FLAMELESS OXIDATION IN GAS FIRED RADIANT TUBES

Joachim G. Wuenning
WS Wärmeprozesstechnik GmbH, Germany
email: j.g.wuenning@FLOX.com

Abstract: Recuperative and r*egenerative combustion air preheating became increasingly popular due to rising energy costs. Advances in the abatement of NOx-formation made it possible to lower emissions in new installation despite high air preheating temperatures.*

Besides the large firing capacities in reheating furnaces, there are many heat treating furnaces with smaller capacity burners and also radiant tube heated furnaces. Small capacity recuperative and regenerative burner systems require different concepts which will be discussed in this paper. Key Words: flameless oxidation, heat treating, industrial furnace, radiant tube, recuperators, regenerators

1. INTRODUCTION

Gas fired radiant tubes are the most commonly used heating devices for heat treating furnaces in the steel industry which are operated with a protective atmosphere. Gas burners are firing into a tube which transfers the heat to the furnace predominantly by radiation. This form of heating is also referred to as indirect heating since the products of combustion are not in direct contact with the product. The furnace atmosphere can be a composition of nitrogen, hydrogen, carbonmonoxide or other substances to achieve desired surface effects on the product surface.

The main goals for the development of radiant tube heating systems are efficiency and low emissions next to usual demands regarding cost, safety and performance

2. FLAMELESS OXIDATION

Flameless oxidation (FLOX® - registered trademark of WS Wärmeprozesstechnik GmbH, Renningen) was developped to supress thermal NO-formation in high temperature processes even when highly preheated combustion air is used [1-4]. A definition of flameless oxidation was given as [5]:

Flameless oxidation is stable combustion without a flame and with defined recirculation of hot combustion products

In contrast to often expressed assumptions, flameless oxidation does not need:

- preheated combustion air
- low oxygen levels
- separate injection of air and fuel or
- large combustion chamber volumes.

Flameless oxidation does need recirculation of hot combustion products and suitable measures to avoid the formation of flames.

Not every chemical reaction is considered to be combustion and not every combustion is accompanied by flames. A classification of different redox-reactions is given in Figure 1. Relatively slow redox-reactions with low intensity are going on almost everywhere. Examples are rusting of steel, browning of a fresh cut apple but also various reactions in the earth's atmosphere. Combustion can happen naturaly as forest fire which could be sparked by a lightning strike. Controlling combustion was one of the fundamental skills of mankind which allowed civilazation. Most combustion processes involve flames which enable controlling combustion by visual examination. There are also some combustion processes which are not accompanied by flames. Catalytic surfaces can lower the activation energy for reactions and therefore enable reactions at lower temperatures without formation o flames. A camp fire will first burn with blazing flames. Later on the flames will extinguish but reactions will still occur in the firebed until all char is burnt to ash. Flameless oxidation is also combustion with the absence of flames.

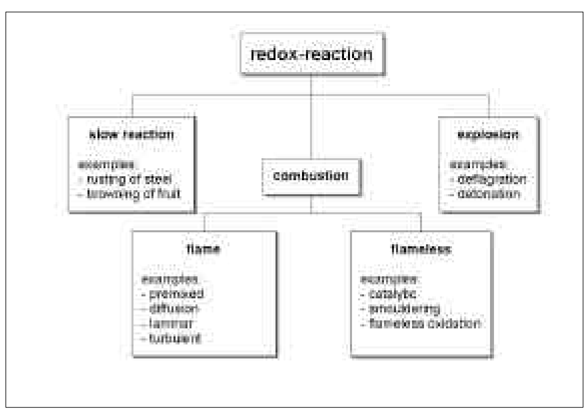

Fig. 1: Redox Reactions

Flameless oxidation was first introduced into heat treating furnaces but since then many other applications were examined and developped [5-8]

3. RADIANT TUBE DESIGNS

The most commonly radiant tube designs, used in industrial furnaces, are shown in Figure 2.

