# STUDY ON THE APPLICATION STRATEGY OF THERMAL RADIATION COATINGS IN RONGDAO KILN OF CERAMIC DESIGN INDUSTRY UNDER THE BACKGROUND OF ENERGY SAVING AND EMISSION REDUCTION

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*Under the background of energy saving and emission reduction, energy-saving renovation of kilns in ceramics industry has always been the key step to promote sustainable development strategy in ceramics industry, and also one of the key points for enterprises to reduce production costs. For the manufacturing enterprises of gongdao kiln in ceramics industry, the choice of refractory and heat preservation materials is one of the keys to manufacturing high efficiency and energy saving kilns. Through a series of technological innovations and development experiments, the researchers solved the problem of surface peeling of thermal radiation materials after sintering on the inner wall of kiln, and made the thermal radiation materials more widely used. This paper introduces the development process, physical and chemical characteristics, energy-saving principle and application methods of heat radiation energy-saving coatings, and lists specific examples for analysis. Through energy-saving comparative experiments and specific application cases, it shows that thermal radiation energy-saving coatings have great application prospects in the ceramic industry, and should be vigorously promoted to provide direction for energy-saving and emission reduction in the ceramic industry.*

Key words*: energy saving and emission reduction; thermal radiation coating; ceramic industry; rongdao kiln*

## 1. Introduction

Thermal radiation energy-saving coatings have been applied to the inner walls of heating furnaces in many industries, such as steel, petrochemical, ceramics, mechanical processing, etc. With its excellent near infrared radiation, the thermal radiation intensity in the furnace has been strengthened. Through this measure, the original firing process has been improved, thus greatly improving the thermal efficiency and productivity of the furnace, reducing the heat loss, prolonging the service life of the furnace wall, and achieving the purpose of energy saving and emission reduction [1].The research and application of radiation coatings have been widely concerned. Coating radiation coatings with high radiation efficiency on the lining of kilns can effectively improve the thermal efficiency of kilns. In order to save energy consumption, it has been successfully reported in the application of high temperature equipments such as reaction furnaces in petrochemical industry and annealing furnaces in metallurgical industry [2].

Since the end of 2002, there has been a precedent for the application of thermal radiation energy-saving coatings in ceramic industry, but Japan has listed the ceramic industry as a forbidden zone for energy-saving coatings [3]. The reason is that the ceramic industry has a higher requirement for energy-saving coatings: peeling phenomenon should not occur. Because the thermal radiation coatings are black, the ceramic products produced are white or light color. If the black coatings fall off, the products will be scrapped. At that time, similar products in Japan still had a few peeling problems. In order to overcome the technical difficulties and make energy-saving coatings enter the ceramic industry smoothly, Nissan company has made hundreds of dispatches in the raw material production of energy-saving coatings [4]. A heating simulator is specially manufactured in the factory. It takes more than one year to repeatedly test and sinter the coatings of various proportions. After hundreds of failures and setbacks, the coatings that meet the requirements of ceramic enterprises are finally manufactured. The new thermal radiation energy-saving coatings were put on the ceramic production line at the end of 2004 [5]. Up to now, the thermal radiation energy-saving coatings have been used in more than 100 ceramic kilns, achieving the expected energy-saving effect, bringing huge energy-saving benefits to these enterprises [6].

In recent years, the construction pottery industry has made great progress with the rapid growth of China's economy. Although the energy consumption of building ceramics is decreasing due to technological progress, the total energy consumption is still increasing, so it is very important to continue to strengthen the popularization and application of energy-saving technology. However, in the design and renovation of kilns in the pottery industry, radiation coating has not been recognized by the vast number of practitioners, nor has it been widely used. The reason is caused by many factors. The reasons for this and the problems related to the application of radiation coatings in energy saving of kilns and furnaces in ceramics industry are analyzed and discussed.

## 2. Energy-Saving Mechanism of Radiation Coatings

According to the thermal principle, the products are heated and sintered in the kiln, mainly relying on radiation heat transfer and convective heat transfer to complete the heat transfer of heat source and heated products [7]. The main function of refractory and thermal insulation materials of kiln lining is to prevent heat dissipation to external environment. In order to improve the thermal insulation effect, refractories and insulation materials with low thermal conductivity and small thermal capacity are usually selected to prevent heat dissipation to the external environment, or to further improve the thermal insulation effect by increasing the thickness of refractories or insulation materials, as shown in Figure 1.

