Radiant tube concepts

Two main groups of radiant tube concepts can be differentiated. One group is called non-recirculating radiant tubes and the other one the recirculating radiant tubes. As it can be seen in Fig. 1 with the exception of the non-recirculating single ended radiant tube, all the non-recirculating radiant tubes have a burner at one end of the tube and the flue gas outlet at the other end of the tube. Usually, slow mixing burners are used to distribute the heat as good as possible over the length of the tube. Recirculating radiant tubes are using high velocity burners to circulate the combustion gases within the radiant tube thereby distributing the heat evenly over the radiant tube surface. The temperature differences on the tube surface can be minimize to a fraction, compared to non-recirculating tubes. Non-recirculating tubes are still widely used, especially U-tubes in the heat treating industry and U-and W-tubes in the steel industry, but within the last years, most of the major burner companies included recirculating single ended radiant tubes in their product portfolio.

Radiant tube material

In the present time, three different material classes are used:
1. cast alloy tubes
2. fabricated alloy tubes
3. ceramic tubes

There are various pros and cons for cast and fabricated alloy tubes, but in general both types can be used under similar conditions. Ceramic tubes gained importance since the introduction of silicon carbide, especially reaction bonded silicon carbide SiSiC. These materials overcome the problem of thermal shock sensitivity from tubes made from mullite and others.

The material properties of SiSiC at high temperatures are superior to alloy, especially regarding strength, creep stress and thermal oxidation, allowing for net heat fluxes of up to 110 BTU/hr in² and can be used in furnaces with zone temperatures up to 2250°F. Alloy tubes are generally used for heat fluxes of 60 BTU/hr in² and less and for furnace temperatures of maximal 2000°F. On the other hand, the ceramic production process permits only certain shapes and the possibilities for machining and joining (welding, brazing) are very limited. The mechanical brittleness must be also considered. However, proper design and some training of the operators can overcome these difficulties and many thousand ceramic radiant tubes are in operation now, providing reliable high performance to their users. In strip lines, ceramic radiant tubes open the opportunity for considerably increased production of 30\% and more. However, the furnace and the process have to be checked thoroughly to avoid problems like tube damage caused by strip breakage and also problems which can result from higher furnace temperatures, which can be well above the final strip temperature (strip breakage at reduced strip speed, etc.).

Flameless oxidation burners for heating strip lines

Natural gas is the most widely used fuel for heating strip in furnaces due to its availability and clean combustion and is enabling much lower energy costs, compared to electrical heating systems, provided that an efficient system is used. Besides energy costs issues, heating systems play an important role for the performance of a furnace, especially regarding temperature uniformity / product quality, net heat input / productivity, energy efficiency / operating costs, maintenance / operating costs, tube life / operating costs, flue gas emissions / pollution, furnace downtime, ease of operation and investment costs. The following reports shows that all these aspects have to be considered to make a decision for a new heat treating furnace or a retrofit project.
rollers, furnace insulation). Alloy tubes remain a good choice for many applications due to their greater flexibility in shape and in applications where mechanical damage cannot be avoided, e.g. strip breakage in a vertical strip line, strong vibrations, shocks or derailed baskets.

**Efficiency**

The efficiency of fuel fired systems is often defined by the term available heat. The available heat is the heat, available to the furnace and the workload and is equal to the gross input minus the flue gas losses [1]. Rising flue gas temperatures are leading to higher flue gas losses and thereby to lower available heat (Fig. 2). For example: at flue gas temperatures of 1800°F, without air preheating, only about half of the energy, provided in the form of fuel is available to heat up the furnace, the rest is lost with the flue gases, even when the burners are adjusted properly. This effect is even more important for radiant tube systems compared to direct fired furnaces since the flue gas temperature can be substantially higher than the furnace temperature (Fig. 3).

For example: For a furnace temperature of 1300°F, the tube temperature is 1700°F and the internal gas temperature (flue gas temperature prior to an optional heat exchanger) is 2000°F and more, if a ceramic radiant tube with a net heat flux of 110 BTU/hr in2 is used.

Therefore, without proper heat recovery methods, efficiency can be very poor (available heat < 50%) even at relatively low furnace temperature. For even higher furnace temperatures, the available heat can drop even further, eliminating the cost advantage of natural gas over electricity completely.

