# High Emissivity Coating Technology Improves Annealing Furnace Efficiency

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## INTRODUCTION

High emissivity coating technology has been used successfully to optimize process efficiency in fired heaters in the refining and petrochemicals industries for many years. Recently, the technology has been shown to provide similar benefits in the steel industry. This case history summarizes the application of this emerging technology to one of the most modern, best-instrumented rolling mills in the world. All aspects of the application will be discussed, including the engineering evaluation, application details, and benefit measurement approach, which proved that significant fuel savings and efficiency gains were realized as a result of the coating application.

### AK Steel's Rockport Works

Rockport Works is located on the Ohio River in southwest Indiana, about an hour's drive east of Evansville. The state-of-the-art carbon and stainless steel finishing operations are housed in more than 1,750,000 square feet of buildings. Utilizing the latest manufacturing technologies, the plant incorporates Automated Guidance Vehicles (AGV) and automated cranes to move the steel through the various finishing operations. The plant produces in excess of 2 million tons of steel (all types) annually.

Steels from Rockport Works include a full range of cold rolled carbon, coated and stainless steels in either the annealed/pickled or temper rolled surface condition. Among Rockport's products are:

- Carbon and stainless steels produced on the only cold mill in the world designed to tandem roll austenitic and ferritic grades of stainless steel, as well as carbon steel.

- All stainless steels are finished on the world's largest annealing/pickling line whereby both austenitic and ferritic stainless steels are ready for end use.

- Hot dip galvanized products that are continuously coated on both sides with free zinc, a process that provides a tight metallurgical bond.

- Hot dip galvannealed products that are continuously coated on both sides with zinc, then heated by induction to alloy the zinc and create a zinc-iron coating.

- The Rockport hot dip galvanizing and galvannealing line incorporates revolutionary proprietary technologies, including induction transition heating which provides rapid, accurate annealing temperature control. In addition, the Rockport Works line produces the widest sheet steel in North America at 80 inches. [1]

Figure 1. AK Steel Rockport Works is the most modern, best-instrumented Rolling Mill in the World.[2]

The products run on the Annealing Pickling line include: Both Hot-rolled and Cold-rolled Type 300 and 400 Austenetic and Ferritic, ranging in gauge from 0.210-0.019" and widths from 26" to 62". The type 300 products are generally used for the appliance market, while the 400 is used in the automotive sector. For both of these sectors, aesthetics are very important and surface defects are tightly monitored to adhere to the customer-driven specifications.