Coating radiation coating on the inside of the kiln can obviously improve the thermal insulation effect of the kiln material. If we consider the kiln body, heat source and firing products as a system, when the temperature T1 inside the kiln body is higher than the temperature T2 of the products during the firing process (usually T1 > T2 during the heating process of the products under non-thermal equilibrium state), the kiln body is not only the heater of the heat source, but also the heating body of the firing products. The kiln body absorbs the heat transferred by the heat source through radiation heat transfer and convection heat transfer. Part of the heating of the kiln products is maintained by reflection and re-radiation, and part of the heat is dissipated by heat conduction of refractories and thermal insulation materials in the kiln body. If the coating with high emissivity is coated on the inner lining of kiln, besides reflecting heat, the heat absorbed by radiation and convective heat will be emitted in the form of re-radiation [8]. Because of the high emissivity of the coating, its radiation efficiency will be high. When the re-radiation heat acts on the sintered products, it not only improves the utilization efficiency of heat energy, but also reduces the heat conduction potential energy of the kiln body, reduces the heat conduction loss, improves the heat resistance effect, and achieves the purpose of energy saving, as shown in Figure 2.

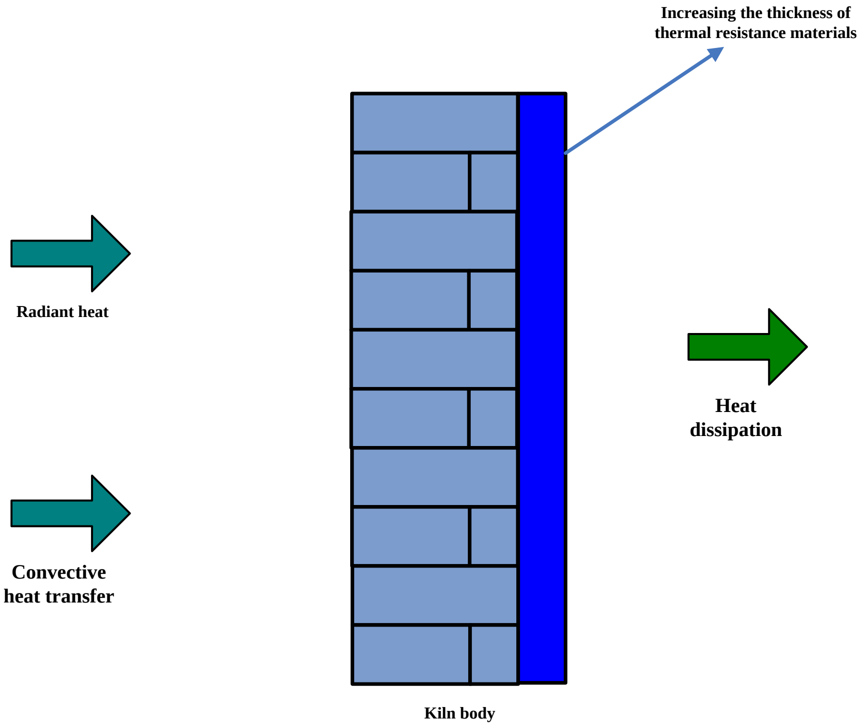


**Figure 1** Schematic diagram of kiln heating

The re-radiation energy of coatings can be expressed by Q, and the relationship between re-radiation energy and radiation coefficient of coatings can be expressed by the following formula:

$$Q = E_w \cdot \sigma \cdot \left(T_C^4 - T_L^4\right) \tag{1}$$

In the formula:

$Q$ ——Reradiation energy;

$E_w$ ——Radiation coefficient of coatings;

$\sigma$ ——Stephen-Boltzmann constant;

$T_C$ ——Paint temperature;

$T_L$ ——Temperature of fired products.

As shown in the above formula, the re-radiation energy increases with the increase of the radiation coefficient of coatings and the temperature difference between coatings and firing products.