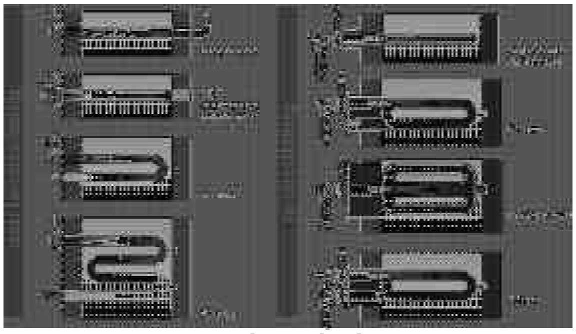

Fig. 2: radiant tube designs

Since flameless oxidation requires the recirculation of hot combustion products, the recirculating tube designs on the right side of Figure 2 are preferable. These designs incooperate an internal recirculation of hot combustion products. The tube designs on the left side of Figure 2 would require external recirculation of combustion products. Since flameless oxidation requires the recirculation of combustion products which are hot would make the task very difficult and hard to achieve in an economical way.

Another key development goal besides low NO_x is providing maximized efficiency. For radiant tubes, decentralized heat recovery is preferable. Central heat exchangers, which are common for large direct fired furnaces are not practical for radiant tube fired systems because there is no central exhaust outlet of the furnace. The hot exhaust gases would have to be transported to the heat exchanger in costly insulated ducts and then the hot air has to be distributed back to the individual radiant tubes. For radiant tube heating, a good heat recovery system is essential since the exhaust temperatures are often substantially higher than the furnace temperature. That is particularly true for ceramic radiant tubes with high heat release rates.

The different radiant tube designs (see Figure 2) require different strategies for heat recovery.

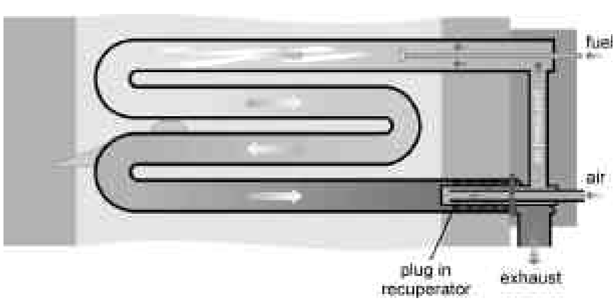

Figure 3: W-tube with plug in recuperator

In straight through tubes, heat recovery is very rare. For U- or W-tubes, the most common way to preheat the combustion air is to use plug-in recuperators (Figure 3). To enhance the air preheat, external recuperators are also possible. The limitation for air preheat is coming from the necassity to guide the hot air from the exhaust leg to the burner and also from the coflow heat exchanger design.

Higher air preheat temperatures and thereby higher effiency can be achieved with regenerative burner systems in U-, W- and A-tubes. Two burners per tube are firing alternating (see Figure 4). The regenerative systems allow air preheat temperatures close to the furnace temperature. Energy savings of more than 20% compared to systems with plug in recuperators are typical. Besides energy savings, the temperature uniformity of the tubes are much better due to the alternating flow direction in the tube. Attention has to be paid to NOx-formation due to the high air preheat and also the complexity of the system due to two burners per tube.

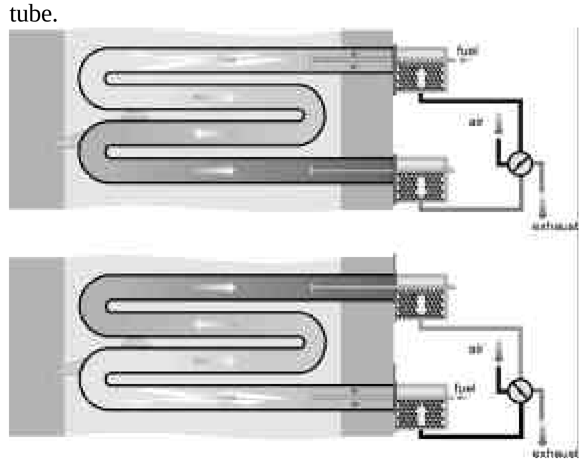

Figure 4: regenerative fired W-tube

Single ended, P- and Double-P tubes are usually fired with self recuperative burners. The counterflow heat exchanger, which is placed inside the furnace wall, allows high air preheat temperatures and there is no hot air piping required outside the furnace. For high temperatures, self recuperative burners with ceramic heat exchangers are available [9]. Air preheat temperatures in the range of 500 to 700°C are typical. Figure 5 shows a double-P tube with a self recuperative burner. High velocity combustion results in a good temperature uniformity and internal recirculation allows the application of flameless oxidation FLOX®, as an effective method to reduce thermal NOx formation. Self recuperative burners a widely used since they combine good performance with a high efficiency.