The most effective way to reduce flue gas losses is to use heat recovery systems to preheat the combustion air. Several heat recovery concepts are used:

- plug in recuperators and central heat exchangers provide moderate air preheat temperatures
- self recuperative burners provide higher air preheat temperatures by eliminating transport losses since the heat exchanger is integrated into the burner and placed within the furnace wall
- regenerative burners enable large heat transfer areas in a compact design, obtaining air preheat temperatures which are close to the flue gas temperature (prior to the heat exchanger)
Central heat exchangers and plug in recuperators are used in combination with non-recirculating radiant tubes. Self recuperative burners are generally used for recirculating radiant tubes. Regenerative burners were used in non-recirculating tubes but the challenges coming from the high air preheat temperatures often lead to difficulties. A newly developed regenerative burner design in combination with A-type radiant tubes will overcome these difficulties and is ready for the market introduction. It will be mainly depend on the future energy prices how long it will take until this concept gains a considerable market share.

**Emissions**

For the most common gaseous fuels like natural gas, NOx-emissions are the greatest concern. High temperatures, confined flow conditions and high air preheat temperatures contribute to strongly rising NOx-emissions. Therefore, very effective low NOx-combustion concepts must be used. The high velocity concept was a first step, but not enough as the air quality standard started to became more severe. The introduction of air staged, high velocity combustion allowed for a further reduction but future air quality standard will require even further reduction. The development of self recuperative and regenerative burners operating in the so called FLOX®-mode (Flameless Oxidation) enabled low emissions even at highest air preheat temperatures. In FLOX® mode, large amounts of combustion products are re-entrained into burner jet before the combustion takes place. Thereby, peak temperatures are avoided, minimizing NOx-emissions and reducing the thermal stress on the burner [2] (Fig. 4 and 5).

**Controls and Flame Safety**

Many non-recirculating radiant tubes are proportionally or high low controlled. The main reason is cost savings since one air and gas valve can be used to control a whole temperature control zone. But there are some things to consider. The performance of a radiant tube can be optimised only for one point of operation. Operating with higher or lower input will compromise, especially the temperature uniformity and NOx-emissions. Another important fact is flame safety. If flame safety is applied or has to be applied, the advantage of having only one air and gas valve per zone would led to the loss of a whole temperature control zone, if only one burner fails. On/Off or pulse firing systems (Fig. 6) are suiting the high performance radiant tubes the best. Each radiant tube is an independent unit what makes burner adjustment very simple. Often, flame safety is mandatory for ceramic radiant tubes.

**Applications**

Energy efficient radiant tube systems are used in a wide variety of applications. Recirculating type radiant tubes can be installed wherever non-recirculating tubes are in operation. In addition, SiSiC single ended radiant tubes can be installed in furnace atmospheres and temperatures where expensive electric heating was the only option. There are tens of thousand recirculating radiant tube systems operating in furnaces including:

- batch furnaces
- pusher furnaces
- roller heart furnaces
- rotary hearth furnaces
- vertical and horizontal strip lines
- and many others.

Fig. 7 is showing a silicon steel strip line. In the fall of 2001, more than two hundred 8"-ceramic single ended radiant tubes (Fig. 8) where installed to
increase production in an existing line. In these works, a total of more than two thousand single ended, recuperative radiant tubes are installed. Also in the fall of 2001, a galvanizing line with a vertical furnace, containing about 200 alloy double-P-type radiant tubes was started up (Fig. 9 and 10).

Conclusions
Efficient reliable radiant tube systems are available on the market. New designs and material, especially SiSiC ceramic improved the performance and life of radiant tubes considerably. However, rising internal temperatures require proper design and adaptation of burner and radiant tube. Recuperators and regenerators are exposed to high temperatures and must be made from ceramic material as well. WS specialized on these type of burners and sold more than one thousand ceramic radiant tube systems in 2001 alone. At the current energy price level, additional expenses for efficient radiant tube systems can be recovered in a few years. Counting the other advantages, especially increased production, but also less downtime, better temperature uniformity, flame safety and better tube life can reduce the payback period for these systems considerably. In many cases, when ceramic radiant tube allow for smaller furnaces or increased production, investment costs and operating costs can be reduced at the same time.

Literature