The radiation coefficient of most refractories is relatively low, especially in high temperature environment. The radiation coefficient of many refractories is only 0.2~0.5. At present, the radiation coefficient of radiation energy-saving coatings with high radiation coefficient can reach 0.8~0.9. Therefore, coating energy-saving radiation coating with high radiation coefficient can greatly improve the re-radiation energy inside and outside the kiln body. At the same time, the re-radiation characteristics of the high radiation coating can reduce the heat conduction loss of the kiln body material, which reduces the dissipation of heat energy and plays a protective role on refractories.

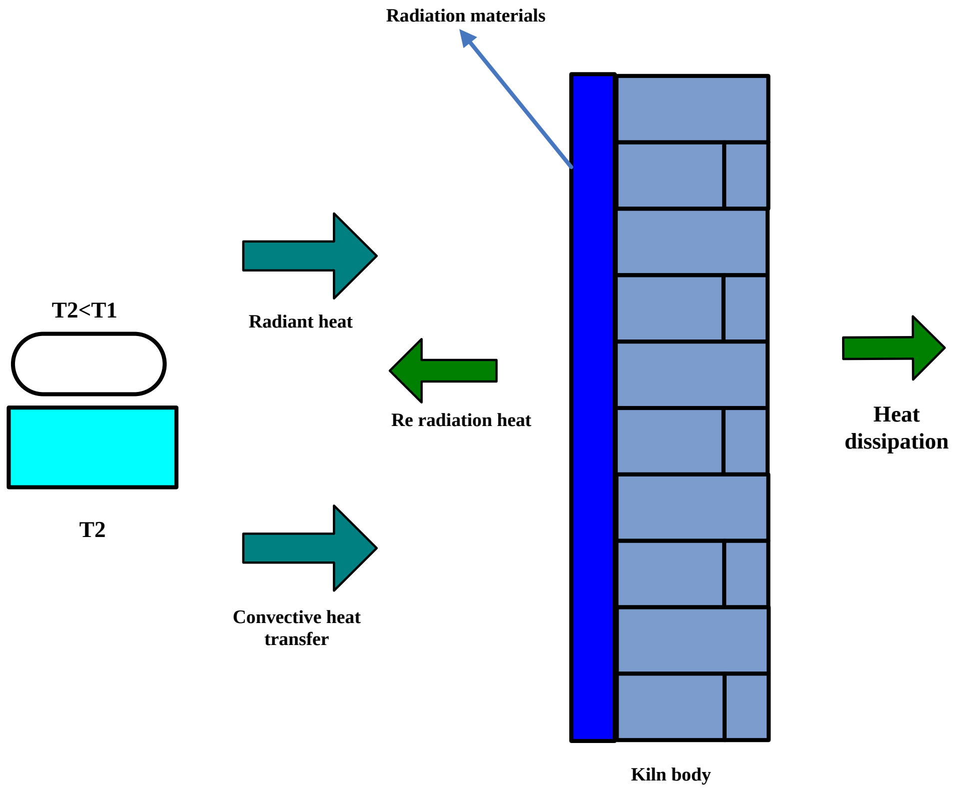


**Figure 2** Schematic diagram of radiation coating kiln body heating

## 3. Application of Thermal Radiation Energy Saving Coatings in Ceramic Furnace

### 3.1. Basic theory of radiation energy

Heat conduction, convection heat and radiation heat are three ways of heat conduction. In industrial heating furnaces, the heat conduction modes are somewhat different due to the different structures of various furnaces such as pottery roller kiln, steel thermal SLN furnace and petroleum cracking furnace. Some of the heat energy transfer is in the form of radiation conduction. The magnitude of thermal radiation energy increases sharply with the increase of temperature in the furnace. At high temperature, thermal radiation plays an absolute dominant role in heat transfer, accounting for more than 90% of the total heat conduction energy. Therefore, improving the thermal radiation energy of the furnace is the key to improve the thermal effect of the furnace.

Table 1 shows the proportion of visible light to infrared light at different temperatures. It can be seen from the table that when the temperature of an object is below 550 C, there is actually no visible light radiation, and the thermal radiation is mainly infrared. When the temperature of the sun is close to 6000K, visible light accounts for a large proportion of its thermal radiation.

