Application Bulletin

Crucible Furnaces

Introduction

Operators of all industrial furnaces are facing significant operating cost increases due to constantly-increasing fuel costs. This is particularly true for crucible furnace operators for whom fuel is one of the largest operational cost components. Increasing world demand for energy and political instability in energy-producing countries has caused commodities analysts to forecast that energy costs will continue to increase throughout this decade. Besides the high cost of fuel, capital expenditures to replace crucibles and crucible maintenance expenses represent significant costs that negatively affect profitability. EMISSHIELD® high emissivity coatings[1] present an opportunity to reduce fuel, maintenance, and crucible replacement costs. In addition, the application of EMISSHIELD® to crucibles can improve productivity by shortening cycle time and reducing downtime.

What is EMISSHIELD®?

EMISSHIELD® is a family of high emissivity ceramic coatings manufactured by Wessex, Inc. based on patented technology licensed from NASA. NASA developed this latest emissivity technology for the next generation of space vehicles that is intended to replace the existing shuttle fleet when retired in 2010 (Figure 1).

Figure 1 - X-33 Orbiter

Wessex has combined their own patented binder systems with the NASA technology to produce high emissivity coatings that strongly adhere to dense refractories, insulating fire brick, refractory ceramic fiber, and most metals. Coating the refractory and crucibles with EMISSHIELD® will provide more even heating, increased productivity, longer refractory and crucible life, and fuel savings.

How Does EMISSHIELD® Work?

EMISSHIELD® is not an insulator. It is not a barrier to the conduction of thermal energy through a furnace wall. Insulating refractories are generally placed behind dense refractories at the cold face of furnace linings. While this reduces heat loss, the amount of heat stored in the dense refractory is increased and the refractory materials must withstand higher mean temperatures. Because the working lining acts as a heat sink, valuable process energy (Figure 2) is repeatedly lost during cyclical operation.

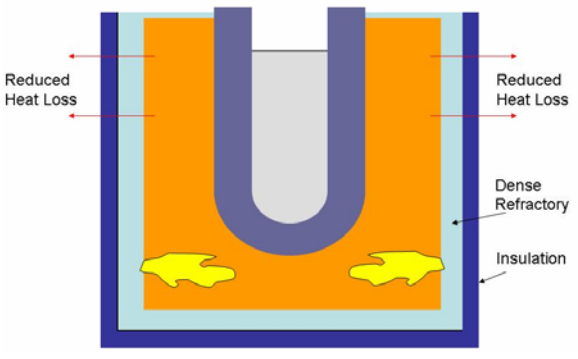

Figure 2 - Crucible furnace with insulating refractory backing up dense refractory working lining.

[1] US Patent 6,921,431, Other Patents Pending

When EMISSHIELD® is applied to the hot face of the furnace lining (Figure. 3). Radiant and convective energy from the burners and hot furnace gases are absorbed at the surface of the coating and reradiated to the cooler crucible.

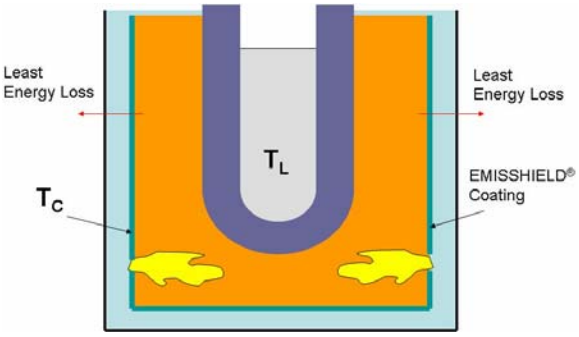

Figure 3 - Crucible furnace with EMISSHIELD® high emissivity coating applied to the refractory hot face. The thermal energy absorbed by the coating, T_C, is re-radiated and absorbed by the colder crucible and its contents, T_L. The refractory lining is subsequently cooler and retains less heat energy.

