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Study on Effective Energy Saving of Aluminum Silicate Refractory Fiber in Gas Furnace

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Abstract

At present, compared with traditional materials, aluminum silicate refractory fiber has the advantages of high temperature resistance and energy saving, which can help save the cost of gas furnace. However, during the application of aluminum silicate refractory fiber in the gas furnace at present, due to the problems of low strength, serious shrinkage and common pulverization of aluminum silicate refractory fiber, there is still room for improvement of aluminum silicate refractory fiber. Therefore, how to improve the application of aluminosilicate refractory fiber in gas furnace has become one of the important problems. This paper first summarizes the aluminum silicate refractory fiber, then analyzes the characteristics of the aluminum silicate refractory fiber, and finally discusses the existing problems and protective measures of the application of aluminum silicate refractory fiber in the gas furnace for reference.

Keywords

Gas stove; Aluminum silicate refractory fiber; Energy conservation

1. Introduction

Currently, gas furnaces are typically constructed using high-alumina bricks. While high-alumina bricks offer high compressive strength and refractoriness, their high heat capacity leads to high heat loss and low temperature retention, resulting in frequent temperature increases, wasting both energy and resources. Therefore, a new insulation material is needed that can withstand both cyclical and intermittent operation in industrial furnaces. Aluminosilicate refractory fibers, with their inherent high heat resistance and low heat capacity, are gradually gaining popularity in domestic factories. After use in numerous factories, they have demonstrated excellent performance and are effective in reducing gas consumption. A comparison of pre- and post-modification results shows significant improvements in operating time, rolling mill efficiency, and burner efficiency. The modified process significantly reduces operating time, allows for uninterrupted rolling, and reduces or eliminates burner operation, reducing energy consumption and achieving energy savings. However, significant room for improvement in the current use of aluminosilicate refractory fibers remains, and in-depth research into potential improvement paths and directions is a key focus of current research.

2. Overview of Aluminum Silicate Refractory Fiber

Aluminum silicate refractory fiber itself is an inorganic material, also known as ceramic fiber. It is made of high-quality charcoal, silica, zircon sand, high-purity alumina and other materials as raw materials, and is processed through three steps of raw material processing, melting and fiberization by selecting appropriate processes. It is melt-blown or spun in a resistance furnace to polymerize dispersed materials with different chemical compositions, and finally obtains a fiber material. According to different raw materials, the processing technology can produce

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aluminum silicate refractory fiber products with different refractory temperatures, including ordinary refractory fiber cotton, standard refractory fiber cotton, high-purity refractory fiber cotton, high-aluminum refractory fiber cotton, zirconium-containing refractory fiber cotton and other products [1]. At the same time, based on the above-mentioned fiber cotton, it can also be processed into different materials such as fiber blankets, fiber mats, fiber boards, fiber bricks, etc.

As early as the 1940s, workers could use kaolin as raw material to produce ordinary aluminum silicate refractory fiber through melt blowing, and it was promoted rapidly during the development process and has been widely used abroad. Currently, China has increased its attention to aluminum silicate refractory fibers and is using them as thermal insulation materials in gas furnaces. However, gas furnaces currently consume a lot of energy, so exploring the application of aluminum silicate refractory fibers to reduce energy consumption has become a key research topic.

3. Characteristics of Aluminosilicate Refractory Fibers for Gas Furnaces

3.1 High-temperature Resistance

High-temperature resistance is a key and essential characteristic of refractory fibers. Generally speaking, ordinary aluminosilicate refractory fibers are amorphous fibers made by molten alumina, high-alumina raw materials, and refractory clay through a special cooling process. Because aluminosilicate refractory fibers have a thermal conductivity and heat capacity very similar to those of air, their porosity can reach over 90%. This allows the pores to be filled with a large number of low-thermal-conductivity particles, disrupting the continuous network structure of the solid molecules and achieving excellent heat resistance and thermal insulation properties. Therefore, the operating temperature of aluminosilicate refractory fibers is typically around 1000°C, with some even reaching 1300°C, making them suitable for high-temperature applications.

3.2 Chemical Stability

For aluminosilicate refractory fibers, their chemical composition and impurity content determine their chemical stability. Due to their low alkalinity content, the material is virtually insensitive to both hot and cold water, making it very stable in oxidizing atmospheres. However, if the aluminum silicate refractory fiber is placed in a strong reducing atmosphere, various impurities such as Fe2O3 and TiO2 in the fiber are easily reduced [2], which greatly affects the service life of the aluminum silicate refractory fiber.

3.3 Simple Construction

Aluminum silicate refractory fiber itself is light in weight and easy to process. After adding a binder, it can be formed into many different products. There are also finished products such as felt and blankets of various specifications. It has a wide range of uses and is relatively convenient to use. In addition, the current application range of aluminum silicate refractory fiber is relatively wide. There are many aluminum silicate material products in China that can be applied in most fields and can be applied without repeated research and development.