**Table 1** Visible and infrared light occupied at different temperatures

| Temperature(C) | Proportion | |
|---|---|---|
| | Visible light | Infrared |
| 1200 | <0.1 | >99.9 |
| 1600 | 0.14 | 99.96 |
| 3500 | 11.5 | 88.6 |
| 6000 | 45.6 | 42.8 |

In industrial furnaces, when the temperature in the furnace is near 800 degrees celsius, near infrared and far infrared rays account for almost half of the total. When the furnace temperature is between 1000 and 1300 degrees celsius, the near infrared ray will account for more than 90% and the other 5% is visual light. Near 800 nm, the photon carrying energy is 1.5 eV, while at 4 um, it is 0.4 eV, which is four times the difference. Therefore, in order to improve the emissivity, attention should be paid to the near infrared near the visible light. If it is not the material that absorbs infrared rays, the effect of thermal radiation will not be great. When an object is irradiated by infrared radiation, it will cause resonance vibration and generate heat. The energy absorbed by infrared radiation is the same as that of atomic and molecular vibrations. The atoms and molecules of an object vibrate continuously, and the heat increases continuously.

Beams containing a lot of energy, in the form of infrared, consist of many photons, which hit the surface of the inner wall of the furnace. Substances on the inner surface absorb photons, which disappear because the energy is taken away by the electrons of the surface material. However, when the electrons acquire energy, they begin to vibrate violently, resulting in new photons diffusing outward. The new photons hit the surface of the processed parts such as porcelain and are absorbed. Their energy can be absorbed by the material on the surface of the processed products, thus heating the surface of the processed products. Thermal energy is transmitted to the interior of the processed product through heat conduction and accumulated continuously, thus increasing the overall temperature of the processed product until it reaches the required temperature, and then moving to the next stage of production.

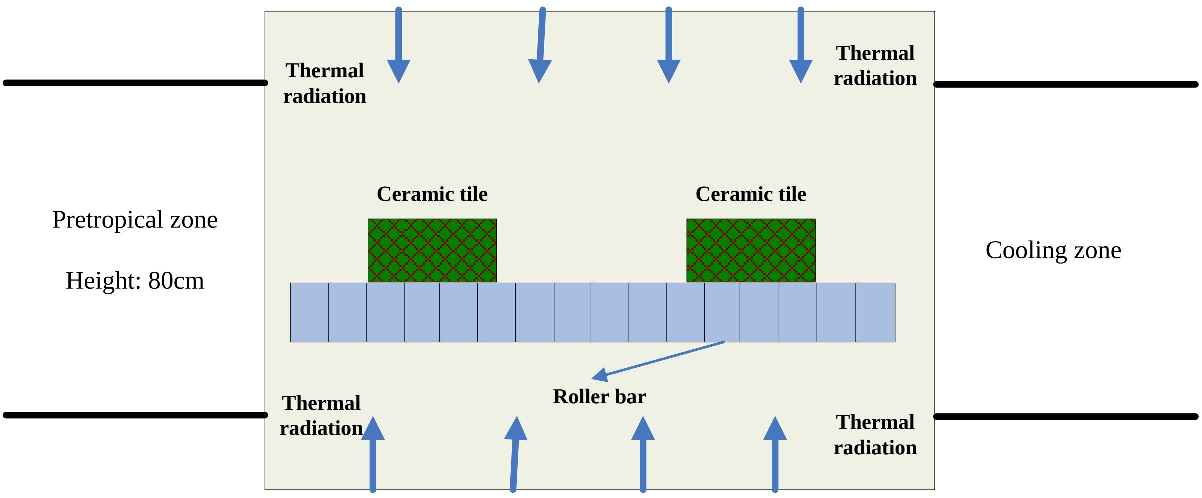


**Figure 3** Production schematic diagram of Rongdao kiln

Because the radiation energy is inversely proportional to the square of the radiation distance and COS is related to the radiation angle, the larger the volume of the furnace body, the farther the distance between the top wall and the processed object, the worse the radiation intensity and effect. Roller-type ceramic tile kiln has a close top surface to the ceramic tile surface (only 30-50 cm), so its radiation performance is much stronger than that of the heating furnace in the iron and steel industry, and it can receive radiation more effectively, as shown in Figure 3.

### 3.2. Analysis of energy-saving application of thermal radiation coatings

The radiation rate of refractory bricks and castables used in industrial furnaces is 0.6~0.7, while the radiation rate of thermal radiation coatings is above 0.95 at 200~800 C, and higher than 0.97 at

950~1100 C. The higher the temperature in the furnace, the stronger the radiation energy of the furnace itself. The radiation rate of one of the heat radiation coatings (HRC) is shown in Figure 4.

