy through subsidies and tax incentives.

The government encourages boiler plants to carry out technological innovation and transformation and upgrading, and promotes the development of boiler plants in the direction of high efficiency, cleanliness and intelligence. The government provides support and financial guarantee for technological innovation and transformation of boiler plants through science and technology policies and innovation funds.

The government strictly supervises the safety production of

boiler plants, requiring boiler plants to strictly abide by safety production laws and regulations, strengthen equipment maintenance, improve equipment operation safety and prevent accidents. The government strengthens the safety inspection and supervision of boiler plants, and rectifies and punishes boiler plants with hidden safety problems.

The government manages the market access of boiler plants, formulates relevant industry standards and norms, and regulates the production and operation behaviours of boiler plants. The government strengthens the supervision and management of boiler plants through market supervision and industry associations to maintain market order and fair competition.

### **3. Influence of Design Factors on the Boiler Heat Transfer System**

Boiler combustion process are present in the flue gas temperature, velocity, gas composition, wind and powder concentration, powder particle size, combustion degree, ash particle size and ash concentration in the flue gas distribution differences, known as the smoke side of the thermal deviation. This smoke-side thermal deviation is affected by two factors: one is the combustion process of the system involved in combustion in the boiler hearth; the second is due to the structural impact of the heat transfer system of heat absorption uniformity, different parts of the heat absorption is different. Different combustion methods have different furnace process characteristics, different furnace structure reflects different heat absorption characteristics, different combustion methods of the smoke side of the thermal deviation of different forms of expression. Such as cutting circle rotary combustion, with a deviation of the flue gas in the process of rotating up around the water-cooled wall at the same time, the heat absorption deviation is small; when the rotating cutting circle deviates from the centre, the heat absorption deviation increases. If you take the flue gas rotation direction and spiral water-cooled wall rotation direction is opposite, can more effectively reduce the heat absorption and smoke side deviation. Another example is advection rising combustion, when the furnace process organisation and combustion control is reasonable, the flame deviation is small, the total flame thermal deviation and heat absorption deviation can reach the expected goal, but when the load change amplitude is large and need to shut down part of the burner, due to the combustion unit complementarity is poor and make the total flame to produce a large thermal deviation, and sometimes even unpredictable.

#### **3.1. Influence of Thermal Calculation Results**

Heat transfer calculation results can help assess the heat transfer efficiency of a boiler, including parameters such as the heat transfer coefficient of the water wall, heat exchange surface area and heat transfer rate. Accurate heat transfer calculation results can guide boiler operation and design to optimise heat transfer efficiency and improve boiler thermal efficiency. Thermal calculations can be used to assess the risk of coking during boiler combustion. Thermal calculations can analyse factors such as the combustion characteristics of the fuel, the temperature distribution of the flue gas, and the composition of the combustion products, so that the likelihood of coking can be determined and appropriate measures can be taken to prevent and deal with it. The results of heat transfer and coking calculations can also influence the

treatment and discharge of boiler flue gases. Based on the composition and temperature distribution in the flue gas, suitable flue gas treatment methods can be determined, including dust removal, desulphurisation, denitrification and other processes, to ensure that the boiler emissions are in line with environmental standards. Thermal calculations can be used to assess the safety of boiler operation, including thermal stress and thermal expansion of water walls and pipes. Accurate thermal calculations can help predict and avoid thermal stress and deformation of the boiler in high temperature and high pressure environments to ensure the safe operation of the boiler. The results of thermal calculations for boiler heat transfer and coking can also be used to assess energy consumption. By analysing factors such as fuel combustion efficiency, heat loss and heat transfer efficiency, the energy utilisation of the boiler can be determined, thus guiding energy conservation and optimising energy consumption [13-14].

#### **3.2. Furnace, Boiler Shape on the Impact of Selection**

Power boiler was built in the late 1970s, in the design and manufacture, there is not sufficient theoretical and practical experience of mutual integration. This is the selection of the boiler, the internal structure of the boiler arrangement are no standard reference. This makes the design of the furnace cannot adapt to the gradual change of operating conditions. Unreasonable boiler hearth structure will make the water-cooled wall tube bundle local over-temperature, resulting in tube burst. The height of the furnace also affects the water-cooled wall and superheater tube bundle steam temperature, high hearth, will make the steam temperature is low. On the contrary, the low height of the hearth may cause over-temperature.