3.4 Bulk Density and Thermal Conductivity

For aluminum silicate refractory fibers, the use of different production processes will result in different aluminum silicate refractory fibers having large differences in bulk density, which is generally in the range of 50-200 kilograms per cubic meter. Compared with other materials, aluminum silicate refractory fibers have better refractory and thermal insulation properties and a lower thermal conductivity coefficient. The thermal conductivity coefficient can effectively measure the performance of refractory and thermal insulation materials. In addition, the thermal conductivity coefficient itself is not a constant, but is related to the bulk density and temperature. Compared with other materials, the bulk density and temperature of aluminum silicate refractory fibers are more suitable for gas furnaces [3].

4. Problems with Using Aluminosilicate Refractory Fiber in Gas Furnaces

4.1 Low Material Strength and Poor Resistance to Airflow Impact

On the one hand, aluminosilicate refractory fibers have low inherent strength. Due to the high energy consumption of the flame outlet, fiber bricks are often damaged by erosion. On the other hand, due to long-term exposure to high-temperature environments, the surface grains of aluminosilicate refractory fibers gradually grow and become brittle, reducing their tensile strength. After pulverization, the fibers are eroded by high-velocity airflow, causing the pulverized particles to flow with the medium and be continuously blown away. This affects the furnace temperature and increases heat loss, shortening the furnace's service life and impacting the surrounding environment.

4.2 Harmful Gas Erosion Destroys the Aluminosilicate Refractory Fiber Structure

In gas furnaces, the air composition inside the furnace is complex. Fuel combustion produces a high concentration of harmful gases with a complex composition. Furthermore, the raw materials contain various metal ions. Water vapor is also present. Refractory fibers themselves have a large specific surface area. If there is water vapor in the air, the refractory fibers will absorb a large amount of moisture, causing carbon dioxide and sulfur dioxide to dissolve in water to form weak acids. The weak acids will undergo a replacement reaction with the hydroxide ions in the fibers, thereby destroying the fiber structure. If used for a long time, the fibers will be corroded, rotted, and deteriorated. At the same time, some metal ions will react with aluminum silicate refractory fibers to form different solid products, thereby destroying the fiber network structure and affecting the service life of the aluminum silicate refractory fibers. In addition, harmful gases in the furnace will undergo more complex reactions with the refractory fibers, corroding the refractory fibers and destroying their own structure, causing the refractory fibers to pulverize, crack, shrink, and other undesirable phenomena, seriously affecting the service life and work efficiency of the refractory fibers.

4.3 Pulverization at High Temperatures

From a thermodynamic perspective, every substance has the property of minimizing its surface energy, so the total surface area of refractory fibers tends to be minimal. On the surface of refractory fibers, small crystallites gradually merge to form larger grains and particles. As the temperature rises, the unit volume increases, ultimately leading to a decrease in resistance to rapid cooling and heating. Since the volume change of crystallites is generally irreversible, cracks will form in densely sintered oxides based on grain size, and the fiber surface will gradually become rougher. When the surface crystallites of refractory fibers approach the fiber diameter, the fiber strength drops sharply, making it unable to withstand the operating pressure, resulting in pulverization. Furthermore, due to the long-term high-temperature operation of refractory fibers, the surface gradually roughens, increasing their curvature, causing them to sinter together and lose their elasticity, resulting in pulverization, shedding, and cracking.

When refractory fibers pulverize, the fibers will peel off layer by layer, but the appearance of the internal fibers will not change significantly. During operation in high-temperature environments, the surface fibers are corroded by harmful gases, causing their structure to deteriorate and forming a relatively viscous glass melt. Fine crystals within the glass melt are more likely to grow, disrupting the fiber structure, but forming a protective layer to protect the internal fibers.

4.4 Improper Installation and Improper Material Selection

There are numerous types of aluminum silicate refractory fibers, generally classified as standard, high-purity, and high-aluminum. Currently, the application of composite refractory fibers is not widespread. Factories typically select different types based on the characteristics of local raw materials. For example, if the raw materials contain high alkali or sulfur content, composite refractory fibers may be necessary.

Furthermore, current refractory fiber installation standards are insufficient. Many refractory fiber manufacturers use anchors and hooks to secure refractory fiber modules. These modules are secured entirely by applying external compression to the modules, which are then secured with strapping. The strapping is then released, allowing the expansion after compression to close the gaps between the modules. If the anchor nails are not completely positioned, the modules will move. At the same time, the shrinkage caused by high temperature will cause gaps between the modules, which will eventually cause the anchors to oxidize, causing the modules to fall off and become unable to be fixed, increasing material and labor costs and affecting work quality.