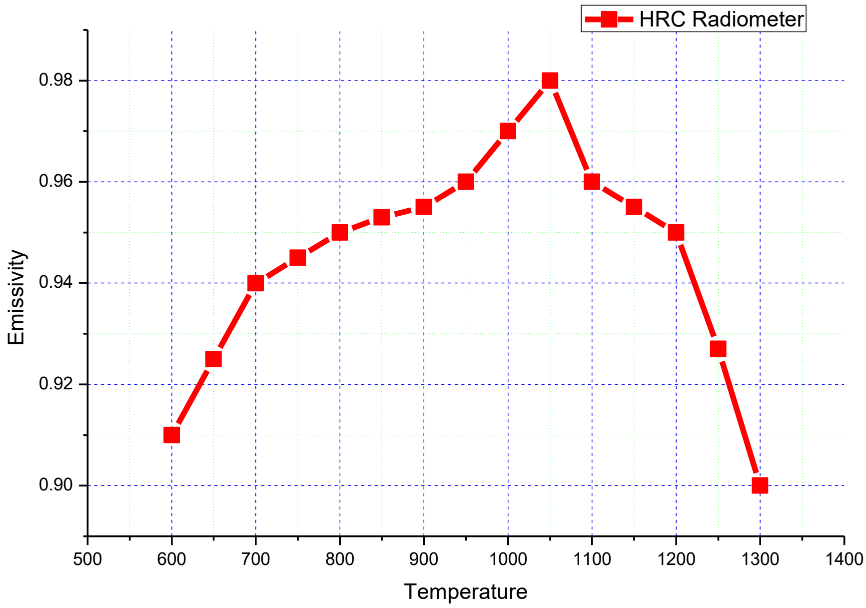


**Figure 4** Radiation rate of HRC for thermal radiation coatings

Table 3 is an energy-saving effect of a thermal radiation coating (HRC). According to the famous four-power principle of thermal engineering, namely Stephen-Boltzmann formula:

$$E_{\beta}=\delta\left(T/100\right)^{4} kcal/\left(m^{2}\bullet h\right), \delta=4.88kcal/\left(m^{2}\bullet h\bullet k^{4}\right)$$

$$E_{w}=\varepsilon_{w}\times 4.88\times\left(T_{w}/100\right)^{4} kcal/\left(m^{2}\bullet h\bullet k^{4}\right)$$

$$E_{w}=\varepsilon_{w}\times 4.88\times\left(\frac{T_{w}+273}{100}\right)^{4}$$

$$T_{w}=\sqrt[4]{\frac{E_{w}}{\varepsilon_{w}\times 4.88}}\times 100-273$$

In the formula:

$E_{\beta}$ ——Total radiation heat energy of blackbody;

$E_{w}$ ——Full radiation heat energy of furnace wall;

$\varepsilon_{w}$ ——Furnace wall total radiation rate;

$T_{w}$ ——Temperature of furnace wall.

**Table 2** Energy saving effect of a thermal radiation coating (HRC)

| Firing section | $E_w$ | | $\varepsilon_w$ | $T_w$(C) |
|---|---|---|---|---|
| | (kcal/m$^2$.h) | (kJ/m$^2$.h) | | |
| High temperature section A | 122495 | 508732 | 508732 | 1200 |
| | 167597 | 697289 | 697289 | 1200 |
| | 122495 | 508732 | 508732 | 1000 |
| | 89418 | 369376 | 369376 | 1000 |
| Low temperature section B | 19952 | 83978 | 82978 | 650 |
| | 26895 | 198971 | 198971 | 650 |
| | 19952 | 82978 | 83978 | 500 |
| | 15385 | 63964 | 64964 | 500 |