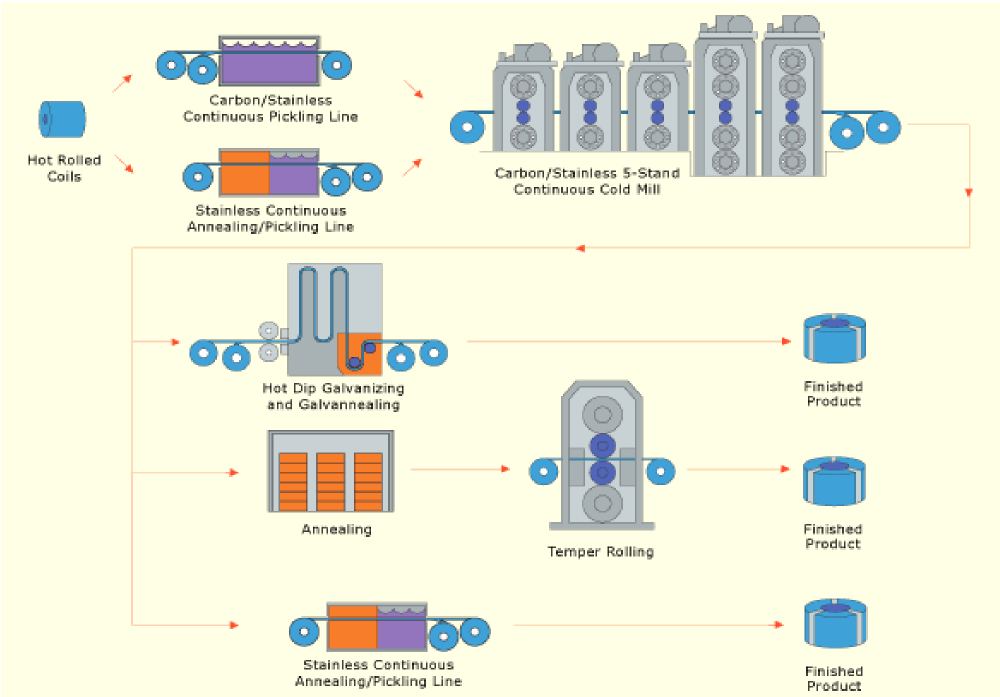



Figure 2. Carbon and Stainless Steels Production Process at AK's Rockport Facility[3]

The drive for efficiency improvements lead AK technical personnel to seek out energy-reducing technologies. This search lead them to Cetek, Ltd., developer and provider of high emissivity coating technology. Previously, Cetek had focused on the application of their coatings technology to the fired heaters in the refining and petrochemical industries with great success. The stringent engineering requirements Cetek had developed to service those industries made it well-suited to conduct a thorough engineering study of the expected impact on AK's annealing furnaces.

**Technical Introduction to Cetek High Emissivity Ceramic Coatings**

Cetek Ltd., a company based in Cleveland, Ohio has developed high emissivity coatings and markets the service of applying those coatings to furnaces and fired heaters for over a decade. These coatings have been shown to successfully improve the efficiency of radiant heat transfer to the furnace load or feed materials. This is achieved using a high emissivity ceramic coating system on the refractory surfaces of the furnace. The coatings are water-based, containing no Volatile Organic Compounds (VOCs), and are applied to the internal refractory surfaces of a furnace, thus improving the radiant heat transfer to the furnace load from the refractory. These coatings have been shown to provide significant benefits and exhibit long life in the refining and chemical processing industries, but Cetek had not applied them to an annealing furnace prior to this application.

**Refractory Coating System**

In an annealing furnace, thermal energy developed by burning a fuel/air mixture is transferred to the strip by three processes; conduction, convection and radiation. All three are employed successfully, but above 1100$^{o}$F, the radiant heat transfer mechanism is dominant.

In the radiant section of an annealing furnace, much of the radiant energy is transferred from the burners to the steel strip via the refractory surface. The refractory surface receives the radiant energy and transmits it back to the strip. The efficiency with which it achieves this is related to the emissivity of the refractory surface and the quantity of heat absorbed and re-emitted from a surface is calculated from the following equation:

$$\mathbf{Q = Ae\sigma T^4}$$

'A' is the surface area, 'e' is the emissivity, '$\sigma$' is the Stefan Boltzman Constant and 'T' is the temperature. A perfect radiator or "black body" has an emissivity equal to 1. In a steady state, the amount of heat absorbed by a surface is also related to the emissivity; a perfect radiator will absorb all radiation striking it.

