CHARACTERIZATION OF POLLUTANT EMISSIONS IN A RADIANT TUBE NATURAL GAS BURNER

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Abstract

The aim of this work is the characterization of pollutant emissions at the exhaust of a radiant tube natural gas burner, equipped with a screw-type swirl generator to impart a rotational motion to the air stream. In this burner typology the flame is confined inside a long tube (L/D≈15) which is used as a radiant heater for steel industrial ovens. The analysis of pollutant emissions (nitric oxides by chemiluminescence, CO by infrared system) has been carried out for different operating conditions of the burner, similar to industrial appliances: input thermal powers from 12.8 up to 18 kW and equivalence ratio from 0.5 (very lean flame) to 0.95 (quasi-stoichiometric condition). Moreover, pollutant emissions sensitivity to burnt gas external recirculation has been analyzed. The influence of the different parameters upon pollutant emissions has been clearly identified, determining the optimal operating range of the device and suggesting possible solutions for the design of new burners of similar typology.

Introduction

This work analyses the influence of operating conditions on flame morphology and pollutant emissions of an industrial natural gas – air swirl burner characterized by a rotational motion imparted to the air with the fuel injected coaxially to the air stream. The aim of swirl motion is usually to enhance the mixing process between the reactants increasing flame stabilization [1], contributing also to a reduction of pollutant emissions such as NOx and CO.

The external exhaust gas recirculation (external EGR) has been used to reduce the nitric oxide emissions, by reducing the overall temperature in the combustion region. In fact the high temperature in the reactive zone is known as the main factor influencing Thermal NOx formation [2], while temperature reduction may influence the overall combustion performance carrying to higher CO emissions. The flame was investigated through direct imaging and pollutant emissions measurements at the exhaust.

Experimental set-up

In figure 1 it is showed the analysed burner, which is used in the steel industry for surface treatment. Because of the presence of a strict composition atmosphere in the treatment oven the flame has to be confined inside two coaxial tubes: in the inner one (D_{tube}/D_{efflux} = 1.2, L_{tube}/D_{tube} ≈ 15) the combustion reaction is carried out, while the annular enclosure between the inner and outer tubes is used to carry the combustion products out and to heat up the incoming air stream.

Figure 1: the burner geometry.
This burner is characterised by air swirl motion produced by a screw type swirl generator; the natural gas is injected through an annular section coaxial with the air flow. Centrally to the burner, there is a premixed pilot flame used to ignite the mixture and to prevent burnout. The analysed operating conditions of the burner are listed in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th>Methane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Flow Rate [NI/min]</td>
<td>240</td>
<td>21.3</td>
</tr>
<tr>
<td>Nominal Reynolds Number</td>
<td>≃8000</td>
<td>≃500</td>
</tr>
<tr>
<td>Swirl Number S</td>
<td>0.85</td>
<td>0</td>
</tr>
<tr>
<td>Pilot Burner Flow Rate [NI/min]</td>
<td>23.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Analized equivalence ratio Φ of the main burner</td>
<td>0.5 ÷ 0.95</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: burner operating conditions.

Flame direct imaging and pollutant emissions measurements have been performed for different input thermal powers (from 10 kW to 18 kW) and equivalence ratio (from 0.5 to 0.95). Swirl number of the air flow, defined in [1], has been estimated by integration of axial and tangential velocity radial profiles, measured by LDV in isothermal conditions along a diameter at the minimum available axial distance from the burner exit (3.5 mm), and resulted equal to 0.85. The flame imaging has been carried out by means of a digital camera and the tube used to confine the flame has been replaced by a quartz transparent tube (tube length=1000 mm). The external gas recirculation has been obtained by means of an ejector system put on the air feeding line. This ejector creates a pressure difference between the exhaust duct and the air inlet driving to entrainment of combustion products into the main air stream. Pollutant emissions measurements have been performed by means of a conventional apparatus. Measurement techniques are based on chemiluminescence for NOx analysis, infrared techniques for CO and CO2, and paramagnetic properties for O2.

**Experimental results**

By the imaging it was possible to determine the combustion behavior for different operating conditions in terms of flame length and color. Figure 2 reports the flame length as a function of the air inlet Reynolds number (increase of inlet Reynolds number corresponds to lower value of equivalence ratio).
It has to be noticed that the flame length reduces increasing Re and this behavior is the same for different input thermal powers, the only difference being that the curves are shifted toward higher Re increasing the input thermal power, in accordance with [3]. Moreover it has to be mentioned as increasing the air inlet Re the color flame changed from a yellow color to a blue color. In the first case the flame is similar to a typical diffusion flame with a fuel jet surrounded by a coaxial air jet, with long reaction time due to the low mixing efficiency between the reactants. In the second case the flame is more similar to a quasi premixed flame with fast mixing and an intense blue color. Figure 3 reports two flame images for two different Re and same input thermal power. The pollutant emissions measurements have been carried out for the same thermal powers and equivalence ratios of the previous images. The results are reported in figures 4 and 5 as EINOX and EICO index [4].

From figure 4 it is possible to notice as the NO\textsubscript{x} emission increases with the equivalence ratio and after a value of 0.85 it begins to reduce strongly. In the lower equivalence ratio zone the flame is shorter (low equivalence ratio means higher Re) and the reduction in NO\textsubscript{x} emissions is due to the lower flame temperatures or shorter residence time.

CO emission has been reported for equivalence ratio lower than 0.85 because beyond this value it increases rapidly, due to the bad reactants mixing and the very long flame: in fact in this case the reacting flow impacts to the end of the radiant tube and the reactions are quenched carrying to high CO values. Figs. 6 and 7 report NO\textsubscript{x} and CO emissions at the same input thermal power (12.8 kW), with and without the external gas recirculation. Figs. 8 and 9 are referred to the 18 kW input thermal power operating condition.
The mass amount of recirculating combustion products ranges from 30 to 35% of the air mass flow inlet. For equivalence ratio close to the stoichiometric value the EINOx is similar with and without EGR. In this case it has to be reminded as in this region the reactants mixing is not good and the fluid dynamic plays the main role in the combustion process. At the contrary, the emission level is lower moving toward lean equivalence ratio because of a good mixing and the lower mean combustion temperature reached through the addition of cooler combustion products. Because of the lower mean combustion temperature the CO level is higher as it is highlighted in figures 7 and 9 moving toward lower equivalence ratio. This fact reduces the optimal operating field of the burner, in the presence of EGR.

It has to be underlined that the more stringent emission limit for this burner typology is 2.7 and 1 for EINOx and EICO respectively. By the external exhaust gas recirculation it is possible to reach the limit for EINOx but for EICO it is not satisfied.

Conclusions

In this work it has been highlighted as the combustion regime for a confined flame is strongly dependent on the fluid dynamic, the Reynolds number being the governing factor. Moreover it has been showed as the external exhaust gas recirculation can reduce the NOx emissions only when the combustion regime is characterized by good reactants mixing, affecting also CO formation.

The future work will continue improving the fuel–air mixing and investigating the use of the internal exhaust gas recirculation to reduce the CO emission, by a change of efflux geometry.

References