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Experimental Investigation to Study the Thermal Performance of a Silicon Carbide Coated Furnace

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Abstract: *This paper describes a new method which increases the radiation heat transfer of furnace refractory. As heating-up time is decreased, the method also makes the operation of the furnace more flexible. Application of silicon carbide furnace coating increases the emissivity of ceramic fiber insulation by 40%. The phenomenon is illustrated by infrared gun and their temperature analysis. IR-emissivity (εn, $\Delta\lambda$) was measured by infrared gun. Industrial applications are also referred to. The appearance of some new furnace construction materials, e.g. ceramic fiber insulations and high emissivity coatings (such as 'SiC coating') requires the revision of the wall structure of some furnaces. Research was done regarding a silicon carbide (SiC) based furnace coating. Its emissivity is considerably greater than that of the material onto which it was applied. The basic phenomena resulting from the application of 'SiC coating' and its thermal effects were examined in the case of several continuous furnaces of brick factories. The increase of heat radiation due to SiC coating of refractories decreases the heat losses and results in the recuperator (cooling) part of the furnace a better cooling of brick piles and some decrease in environment pollution too.*

Keywords: Emissivity, Silicon Carbide, Refractory Materials, Heating Enclosure.

1. INTRODUCTION

The turn of the 21st century has ushered in a very fast development leading to high demand for energy, leading to very high demand for natural mineral resources of crude oil, coal and natural gas. Our consumption of these minerals is so high that the deposits would be extinct in next 50 years. The searches for alternative energy sources are being developed, but till then we have to stretch the available mineral resources to avoid crisis. In this attempt all the methods for energy saving conservation and judicious use of energy have emerged in all processes involving heating (like ovens, kilns and furnaces).

Over a period of time it was observed that components loaded inside the enclosure were not uniform and there were rejections. To overcome this practice of setting higher temperature was resorted to which again caused rejections due to overheat. Then attempts to map the temperature of the furnace interior showed large areas which did not attain the set temperature were found. Then radiation was recognized as the primary cause and study of the emissivity of furnace interior walls was taken up.

The factors affecting the infrared radiation of furnace surfaces and high temperature industrial equipment have not yet been studied widely enough. Emissivity value depends on the surface temperature and material properties of the radiating object, and on the radiation wavelength. For instance, the emissivity of a given type of a chamotte refractory brick is 0.5 at a temperature of 1030°C. Recent research has been focused on high emissivity coatings of ceramic fibers, which increase the fibers

mechanical strength and the emitted energy. Experiments revealed that by employing a silicon carbide based coating the emissivity of a ceramic fiber can be increased to 0.56-0.63 from 0.45

2. WORKING PRINCIPLE

2.1 Stefan-Boltzmann Law

The Stefan–Boltzmann law describes the power radiated from a black body in terms of its temperature. Specifically, the Stefan–Boltzmann law states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time (also known as the black-body radiant exitance or emissive power), is directly proportional to the fourth power of the black body's thermodynamic temperature T.

$P = \sigma A T^4$, Where , P = Total radiated power, W

σ = Stefan’s Boltzman constant, 5.67 x 10^{-8} W/m^2K^4

A = Surface area, m^2

T = Surface temperature, K

2.2 Emissivity

The emissivity of the surface of a material is its effectiveness in emitting energy as thermal radiation. Thermal radiation is electromagnetic radiation and it may include both visible radiation (light) and infrared radiation, which is not visible to human eyes. The thermal radiation from very hot objects is easily visible to the eye. Quantitatively, emissivity is the ratio of the thermal radiation from a surface to the radiation from an ideal black surface at the same temperature and wavelength as given by the Stefan–Boltzmann law. The ratio varies from 0 to 1. The surface of a black object emits thermal radiation at the rate of approximately 448 watts per square meter at room temperature (25 °C, 298.15 K); real objects with emissivities less than 1 emit radiation at correspondingly lower rates.

3. EXPERIMENTAL SETUP

3.1 Heating Enclosure

A heating enclosure was constructed for heating up of brick samples so that the experiment could be performed. The enclosure was made to withstand temperatures around 900 °C. The enclosure uses electrical heater coils for heating process. The heater coil was made of Kanthal wire which could withstand very high temperatures. Insulation for the enclosure was given using low alumina bricks and ceramic wool material. The dimensions for the enclosure are shown in the Fig. 3.1. The enclosure took around 3-4 hours to attain desirable temperatures.

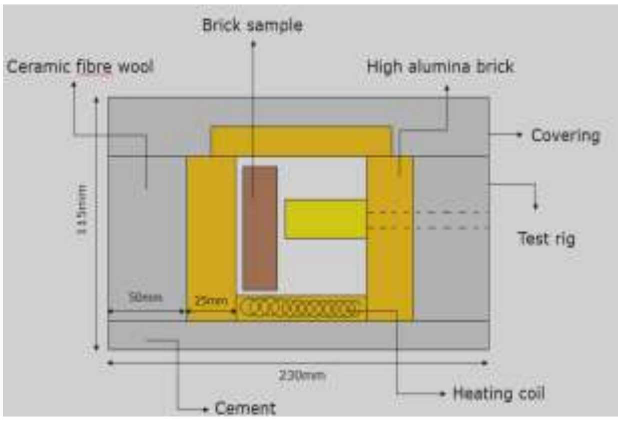

Fig. 1 Heating Enclosure **Fig. 2 Top view of enclosure with brick sample**

3.2 IR Gun

An IR gun or infrared thermometer was used to note down the surface temperature readings. An IR gun is a device which can give surface temperature values emitted due to radiation. It emits out infrared rays to the surface to note down the temperatures. The specifications of the IR gun are given below.