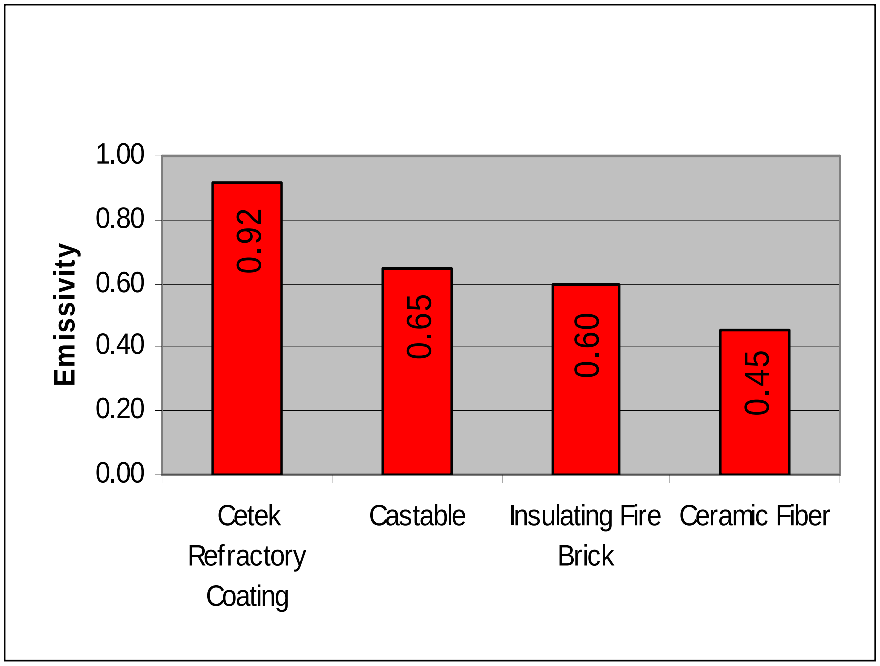



Figure 3 - Typical Emissivity of Refractory Materials at 1800$^{o}$F

At annealing furnace operating temperatures, new ceramic fiber linings, for example, have emissivity values of around 0.4. Insulating fire brick (IFB) and castable materials have emissivity values around 0.6. These materials have been designed with structural considerations and insulating efficiency as the primary requirements. They tend not to handle radiation in the most efficient way. Cetek Ceramic Coatings, however, with emissivity values of above 0.9 have been designed to have permanent high emissivity (See Figure 3).

It is important to understand how the emissivity property of a surface can affect the efficiency of heat transfer. There are two factors which need to be taken into account. The first is the spectral distribution of the radiation absorbed/emitted from a particular surface and the second is the value of the emissivity of that surface.

All materials absorb and re-radiate energy differently. In the visible spectrum this is readily understandable as differences in color. In the infrared, the effects are the same, but not so immediately apparent. The chart in figure 4 shows the energy spectra for two major components of the combustion products of natural gas; water vapor and carbon dioxide. They are compared with the spectrum of a perfect radiator, or black body, at the same temperature.

The combustion products will radiate and absorb energy in the narrow wave bands shown, whereas a black body will radiate and absorb energy over a much wider wavelength range.