5. Protective Measures for the Application of Aluminum Silicate Refractory Fibers in Gas Furnaces

5.1 Select the Model and Specifications of Refractory Fibers According to the Raw Materials

The model and specifications of refractory fibers should be selected according to the characteristics and properties of local raw materials. For example, if the alkali content or sulfur content in the raw materials is high, it is best to select composite refractory fibers or high-aluminum refractory fibers to ensure that the refractory fibers will not be affected by chemical reactions of the components and affect their own working efficiency and service life [4]. At the same time, in order to ensure that the aluminum silicate refractory fibers can be used for a long time and are not affected by airflow, lightweight clay bricks can be retained in the furnace to reduce the impact on the aluminum silicate refractory fibers and extend the service life of the aluminum silicate refractory fibers. In the face of fiber volume shrinkage, the method of pasting two layers of fiber felt on the hot surface with a thickness of about 15 mm can be used to compensate for the disadvantage of volume shrinkage. However, this will also increase the workload during the work process. If necessary, preparations can be made in advance.

5.2 Use High-aluminum Refractory Fibers

First, high-aluminum refractory fibers should be used in the high-temperature zone of the furnace, and a high-temperature energy-saving fiber-specific radiation coating should be sprayed on the surface of the refractory fibers, with a thickness of about 1 mm. Secondly, ordinary refractory fibers can be used in the low-temperature zone, and special radiation coatings should also be sprayed. Thirdly, whether in the low-temperature zone or the high-temperature zone, steel plates with a thickness of 3-5 mm need to be laid on the structure, and anchor nails should be welded on the steel plates, and the thickness of the refractory fiber lining should be thickened to more than 300 mm to ensure that it complies with the provisions of GB/T 16400-2006 [5]. Finally, pay attention to the construction points and select a reasonable process according to the actual working environment to ensure that the refractory fibers meet the working requirements. And on this basis, the service life of the refractory fibers can be extended to the greatest extent.

5.3 Select a Reasonable Process to Make Aluminum Silicate Refractory Fibers

Compared with other refractory materials, the production cost of aluminum silicate refractory fibers themselves is relatively low, which can effectively reduce the cost of products. First, during use, alumina forms a skeleton in a high-temperature environment, which can ensure that the aluminum silicate refractory fiber will not deform under high-temperature conditions. Secondly, in the part where the alumina fiber and the aluminum silicate fiber contact, the excess silica in the aluminum silicate and the excess alumina in the alumina fiber can combine together to form a mullite structure, which protects the fiber and thus achieves a high-temperature resistance effect [6]. Thirdly, since the strength of aluminum silicate refractory fiber is relatively low, it can be combined with stainless steel wire or glass fiber as a reinforcing material to make products such as cloth and rope, which can be used as a furnace curtain to protect the surface of the aluminum silicate heat-resistant fiber and thus play a role in insulation. Finally, about 10% of organic fiber can be added during the manufacturing process of aluminum silicate refractory fiber, and the organic fiber needs to undergo special flame retardant treatment. The added organic fiber is mixed with the surface of the aluminum silicate refractory fiber, and then the reinforcing material is added to extend the service life of the aluminum silicate refractory fiber and the service life of the gas furnace.

5.4 Reasonable Selection of Furnace Lining Materials

The main function of the furnace lining is to insulate heat. Therefore, when selecting the furnace lining material, it should meet the requirements of operating temperature, working life, energy consumption, construction difficulty, furnace construction cost, etc., in order to extend the service life of the gas furnace and ensure that work efficiency and progress are not affected. The common problem faced by the current foundry is how to transform the resistance furnace with high energy consumption. First, it is necessary to measure the data of the transformed furnace to ensure that the data requirements can be met after the transformation. For example, multiple data such as rated power, furnace wall temperature, ambient temperature, heating time, etc. Secondly, due to the poor performance of the original heat-resistant insulation material of the old furnace, the lining of the old furnace is relatively thick. Therefore, it is necessary to fill the home insulation material during the transformation process while meeting the design requirements to ensure that the insulation and heat resistance performance are not affected, but the heat storage loss of the furnace lining will increase. In addition, the surface temperature of the furnace body should be between 50-80 degrees Celsius. If the temperature is too high, it will increase heat loss. If the temperature is too low, it will affect the insulation strength. The insulation material needs to be thickened, which will lead to material waste and increase heat storage loss [7]. Therefore, during the transformation and material selection process, it is necessary to reasonably select the material of the furnace lining according to actual usage.

6. Conclusion

Gas furnaces are ideal secondary energy sources for heating furnaces and industrial kilns in a variety of industries, including machinery, chemicals, light industry, building materials, glass, and metallurgy. Because they require gas combustion, the proper selection of refractory and high-temperature-resistant materials is crucial. Aluminosilicate refractory fibers can withstand operating temperatures between 1000°C and 1300°C, effectively facilitating gas furnace operation and serving as a valuable aid. However, current applications of aluminosilicate refractory fibers in gas furnaces still suffer from poor impact resistance, severe pulverization, structural damage, and improper installation. These issues result in a short service life and fail to meet the long-term operational requirements of gas furnaces. Therefore, it is crucial to select the type and specification of refractory fibers based on the raw materials, employ different processes to create fibers suitable for different environments, and carefully select the appropriate furnace lining material to maximize the service life of the aluminosilicate fibers without compromising operating efficiency. This, in turn, extends the life of gas furnaces, achieves energy savings, and significantly supports their development.

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