Development and Properties of Infrared High Radiation Energy-Saving Coatings for Industrial Furnace

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Abstract. A high temperature resistance infrared high radiation energy saving coating for industrial furnaces was developed, and it’s especially suitable for glass furnace with harsh working conditions. The phase composition and microstructure were characterized by XRD and SEM, and the normal spectral emittance of coatings was characterized by EMMA-HT, the energy-saving effect was simulated and tested in laboratory. After being applied to the medium aluminum glass furnace, the energy saving situation was analyzed. The results showed that the main phase of the coating was SiO₂, the particle size of the coating is less than 8.5μm, and the coating firmly combined with the siliceous refractory at high temperature. The normal spectral emittance of the coatings of 1~15 μm band at 1500~1700 oC was 0.93~0.95. It produced 8.26% energy efficiency in medium aluminum glass furnace.

1. Introduction

China's existing infrared high-radiation energy-saving coatings are mainly used in industrial furnaces in the metallurgical, chemical and ceramic industries, and achieved good energy-saving effect [1]. These types of infrared high-radiation energy-saving coating are mainly used in the working condition of long-term working temperature below 1400°C, and the main components are oxides of chromium, titanium, zirconium, iron, aluminum, manganese, nickel, cobalt, copper, lanthanum, cerium and the like and rare earth meta, or silicon carbide [2].

Due to the complicated high temperature working conditions of glass furnace, such as high temperature (about 1600°C), complicated combustion atmospheres (oxidation, reducing and neutral atmosphere segmented coexistence), long continuous working time (5 to 10 years) and the liquid glass is sensitive to impurities. The above infrared coatings can’t be used, and could adverse effects on glass coloring, stones, bubbles, cracks in later deep processing and so on [3].

The high temperature resistance infrared high radiation energy-saving coatings for industrial furnaces made of siliceous material, it has stable and excellent infrared spectral emissivity at 1500~1700°C and does not have any adverse effect on glass. When applied, it is sprayed on the inner wall of silicon refractory in industrial furnaces [4].
2. Text Materials preparation and measurement

2.1. Materials preparation
The high temperature resistance infrared high radiation energy-saving coatings made of self-made silicon high radiation base material, auxiliary high radiation materials, high temperature resistance protective agent, sintering additives, quartz powder, silica sol, pure water and other auxiliary agents. The dry powder in the above raw materials are pre-mixed, and then placed in the fluidized bed airflow mill for ultra-fine and uniform mixing. Mix the uniform mixed powder with liquid material and then enter the nano sand mill, obtained micro-nano-scale infrared high-radiation energy-saving coating.

2.2. Measurement
The particle size was examined by laser particle size analyser (Mastersizer3000). The crystal structures were examined by X-ray diffraction (XRD, Bruker D8). The micromorphology were observed by scanning electron microscope (SEM, FEI Nova450). The normal spectral emittance in wavelength range from 1μm to 15μm were examined by emittance measurement apparatus for high temperature (EMMA-HT) at 1500°C, 1600°C and 1700°C. The energy-saving data of the coating was measured by production control instruments of the glass factory.

3. Results and discussion
Figure 1 and figure 2 shows the particle size distribution, particle size and morphology of homogeneous mixture. As shown in the figures, homogeneous mixture is irregular particle with uniform size, $D_{90}$ is 5.35μm, and the particle size of the coating is smaller than 8.5μm. It shows that the particles of the coating can easily enter the pore of the silicon brick and penetrate into it, which is beneficial for the coating to adhere to the surface of the silicon brick and sinter together.

![Figure 1](image1.png)

**Figure 1.** Particle size distribution of uniform mixed powder

![Figure 2](image2.png)

**Figure 2.** Morphology of uniform mixed powder
Figure 3 shows the XRD patterns of the infrared radiation coating. As shown in the figure, all diffraction peaks are corresponding to SiO$_2$, and there is also a small amount of amorphous material. It shows that the composition of the coating is consistent with the silica brick, which can be well combined with the silica brick and does not pollute the products such as glass.