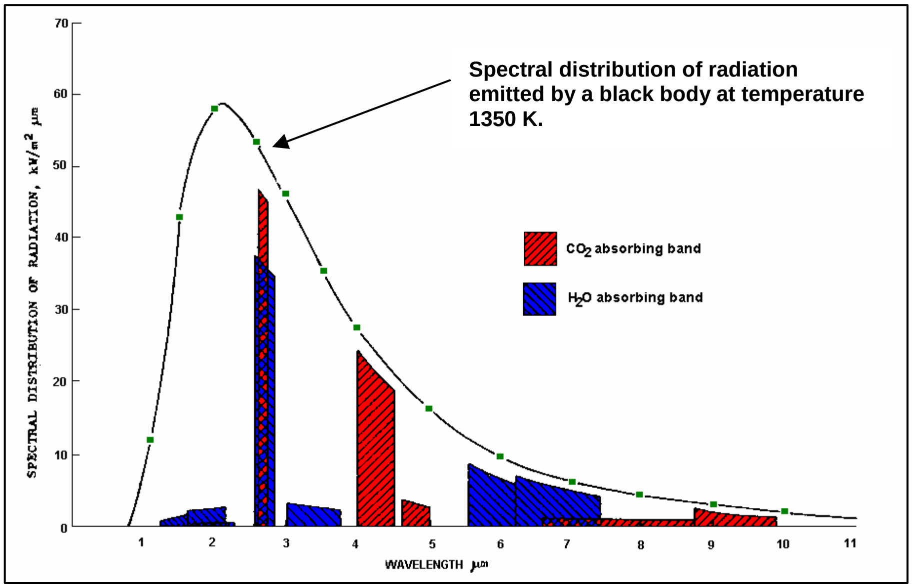


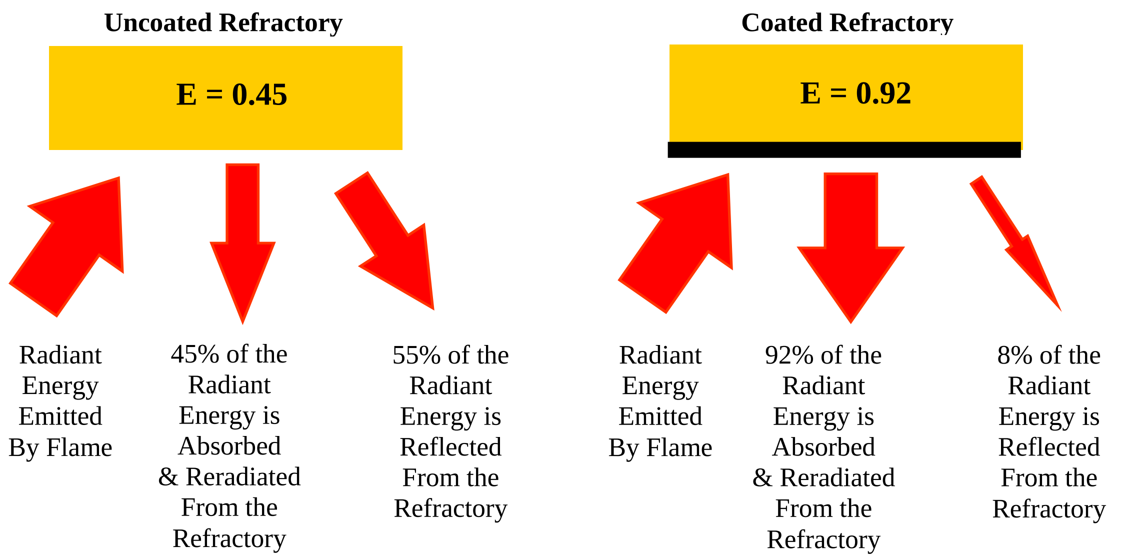

Figure 4. Energy Spectra of Combustion Products of Natural Gas[4]
High emissivity surfaces are able to radiate energy across a broad wavelength band lessening the interference of the $CO_2$ and $H_2O$ in the flue gas.

When the radiation from a flame strikes a perfect radiator, all of the energy is absorbed, but most importantly, it is transformed into "black body radiation", as the wide waveband form. As the energy is re-emitted from the surface, it is able to penetrate the atmosphere in the furnace, composed of the combustion products, with little being re-absorbed and taken to the stack by the draft. Therefore it is more readily available to heat the load in the furnace.

If the surface were a poor radiator, or one having a very low emissivity value, the energy striking the surface would be reflected back from the surface still in its untransformed state, therefore more readily absorbed by the furnace atmosphere. The effect is to "super-heat" the furnace atmosphere, or flue gases, resulting in wasted energy lost to the stack.

In typical furnaces and heaters, refractories with emissivity values from 0.45 to 0.60 are typically used. The emissivity values are increased to over 0.9 with the Cetek Ceramic Coating system. This improves the radiant efficiencies significantly as Figure 5 identifies the effect of refractory coatings on a ceramic fiber lined heater. Cetek High Emissivity Coatings can be applied to all types of refractories, such as hard brick, castable, insulating firebrick, and ceramic refractory fiber.

There are other benefits from the use of the Cetek Coating systems, which include improving the surface durability of the refractory, especially with IFB and more so with ceramic fiber. The coating system applied to ceramic fiber substrates increases the toughness of the surface. This will prevent fiber loss through hot gas abrasion from the flame and there will be no resulting deposition in convection sections or loss through the stack to the environment.




Increasing the emissivity of the refractory surface increases the amount of radiant energy that is reradiated to the load in the furnace and reduces the radiant energy which is reflected back and absorbed by the flue gas.