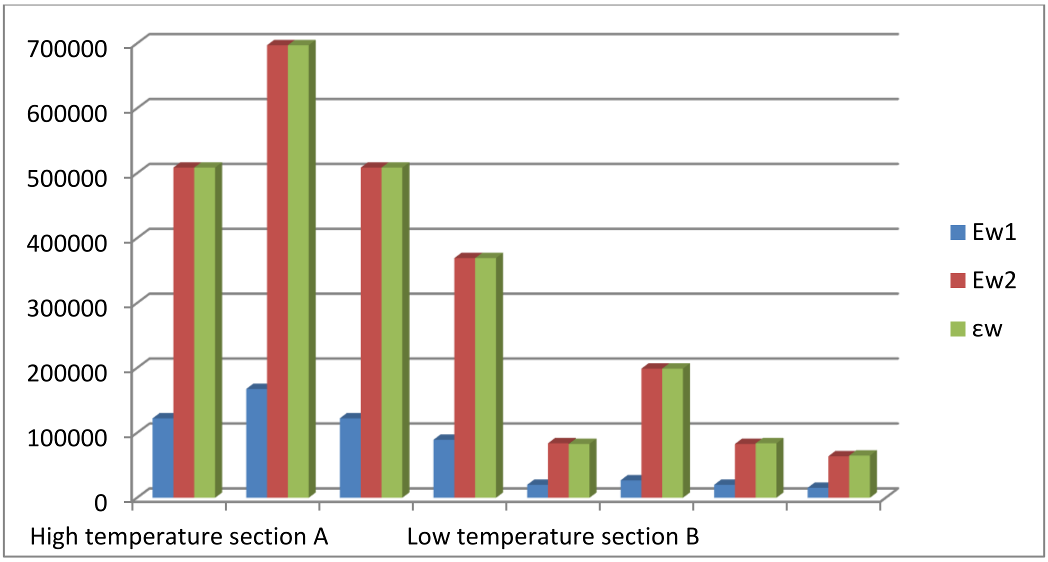


**Figure 5** Energy saving effect of a thermal radiation coating

Table 2 shows that:

- When the inner wall of the kiln is firebrick, its radiation rate is below 0.7, and the radiation heat at 1100 degrees celsius is 518732kJ/($m^2$.h); when coated with thermal radiation paint, the radiation rate rises to 0.96 and the radiation energy rises to 697289kJ/($m^2$.h). Since the thermal energy required for ceramic tile sintering can be considered as a constant, i.e. 518732kJ/($m^2$.h), when the emissivity rises to 0.95.8, the furnace wall temperature can be reduced to 987 degrees celsius.
- In high temperature section A, the furnace temperature can be reduced from 1100 degrees celsius to 997 degrees celsius due to the increase of radiation rate from 0.72 to 0.98, and the temperature difference is 105C. The average reduction of 1 can save 1329 kJ ($m^2$.h). In the low temperature section B, the radiation rate of the furnace wall increases from 0.7 to 0.91 by spraying thermal radiation coating, and the temperature difference is 55 degrees celsius. The average energy saving is 356 kJ/$m^2$.h for every decrease of 1 degrees celsius.

If the input heat energy is constant and the demand energy consumption is constant, the processing time of the other function h can be greatly shortened. That is to say, it can speed up production and increase production (but when using this, it must match the physical and chemical characteristics of the processed object and the next process).

Figure 6 is a schematic diagram of HRC energy-saving principle for thermal radiation coatings. The line above is the thermal energy curve at the corresponding temperature after applying HRC for thermal radiation coatings. The following line is the thermal energy curve of refractory bricks under the corresponding temperature conditions. It is obvious that the difference between the two lines is the increase of thermal energy caused by the use of thermal radiation coating HRC. If the required heat energy is constant, such as 670,000 kJ heat energy required to be released, 1200 degrees celsius required for refractory brick furnace surface, and only 1100 degrees celsius for HRC on a horizontal line, that is to say, the same heat energy can be obtained without that high temperature. In other words, the use of heat radiation coating HRC can reduce a large amount of fuel input, and the higher the temperature used in the furnace, the more significant the energy-saving effect.