Table 1. IR Gun Specifications

FEATURES	RANGE OF VALUES
1. Temperature	Infrared thermometer
2. Temperature range	-50℃~ 1100℃
3. Accuracy resolution	±2% or 2℃
4. Response time	≤ 0.5 S
5. Power / power life	9V / about 12 hours
6. Wavelength	630 nm – 670 nm

3.3 Brick Samples

Three different refractory bricks were used up for this experiment. The ceramic fiber, high alumina and low alumina are having emissivities as 0.45, 0.48 and 0.45 respectively.

Fig. 3 Ceramic Fiber Board with coating

Fig. 4 High alumina brick with coating

Fig. 5 Low alumina brick with coating

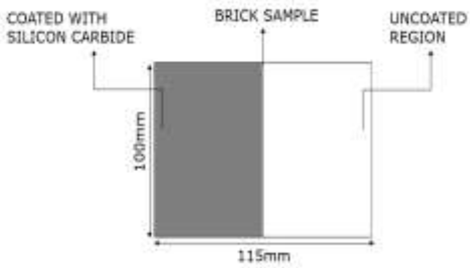

Fig. 6 Brick sample details

The brick samples were half coated with silicon carbide and half of the surface was left uncoated as shown in Figure 6.

These samples were kept inside the heating enclosure and heated up, so that the surface temperature emitted from both the surfaces could be noted.

4. EXPERIMENTAL PROCEDURE

In this experiment, at first the brick sample used in the procedure is half coated with silicon carbide and the other half is left uncoated. The brick sample is now kept inside the heating enclosure where it is heated up to 850℃. The surface temperature readings of both coated and uncoated side are recorded in the range of 600 to 850℃ taken at an interval of 50℃ using the IR gun arrangement. Using the temperatures recorded, we can calculate the radiated energy and then the emissivity of coated side can be calculated using the known emissivity of the brick sample. These readings are tabulated and the percentage increase in emissivity is calculated. The above steps are repeated for the other brick samples. When we analyze the readings, we find the coated surface is at higher temperature proportional to emissivity.

5. CALCULATIONS

The radiated heat energy is calculated using the formula,

$q = \sigma A T^4$.

The emissivity value is calculated using the formula,

$$\varepsilon = q_1/q_2$$

Where,

q_1= heat radiated by brick sample

q_2= heat radiated by black body

$$\varepsilon_c = \frac{\sigma A T_c^4}{\sigma A T_b^4}, \varepsilon_u = \frac{\sigma A T_u^4}{\sigma A T_b^4}$$

$$\frac{\varepsilon_c}{\varepsilon_u} = \frac{T_c^4}{T_u^4}$$

Where,

ε_c = emissivity of coated surface

ε_u = emissivity of uncoated surface

6. RESULTS & DISCUSSION

6.1 Ceramic Fiber Board

Table 2: Ceramic fiber board readings

Sl No.	Silicon carbide coating temp In °C	Uncoated temperature In °C	Emissivity Of brick	Emissivity Of silicon carbide	% Increase in emissivity
1	600	560	0.45	0.55	22.22
2	654	604	0.45	0.56	24.44
3	701	660	0.45	0.55	17.44
4	755	704	0.45	0.56	22.22
5	801	721	0.45	0.55	33.56
6	851	760	0.45	0.63	40

6.2 High Alumina Brick

Table 3: High alumina brick readings

Sl No.	Silicon carbide coating temp in °C	Uncoated temperature in °C	Emissivity Of brick	Emissivity Of silicon carbide	% Increase in emissivity
1	600	573	0.48	0.54	12.5
2	650	634	0.48	0.53	10.41
3	700	676	0.48	0.53	10.41
4	751	725	0.48	0.531	10.6
5	803	775	0.48	0.56	11.04
6	850	811	0.48	0.56	16.67

6.3 Low Alumina Brick

Table 4: Low alumina brick readings

Sl no.	Silicon carbide coating temp In °C	Uncoated temperature In °C	Emissivity Of brick	Emissivity Of silicon carbide	% Increase in emissivity
1	613	583	0.45	0.516	14.67
2	650	620	0.45	0.513	14
3	700	675	0.45	0.55	11.11
4	750	715	0.45	0.517	14.88
5	800	753	0.45	0.54	20
6	851	796	0.45	0.55	22.22

7. CONCLUSIONS

Fabrication of heating enclosure was done to heat the samples till 900 °C. The test samples were successfully experimented on and gave the following results:

1. The emissivity percentage of ceramic fiber board has increased from 22% to 40% for a temperature range of 600-850 °C.

2. The emissivity percentage of high alumina brick has increased from 12.5% to 16.6% for a temperature range of 600-850 °C.

3. The emissivity percentage of low alumina brick has increased from 14.67% to 22.2% for a temperature range of 600-850 °C

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