Figure 5. Effects of Emissivity on Radiant Energy on Uncoated vs. Coated Refractory

## CASE HISTORY

### Engineering Evaluation & Product Testing

In April of 2003, AK plant engineering approached Cetek with an inquiry regarding the possible impact of Cetek's coatings technology on their operation, specifically the Annealing/Pickling Lines. After gathering a number of operational parameters, Cetek conducted an engineering evaluation, outlining the current operational efficiency of the furnaces, as well as the anticipated benefit AK should expect to realize from the coating application. The engineering evaluation concluded that the application of the coatings would provide AK Steel with a 4.5% fuel savings or a 4.7% production increase, depending on whether they were looking for fuel savings or increased throughput. Using a natural gas price of $8 per MMBTU, the payback period was estimated to be approximately 6 months.

The technical merits of the technology were discussed and evaluated based on the many discussions held between Cetek and AK. One major concern expressed by AK was the possibility that the coatings would spall or peel off the furnace ceiling and lead to contamination and defects of the steel strip. Should such a coating failure occur, the results would be very detrimental. Cetek's experience in the refining and chemical processing industry had demonstrated that the coatings would be very stable and would not deteriorate, and should perform for at least 6 years and beyond. It was decided that a test panel of approximately 150 sq. ft. be applied to the side wall of the furnace throat, where any failure would not be detrimental to process or product, and the coating application could be monitored for a period of time to determine if it was stable enough to warrant further consideration.

Due to a number of factors, the evaluation period extended for 2 years until mid-2005, during which time the furnace had undergone a number of thermal cycles. This evaluation period, while longer than originally anticipated, revealed the coatings to be very stable, exhibiting no appreciable deterioration. Simultaneously, the rapid increase in natural gas prices throughout much of 2005 increased the focus on energy conservation within AK Steel.

The issues of minimizing risk to product and process and budget concerns were of the utmost concern to AK Steel. While the risk of product contamination had been satisfactorily addressed, the project still required a capital outlay for what was arguably an unproven technology. Cetek worked with AK to provide a performance-based plan that allowed AK to evaluate the technology without the risk of losing money. The project gained momentum and was approved by AK based on a conservative estimate of a 1 year payback on energy savings.

**The Application**

With the technical and commercial considerations addressed, the project was scheduled for October 2005. The application included the coating of the refractory in #1 and #2 Anneal Pickling lines to be applied by a crew of Cetek technicians. The refractory surface area, which was in excess of 20,000 sq.ft., was coated in less than 48 hours, ahead of the anticipated timeline.

Figure 6. High Emissivity Coatings Applied to Ceramic Refractory Fiber

**Findings**

Immediately following the start-up of the furnaces, notable differences where observed by AK personnel. The furnaces were reportedly operating "hotter" than before, and adjustments were required to reduce the fuel consumption at typical throughput rates.

Over the following months, fuel consumption was measured against product run. Correlations between fuel savings and strip width and gauge were quantified. All natural gas consumption was measured in standard cubic feet measured in a "per ton of product produced" basis. After compiling 3 months of data, AK Steel has measured an average fuel efficiency gain of 5.6% across all product types, with the highest fuel savings attributed to the wider strips. This follows conventional logic that the higher surface area of the receiver (in this case the strip) would be able to absorb more of the radiant energy from the refractory.

Over the months since the application, AK Steel has used the efficiency improvement for both a fuel savings when not capacity-constrained and to improve throughput during times of production constraints. The flexibility of the coating performance allows AK to improve not only the furnace efficiency, but operational efficiency as well.

With current natural gas prices in excess of $12 per MMBTU at the time of this writing, the payback period for the application is now approximately four months.

## SUMMARY

In this age of high energy prices and tightening product margins, high emissivity coatings technology has been proven to be an effective means of reducing energy consumption in natural gas-fired annealing furnaces. This application of high emissivity refractory coatings has demonstrated quantifiable, documented improvements as related to the baseline, uncoated furnace in an annealing/pickling furnace for the first time. The benefits achieved thus far have met and surpassed the anticipated impact, resulting in a significantly shorter payback period. AK Steel confirms the benefits are real and significant.

## ACKNOWLEDGEMENTS

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