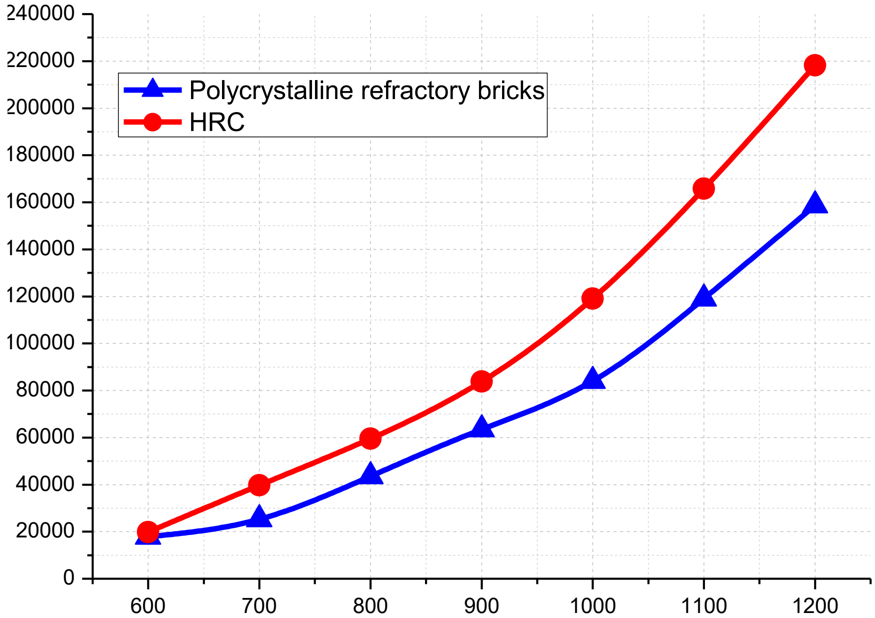


**Figure 6** Schematic diagram of HRC energy-saving principle for thermal radiation coatings

## 4. Application Experiments and Analysis of Thermal Radiation Energy Saving Coatings

Table 3 and Figure 7 are the energy-saving comparative experiments of HRC, a thermal radiation energy-saving coating, in a Ceramic Co., Ltd. in Rongdao kiln. Two furnaces with identical electric power produced by the same factory were used in the experiment. One of them was sprayed with HRC energy-saving paint on the inner wall, while the other was still made of ordinary refractory bricks. Set the same pre-set temperature of 1140 to automatically cut off power after reaching the temperature, and then calculate the power consumption according to the time, voltage and current used for energy saving comparison. Because the furnace is heated entirely by radiation heat, there is no influence of convective heat and heat conduction, so the effect is very intuitive.

**Table 3** Energy-saving contrast experiment of heat radiation energy-saving coating HRC in gongdao kiln

| Project | Starting time | Cumulative time consuming (min) | Temperature (C) | Voltage (V) | Electric current (A) | Power (kW) | Cumulative power consumption (kWh) |
|---|---|---|---|---|---|---|---|
| Roadway furnace using HRC | 14:00 | Start | * | * | * | * | * |
| | 14:10 | 10 | 400 | 176 | 25 | 4.2 | 0.36 |
| | 14:20 | 20 | 650 | 173 | 24 | 3.96 | 1.14 |
| | 14:30 | 30 | 800 | 174 | 24 | 3.98 | 1.72 |
| | 14:40 | 40 | 900 | 170 | 23 | 3.75 | 2.444 |
| | 14:50 | 50 | 1000 | 170 | 23 | 3.75 | 2.96 |
| | 15:00 | 60 | 1100 | 170 | 22 | 3.68 | 3.67 |
| | 15:08 | 68 | 1150 | 170 | 22 | 3.68 | 3.93 |
| Contrast furnace without HRC | 14:00 | Start | * | * | * | * | * |
| | 14:10 | 10 | 300 | 208 | 25 | 4.96 | 0.42 |
| | 14:20 | 20 | 620 | 202 | 23 | 4.5 | 1.25 |
| | 14:30 | 30 | 750 | 206 | 23 | 4.6 | 1.92 |
| | 14:40 | 40 | 850 | 205 | 23 | 4.5 | 2.76 |
| | 14:50 | 50 | 960 | 206 | 22 | 4.4 | 3.43 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 15:00 | 60 | 1050 | 206 | 21 | 4.2 | 4.21 |
| | 15:10 | 70 | 1130 | 206 | 22 | 4.3 | 4.94 |
| | 15:15 | 75 | 1150 | 206 | 22 | 4.3 | 5.15 |

