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Multistage Flameless Oxidation

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Abstract

Flameless Oxidation (FLOX®) is a well established low thermal NO_x combustion method since the early 1990s. Flameless Oxidation can be applied for processes above self ignition temperature. Typically, switching between flame- and FLOX-mode occurs at a temperature of 850°C.

This restriction can be omitted when applying multistage flameless oxidation where a burner can be started directly from cold or after a short preheat. The air/fuel ratio in a first stage flameless oxidation under adiabatic or near adiabatic conditions is chosen to guarantee stable combustion but suppress NO_x-formation. This is followed by a complete oxidation of the hot fuel/exhaust or oxygen/exhaust mixture in a heating chamber.

The method is characterized by a high degree of fuel flexibility and has the potential to suppress both, thermal and fuel NO_x.

Introduction

It was determined in international agreements to limit the global warming to less than two degrees centigrade. Therefore it is necessary, to largely stop emissions of carbon dioxide from fossil sources into the atmosphere by the year 2050.

The majority of industrial high temperature processes is heated by burning natural gas. Using the waste gas heat to preheat the combustion air is in most cases the best way to increase efficiency and to reduce CO_2-emissions. Waste gas losses from high temperature processes are more than 50% when process temperatures are 1000°C and higher corresponding to available heat of less than 50% when no heat recovery is installed. Available heat of more than 80%, or less than 20% waste gas losses, can be achieved using modern regenerative or recuperative burners even for process temperatures up to 1300°C while meeting strict emission limits (e.g. NO_x < 100mg/m3 @ 3% O_2). Changing a gas heating system to electric resistance heating would be counterproductive in most countries with regard to CO_2-emissions. Currently, specific CO2-emissions for electricity generation in Germany are 500 mg/kWh /1/. CO2-emissions from a gas heating system are substantially lower even for systems without heat recovery as shown in Figure 1.

The increase of non fossil regenerative power generating capacity will lower specific CO2-emissions over time. Another pathway to fossil free heating is to replace natural gas by "green" gas from non-fossil sources. This could be bio fuels, hydrogen produced using regenerative energy or synthetic fuels. These green fuels can be used directly or can be blended into the existing natural gas grid, gradually lowering CO2-emissions from burning fuel gas. Synthetic fuels can be hydrocarbons or nitrogen – hydrogen based fuels which are easy to store and transport using existing infrastructure. Synthetic methane (CH4) has the advantage, that existing burners can be used but large quantities of non fossil carbon are required for the production. No carbon molecules are required for ammonia (NH3) and ammonia can be easily liquified using moderate pressure. The challenge is ammonia combustion and flameless oxidation can be the solution.

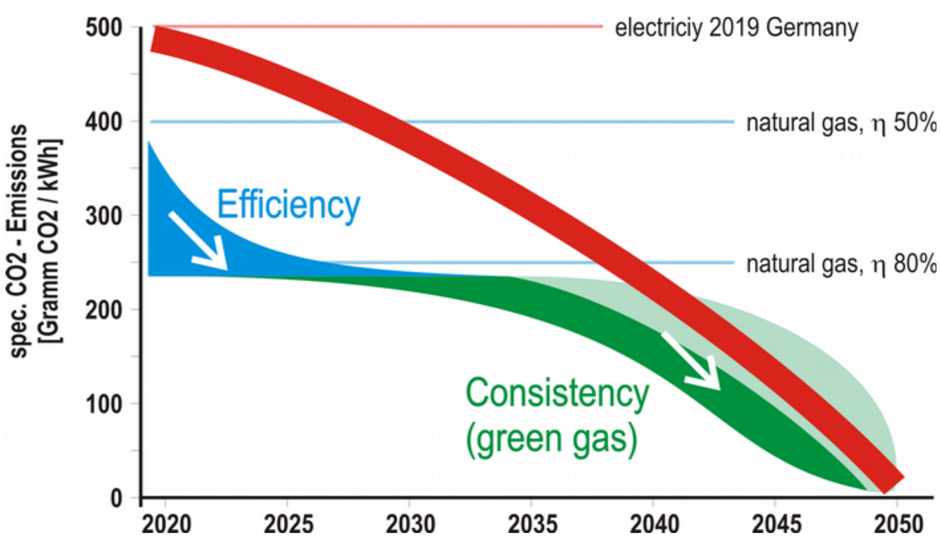

Figure 1: fossile CO2-emissions from high temperature process heating

Flameless Oxidation

The method of Flameless Oxidation (FLOX®) was found during experiments to lower NOx when using preheated air to increase combustion efficiency /2/. Flame formation and resultant thermal NO_x - formation could be suppressed. Flameless Oxidation can be achieved by internal recirculation of hot exhaust gases as shown in Figure 2.