![Figure 3. XRD patterns of the infrared radiation coating](image)

The dry coating and glass batch were mixed according to 1:50 weight ratio, then melted at 1580°C, finally got molten glass sample. Figure 4 shows the XRD patterns of the glass sample, and it’s showed that the diffraction peaks are the typical glass amorphous diffraction peaks, indicated that the coating will not have a crystallographic effect on the glass.

![Figure 4. XRD patterns of the glass sample](image)

The coating was sprayed on the surface of silicon brick and then sintered at 1580 °C. Figure 5 shows the SEM image of cross-section of the coating after sintered on silica brick surface. It can be seen that the coating forms a dense coating on the surface of the silica brick, and has a tendency to penetrate into the loose internal structure of the silica brick. The sintered coating is very dense, so it has a certain protective effect on silica brick.
The normal spectral emittance $\varepsilon_{IR}$ of the sample measured at $T = 1500 \ ^\circ C$, $T = 1600 \ ^\circ C$ and $T = 1700 \ ^\circ C$ in air is plotted in Fig. 6 in the wavelength region between 1 μm and 15 μm. It can be seen from the figure that, the spectral emittance of the coating in the infrared range of 1μm~8μm is greater than 0.92, in the infrared range of 8μm~12.5μm is less than 0.90, in the infrared range of 12.5μm~15μm is greater than 0.90. Absorption peak of glass liquid and glass batch at high temperature is 1.5μm, and well matched with the infrared radiation band of the coating. The spectral emittance of the coating in 8.5μm~12μm is outside the effective absorption band of glass liquid and glass batch materials. As a result, the utilization of heat is increased, resulting in energy saving.

The resulting normal thermal emittances $\varepsilon_{IR}$ of the coating measured at temperatures $T = 1500\ ^\circ C$, $1600\ ^\circ C$ and $1700\ ^\circ C$, spectral range from 1μm - 15μm, are given in Table. 1.

Table 1. Normal thermal emittance $\varepsilon_{IR}$ of the coating measured at temperatures $T = 1500\ ^\circ C$, $1600\ ^\circ C$ and $1700\ ^\circ C$, spectral range from 1μm - 15μm.

| name                  | $T=1500\ ^\circ C$ | $T=1600\ ^\circ C$ | $T=1700\ ^\circ C$ |
|-----------------------|--------------------|--------------------|--------------------|
| Normal thermal emittance $\varepsilon_{IR}$ | 0.93±0.02          | 0.95±0.02          | 0.95±0.02          |
table 1. It is known that at 1500 °C~1700°C the normal thermal emittance is 0.92~0.95, shows the coating has stable infrared radiation property at high temperatures.

4. Application and Discussion
The coating was applied in a 250t/d medium aluminum glass furnace, sprayed on the inner surfaces of all the siliceous walls of the melting section and clarification section, included the crown, the breast wall of the clarification section, the back wall of the melting section, and the vertical wall section of the L-shaped suspended wall.

After the stable production of the glass furnace, the photograph of the inside of the furnace was observed, and the actual production and the unit consumption of the glass were calculated and compared with the design values.

![Figure 7. Photograph of the inside of the furnace](image)

As shown in figure 7, the brick surface and brick joint inside melting furnace were clearly visible. The surface energy-saving coating re-radiates a large amount of heat back into the kiln, avoiding the high-temperature melting of the sprayed refractory material.

Table 2 shows the energy saving situation of high radiation energy-saving coatings in this furnace. The calculation results show that actual unit consumption is 165.2 kcal /kg lower than design value, generated 8.26% energy efficiency.

Table 2. Calculation results of thermal balance tests

| name                     | design production | actual production | design unit consumption | actual unit consumption | energy efficiency |
|--------------------------|-------------------|-------------------|-------------------------|-------------------------|-------------------|
| medium aluminum glass    | 250t/d            | 250t/d            | 2000kcal/kg             | 1834.8kcal/kg           | 8.26%             |
| furnace                  |                   |                   |                         |                         |                   |

5. Conclusion
Infrared high radiation energy-saving coatings for industrial furnace has a small particle size and is well sintered with refractory materials. The normal spectral emittance of the coatings of 1~15 μm band at 1500~1700°C was 0.93~0.95. It produced 8.26% energy efficiency in medium aluminum glass furnace.

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