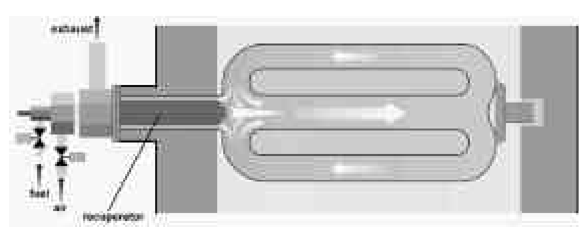

Figure 5: Double-P-tube with self recuperative burner

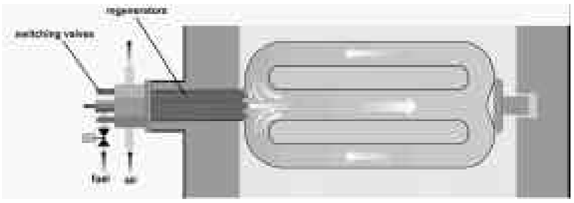

Figure 6: Double-P-tube with self regenerative burner

4. SELF REGENERATIVE BURNER

To combine the advantages of regenerative systems and self recuperative burners, a self regenerative burner for radiant tubes was developped.

Figure 7: Self regenerative radiant tube burner, REGEMAT® 250 (Photo: WS GmbH)

Figure 7 shows a self regenerative burner which could be used for direct firing and for heating of recirculating radiant tubes. The self regenerative burner is used in combination with a pulse firing system, that means, the burner is on/off controlled. All the logic for regenerative switching, flame safety, ignition and valve operation is handled by a local burner control unit. That makes the installation, start up and maintenance as easy as with self recuperative burners. The tube temperature uniformity is excellent because of the internal recirculation and NOx emissions are low (<50ppm) due to flameless oxidation.

Figure 8: REGEMAT® 250 firing in a Double-P-Tube (Photo: WS GmbH)

To keep the number of radiant tubes and burners, and therebye the costs, at a minimum, radiant tubes with a large tube diameter should be used. With double-P tubes, it is possible to heat a furnace with fraction of burners compared to a system with small diameter straight tubes.

5. CONCLUSIONS

There are many options for increasing the energy efficiency and still achieving extremely lo NOx-emissions. Preheating the combustion air is the most effective way to increase efficiency in most furnaces. To fight the challenges of rising energy cost and environmental regulations, a close cooperation of the end user, the furnace builder and the burner manufacturer is necessary to choose the best possible configuration with respect to:

- performance
- energy efficiency
- low emissions
- low maintenance

and of course not higher than needed investment costs.

6. REFERENCES

[1] Wünning J., Flammenlose Oxidation von Brennstoff mit hochvorgewärmter Luft, Chem.-Ing.-Tech. 63 (1991), Nr. 12, S. 1243-1245

[2] Woelk G., Wünning J., Controlled Combustion by Flameless Oxidation, Joint Meeting of the British and German Sections of the Combustion Institute, Cambridge, 1993

[3] Wünning J.G., Flammlose Oxidation von Brennstoff, Thesis, Aachen, 1996

[4] Wünning J.A., Wünning J.G., Flameless Oxidation to Reduce Thermal NO-Formation, Prog. Energy Combust. Sci. Vol. 23, Seite 81-94, 1997

[5] J. Wuenning, Flameless Oxidation, 6th HTACG Symposium, Essen, 2005

[6] Flamme M., Al-Halbouni A. Wünning J., Scherer V., Schlieper M., et al., Low Emission Gas Turbine Combustor Based on Flameless Oxidation, 14th IFRF Member Conference, Noordwijkerhout, Netherlands 2004

[7] Fielenbach C., Holfeld T., Petery C. von, Renz U., Wünning J., NO_x-reduction in a pressurized pulverized coal flame by flue gas recirculation, Pittsburgh Coal Conference, Pittsburgh, USA 2003

[8] Scherello A., Konold U., Schwarz G., Köster B., Anwendungen der Flammenlosen Oxidation für Glasschmelzwannen - erste Ergebnisse des Glas-FLOX® Projektes, Tagungsband zur Glastechnischen Tagung, Dresden, 2006

[9] Flamme M. Boß M., Brune M. et. al., Improvement of Energy Saving with New Ceramic Self-Recuperative Burners, IGRC, San Diego, 1998