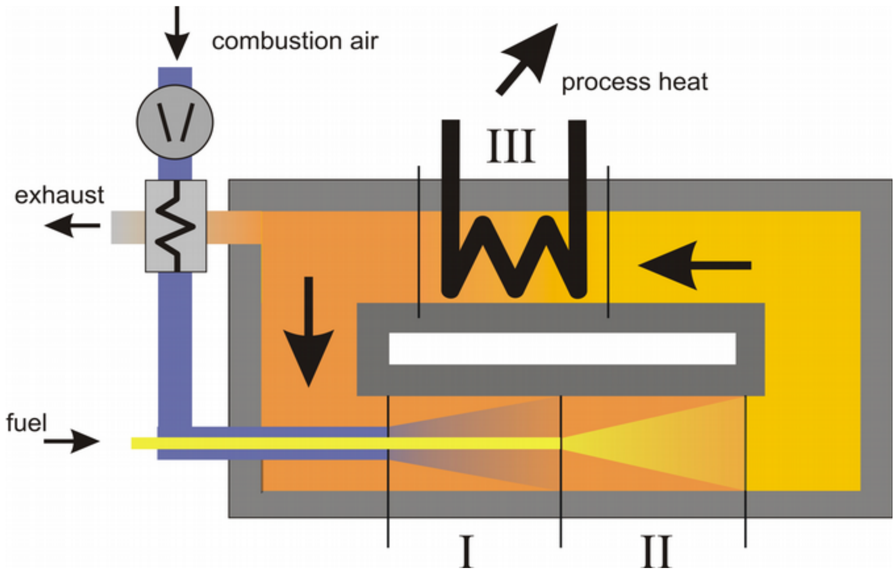

Figure 2: principle of Flameless Oxidation

In the early 1990s, extensive research was carried out to understand the processes and to develop safe and reliable FLOX® burners. Important parameters are the rate of internal recirculation and the process temperature as shown in Figure 3. Flameless Oxidation is now well established, subject of many research activities and applied in many areas of applications. A further advantage of stable flameless oxidation is its fuel tolerance. A constraint is the requirement of high process temperatures. Fuels containing fuel bound nitrogen can lead to high NOx-emissions /4/. It should be possible to eliminate these limitations with multistage flameless oxidation.

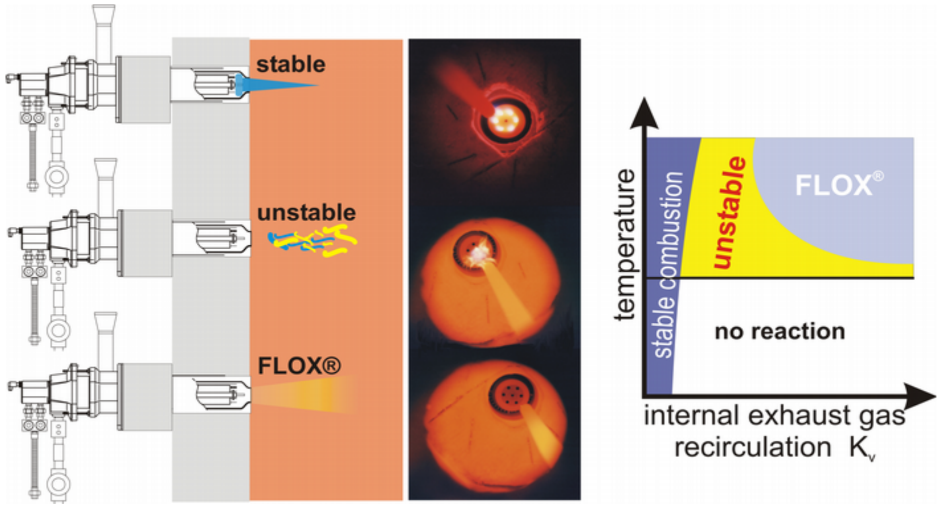

Figure 3: stable and unstable combustion

Multistage Flameless Oxidation

The principle of an air staged flameless oxidation is shown in Figure 4. The first chamber is largely adiabatic and can be operated in flameless mode from cold start or after a short preheat. The temperature of the first chamber is controlled by the fuel/air ratio. The complete oxidation of the hot gas stream takes place in the heating chamber. The process is also possible with fuel staging. The requirement for high temperatures in the heating chamber is eliminated.