The crucible then absorbs the radiant energy and conducts it to the load inside. It is important to remember that for EMISSHIELD® to be effective, the temperature of the coating surface must be greater than the temperature of the furnace load. The amount of heat reradiated from EMISSHIELD® is predicted by the following equation:

$$Q = E_w \cdot \sigma \cdot (T_C^4 - T_L^4)$$

Where: Q = re-radiated energy absorbed by the furnace load
E_w = emissivity of the coating
σ = Stefan-Boltzmann constant
T_C = coating temperature
T_L = load temperature

Since the temperature of the coating and the temperature of the furnace load are raised to the fourth power, it is evident that EMISSHIELD® absorbs and reradiates the most energy when the temperature difference between the coating and the load is the greatest.

The ability of the crucible to absorb radiant energy from the coated refractory can also be enhanced by coating the exterior of the crucible. When EMISSHIELD® is applied to the crucible (Figure 4), the coating absorbs more of the radiant heat emitted from the coated refractory, but there is no lower temperature body to receive energy radiated from the coated crucible.

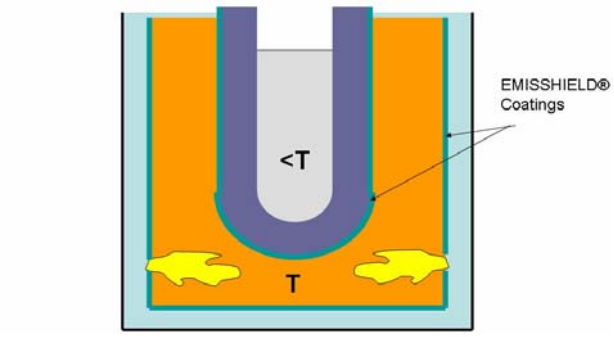

Figure 4 – Since there is no cooler body to absorb radiated heat from the crucible coating, the absorbed heat in the coating is conducted through the coating and the crucible to the cooler load inside the crucible.

According to the Second Law of Thermodynamics, heat cannot flow from a colder body to a hotter body, so the additional heat absorbed by the coated crucible must be conducted through the coating and the crucible to the colder load inside the crucible.

Coating Metallic Crucibles

The amount of heat conducted through a metallic crucible is determined by the ability of the crucible alloy to absorb radiant and convective heat and the thermal conductivity of the alloy (Figure 5). The magnitude of the thermal transfer is driven by the difference

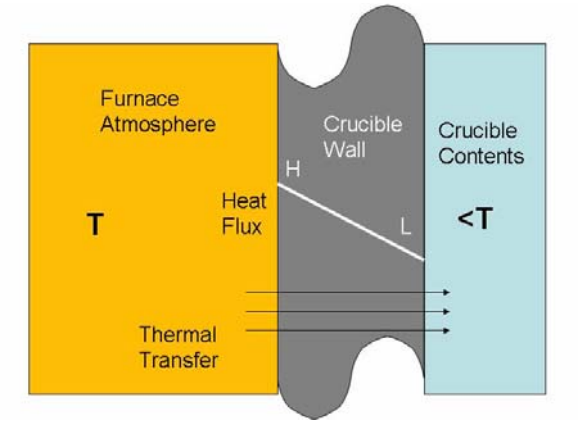

Figure 5 – Thermal transfer and heat flux of an uncoated crucible.

Between the hot face temperature of the crucible and the temperature of its cold face and the load inside. Because the coating increases heat flux and thereby increases the delta T, thermal transfer increases (Figure 6).

In service, oxidation may form insulating scale on the hot face of the crucible, which reduces the ability of the crucible to absorb heat and transfer it to the load inside. While necessary to maintain acceptable production rates, repeated removal of this insulating scale results in maintenance expense and production loss.

This requirement also shortens crucible service life due to progressive wear. EMISSHIELD® M-series coatings form pinhole-free ceramic glazes when fired above 1500°F and thus protect the crucible from oxidation. These coatings increase the amount of heat absorbed on the crucible hot face, which increases the heat flux and the amount of thermal energy transferred to the crucible contents (Figure 6). The same radiant heat transfer principles apply to ceramic and refractory crucibles coated with EMISSHIELD® ST-series coatings.