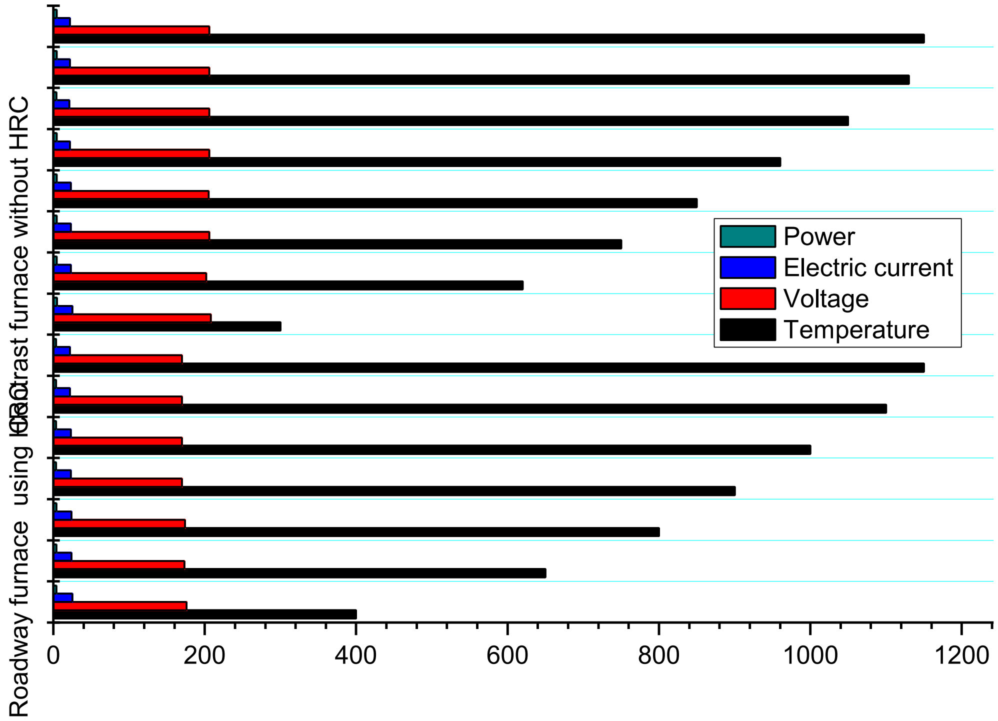


**Figure 7** Data comparison chart

Contrastive conclusion of energy saving: the energy saving rate of HRC furnace is 23.35% when the two furnaces are heated to 1140 degrees celsius. Heat radiation coatings HRC has remarkable energy saving effect and is not easy to peel off, but its unit price is higher than other energy saving coatings, and the cost of one-time investment is higher. Compared with other low-cost coatings, HRC has much higher economic value. When investing in a project, the first consideration should be the return on investment of the whole project, not the investment cost itself. For a furnace, HRC with high quality and value of hundreds of thousands of yuan can be firmly combined with the inner wall of the furnace wall without falling off, and can play its excellent energy-saving role for a long time, so that for several years, it can get more than ten times or even tens of times of return. If we use cheap coatings, although the initial investment is only tens of thousands of yuan, but only 100,000 yuan is received every year, and this kind of coatings will spend tens of thousands of yuan every year to re-spray, the total cost of using more than seven years is higher than the one-time investment cost of high-quality energy-saving coatings. In addition, a large amount of manual work is needed every year to re-construct, and the peeling of paint can not only protect the furnace wall, but also affect the quality of products, even cause huge economic losses.

## 5. Conclusions

In recent years, new refractories and thermal insulation materials have developed rapidly, and a variety of new materials have emerged, such as lightweight thermal insulation materials, high temperature refractory fibers, etc. The use of these new materials plays a key role in the energy-saving effect of kilns. Therefore, kiln manufacturers pay more attention to the choice of kiln structure and new materials in the development of new kilns. After repeated research and improvement by engineers and technicians, thermal radiation coatings have become excellent energy-saving and emission-reducing products, which have been applied in furnaces of iron and steel, petrochemical, automobile and ceramic enterprises in China and other countries, and achieved good energy-saving results. The improved thermal radiation coating has been applied to the kilns of the ceramic industry, which solves the problems of peeling off, dirt and dust emission of the coating, thus greatly promoting its popularity in the ceramic industry. The application practice of some ceramics enterprises shows that the thermal radiation ability of kiln wall is greatly enhanced by spraying thermal radiation coating. Under the same production conditions, the highest firing temperature can be reduced or the firing speed can be accelerated, and the purpose of reducing the energy consumption of firing can be achieved.

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