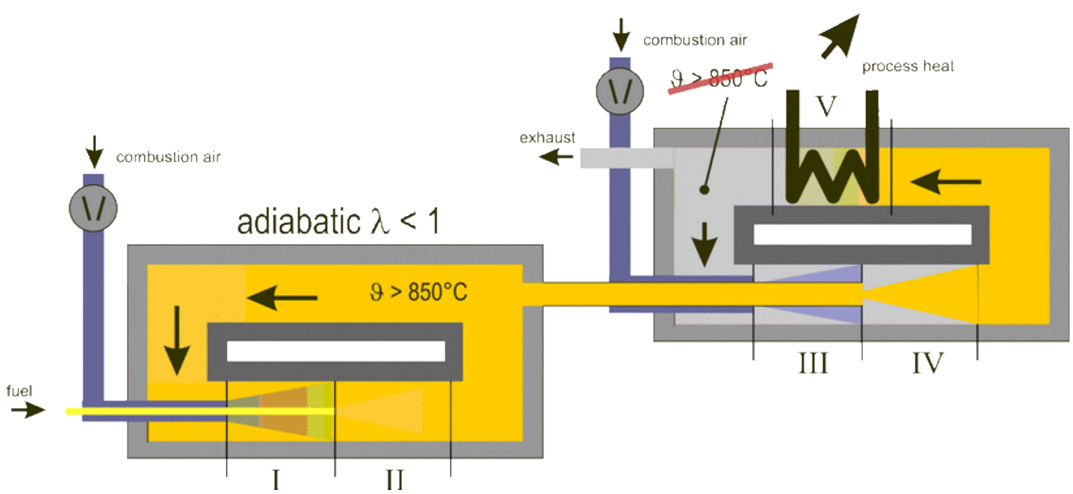

Figure 4: Two Stage Flameless Oxidation (FLOX®-2)

To apply the process of multistage flameless oxidation in a reliable way, it must be fully understood. First CFD – calculations, equilibrium and kinetic assessment have shown the potential for quasi NOx free combustion even when fuel bound nitrogen fuels are used. Figure 5 shows the temperature field of a simple FLOX®-2 burner firing into a heating chamber. The oxidation is complete without the formation of temperature peaks. The calculation time for a cylindrical 2-D grid with 640 cells is only minutes, enabling the calculation with many parameter variations. The first FLOX stage is adiabatic, the second stage in the heating chamber has open boundaries with the definition that inflowing exhaust gases contain 10% oxygen at 300°C.

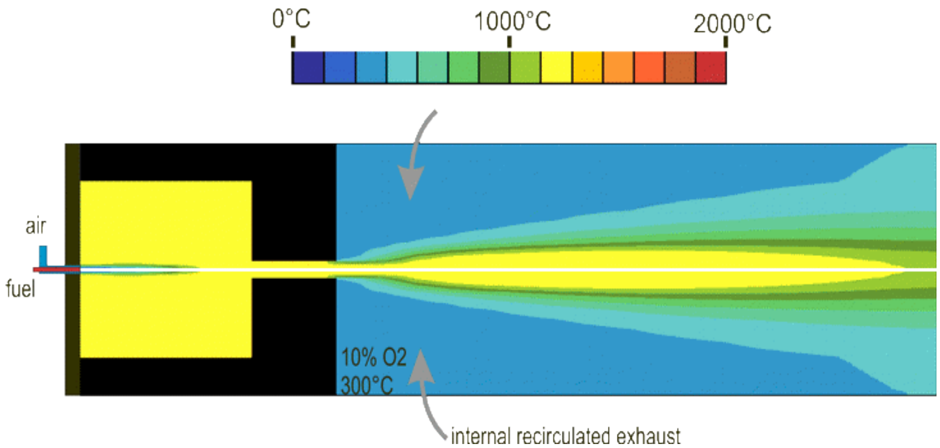

Figure 5: FLOX®-2 CFD

NOx emission in the single digit ppm range could be measured during first burner trials. Figure 6 shows an open fired FLOX®-2 burner firing the first stage overstoiciometric. The secondary air/fuel supply are visible. The second stage is not activated.

Figure 6: FLOX®-2 Burner

Outlook

Extensive work and tests are planned to fully understand all phenomenons occurring at multistage flameless oxidation processes.

The goal is to develop burners which burn extremely clean over a wide temperature range and the ability to use various fuels which could also vary in composition.

Fire and combustion is a human tool for a very long time and it will be an important tool even after a relatively short episode when dominantly fossil fuels were used.

Literature

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