#### **3.3. The Superheater Structure and the Influence of the Arrangement of the Heating Surface**

Boiler heating surface heat pipe arrangement form there are roughly three kinds: vertical rising tube, horizontal tube and oblique tube. Heated surface tube bundle in the mass of a single-phase body, there are also two-phase body. Such as the coal economiser or down in the bundle of only flowing water, in the superheater or reheater in the flow of steam, the flow of a single-phase body. While in the evaporator heat surface tube bundle, the flow is a mixture of steam and water, is a two-phase body. For the single-phase body, its flow form is mainly divided into laminar flow and turbulent flow. Under the influence of a variety of factors, the flow of the steam-water mixture in the tube bundle in a more complex form. Because different forms of flow have different dynamic characteristics and heat transfer characteristics, thus it is necessary to boiler heat transfer system in the medium in the tube bundle of the flow form of careful analysis, and this analysis of the failure analysis of the tube bundle also has a very important significance [15-16].

#### **3.4. The Effect of Imperfect Wall Temperature Calculation Methods**

The boiler superheater is composed of many heat pipes connected in parallel on the inlet header and outlet header to form a parallel tube group. When many tubes work in parallel, the working conditions of the tubes may be different, if the

parallel tube group within the hydrodynamic working conditions are not good, so that one of the tube work is not safe, then the entire heated surface of the tube group of the reliability of the work can not be guaranteed. Parallel tube group can work reliably as an important guarantee to strive to make the parallel tube are designed to work under the conditions of work. But this is impossible to complete the task, because each pipe bundle because of their own factors and the influence of external factors, will make the bundle of hydraulic properties are different [17].

### 3.5. The Influence of Foreign Matter Blockage

Boiler in long-term operation, there will be corrosion down the substance, blocked in the pipeline, especially easy to silt deposition in the lower part of the pipeline horizontal section or elbow parts. As a result of the inability to carry out effective cleaning, it is easy to cause overheating and trigger the occurrence of pipe burst accident. In the manufacturing or inspection and maintenance process, there will also be welding slag or other debris left in the tube bundle can not be cleaned, which will also make the tube bundle due to overheating and pipe burst.

### 3.6. The Impact of Pipe Quality Issues

In the boiler operation, the water-cooled wall tube bundle inside the high-temperature hot water, while the outside is the high temperature generated by the burner; superheater tube bundle inside the high-temperature steam, while the outside is a high-temperature flue gas. These two types of tube bundles inside and outside the wall temperature difference is large. The boiler heat transfer tube bundle of the heating surface is mostly in the role of high-temperature stress, high-temperature creep on the tube bundle has a great impact, which puts forward high requirements for the material of the tube bundle. But in fact, due to China's boiler tube bundle in the production process is not perfect and very advanced, the tube bundle itself is still a lot of defects. These defects seriously affect the mechanical properties and hot working performance of the steel tube bundle. These defects will sometimes produce greater damage to the components, and sometimes even cause the tube bundle of the burst phenomenon occurs[19-20].

### 3.7. The Impact of Installation Quality Problems

Large boilers, boiler heat transfer system in the heat pipe heating area is generally large, wide distribution, in the whole heat transfer system is a complex part. In the installation of these heated tube bundles, to ensure that meet the process requirements, but also to ensure the rationality of the installation of the tube bundles, to avoid the production of flue gas channels, resulting in incomplete exchange and transfer of heat, reducing the thermal efficiency of the boiler.

## 4. Conclusion

Taken together, the above analyses show that the influence of design factors on boiler tube bundles has a large proportion. But this kind of influence, for boilers that have been put into use and operation, can no longer be avoided. And it is quite difficult to improve on it. This requires boiler managers to strengthen the boiler management, to pay attention to operational management, pay attention to the regular testing of the boiler and that into the type of repair, and strive to

reduce the possible failure of the boiler tube bundle phenomenon to a minimum.

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