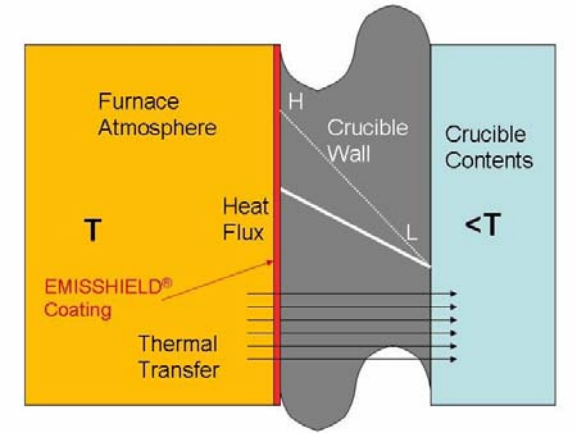

Figure 6 – Increased heat flux and thermal transfer through the crucible to the contents following the application of EMISSHIELD®

Application of EMISSHIELD® in Crucible Furnaces

Unlike the use of insulating materials that have predictable performance characteristics under steady state conditions, the benefits of using EMISSHIELD® depend greatly upon furnace design and operating parameters. Uncoated refractories have emissivities, E_w, in the range of 0.3-0.5 at crucible furnace operating temperatures. The application of EMISSHIELD® to the refractory increases the emissivity of the refractory to about 0.9. With 90% of the energy absorbed and then reradiated by the coating, the amount of radiant heat absorbed and conducted to the load is dictated by the emissivity of the crucible.

Referring to the emissivity equation on the previous page, it is easy to see that by increasing the E_w of the refractory, the heat absorbed by the furnace load, Q, will increase significantly. This means that the crucible will be hotter at the same fuel usage after EMISSHIELD® is applied to the refractory, resulting in shorter cycle time and higher productivity. If a hotter crucible is not desirable, the delta T can be reduced by turning down the burners to maintain the same Q achieved without the coating. Historic production levels can thus be maintained while consuming less fuel.

Furnace efficiency can be further enhanced by coating the crucible with an EMISSHIELD® product designed to adhere to metals. This will shorten cycle time or reduce fuel usage even more, depending upon the desires of the furnace operator. In addition, crucible maintenance expenses, crucible capital costs, and furnace downtime can all be expected to decrease.

Expected Results From Using EMISSHIELD®

When EMISSHIELD® is applied to refractories in crucible furnaces, the coating absorbs about three times the radiant and convective heat from the burner flames and hot furnace gases compared to uncoated refractory. Heat is absorbed by the coating surface and immediately reradiated to the cooler crucible. More heat is made available; subsequently the flue gas temperature will increase. Because less of the available heat is absorbed and stored in the refractory lining, refractory materials stay cooler and are therefore subjected to less thermal shock and thermally-induced stress. Longer refractory life will result. Lower substrate temperature reduces devitrification and associated shrinkage of refractory ceramic-fiber modules, boards, and blankets. Maintenance costs of fiber-lined furnaces coated with EMISSHIELD® are significantly lower.

Since EMISSHIELD® reduces the amount of heat being absorbed by the refractory, IFB linings and dense refractory linings behave more like low thermal mass linings. More heat is available to heat the crucible and the load, rather than heating the furnace lining or being lost out the flues. In addition to the obvious energy saving, the reduction of absorbed energy by the furnace lining allows faster heat-ups and cool-downs when the furnace is operated in a batch mode. When operated in a continuous manner, the crucible contents will heat faster and the furnace recovery time will be shorter.

Applying EMISSHIELD® to crucibles will increase fuel savings and productivity beyond what can be expected when coating only the refractory. In addition, significant non-operational cost savings, including those associated with crucible maintenance and procurement will be gained. With longer crucible life, higher productivity as a result of less downtime can be expected.
