# CHEMICAL ASPECTS OF THE FLAMELESS OXIDATION APPLIED FOR GAS TURBINE COMBUSTOR

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Low pollutant emissions became the basic issues in new combustion technologies concept. One of the ways to achieve this goal is flameless oxidation process (named also "mild combustion"). It was found by Wunning [1], that under special conditions a stable form of combustion is possible for high recirculation rates of exhaust gases. Wunning points that only exhaust gas recirculating into combustor before the reaction flame front must be taken into consideration. The recirculation of hot products into the flame to improve flame stabilization is not considered as the recirculating gas.
All benefits of such combustion, i.e. low-NOx emissions, low noise levels and uniform temperatures at the combustor exit motivated further research in this field. Flameless oxidation principle for flame in furnaces with high temperature inlet air was used by Wunning and Wunning [2 ] Katsuki and Hasegawa [3], Milani and Saponaro [4].
To obtain low $NO_x$ emissions, a critical requirement is to avoid direct combustion before the dilution of air with burnt gases. Intense mixing of air with a significant amount of the burnt gases before combustion is essential and mixing must be enhanced in the preparation process prior to combustion. Internal circulation is initiated by the dynamic action of the flue gases within the furnace. When the fuel is discharged into the air, the shear-generated aerodynamic strain rate is usually high enough to quench both premixed and diffusion flames. Further downstream the strain rate relaxes and consequent burning ensues. Study of such combustion regime is very active during last few years.
The present work is aimed to find the performance characteristics of a gas turbine combustor operating in the flameless oxidation regime. It considers the specific operating conditions of gas turbine combustors with recirculating flue gases. In contrast to industrial furnaces where oxygen content in flue gases is 1-3 % [1], in gas turbine can be more than 10-15%. Its value depends on temperature before combustor (through compressor pressure ratio and efficiency) and combustion temperature (Fig.1). For stirring gas the oxygen content this value can be as high as 17 %.

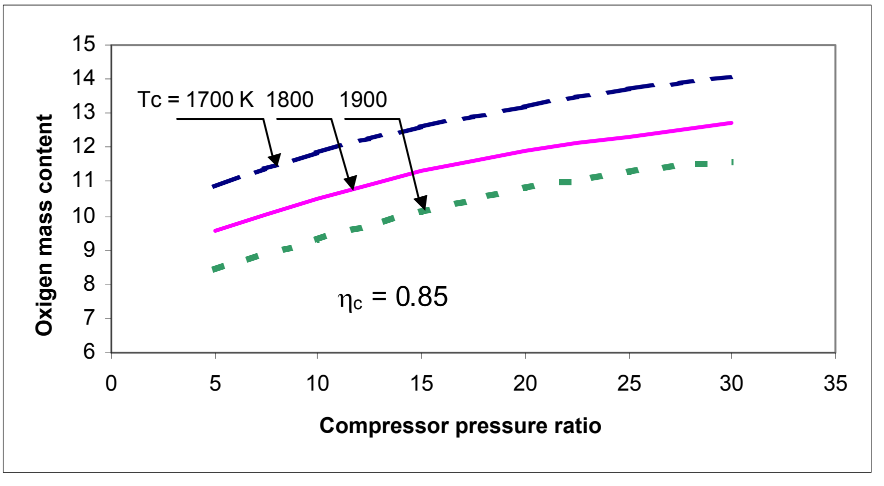


Fig.1.Variation of oxygen mass content (%) after combustion with compressor pressure ratio and efficiency.

Due to the high temperature after compressor, the ignition temperature can achieve, through the recirculation, of much lower gas quantities (hence recirculation ratios) than in industrial furnaces. Residence time in gas turbine is in the range of about 3-20 ms, i.e. in two orders of magnitudes less than in industrial furnaces. Calculation scheme of the present study included a mixing reactor, where air is mixed with combustion products in pre-set proportion (according to recirculation ratio), plug reactor for chemical process simulation, plug reactor for dilution process simulation. Residence time equaled 5 and 10 ms as the actual values for gas turbine combustors. CHEMKIN 3.7 code with application "AURORA" for "PSR" and "PLUG" for chemical reaction calculations were applied. For calculation of chemical reactions used GRI-MECH Version 3.0 package with 350 reactions.
The following main results were obtained:

1. $NO_x$ formation is governed mainly by combustion temperature (Fig. 2), almost does not depend on recirculation ratio (when combustion temperature lower 1850 K) and depends on combustion pressure.

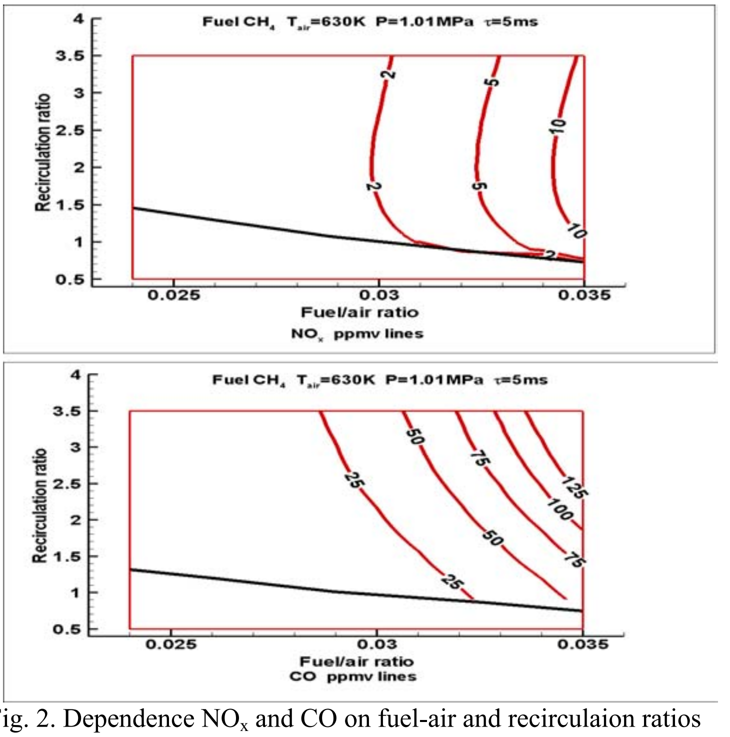


Fig. 2. Dependence $NO_x$ and CO on fuel-air and recirculaion ratios (residence time is equal to 5 ms).

2. Minimal combustion temperature (for a given residence time) depends on combustion pressure. For a given pressure it depends slightly on flue gas content.
3. Combustion delay time decreases with the recirculation ratio as stirring temperature increases (for a given fuel/air ratio *q*).
4. Variation of $NO_x$ and CO with time for combustion pressure indicates that $NO_x$ production increases slowly with time after combustion has completed (temperature achieved 99.9% of its final value).
5. Although this analysis considered only chemical reactions, it enables to estimate the required recirculation ratios for gas turbine combustor and the $NO_x$ and CO emission levels.

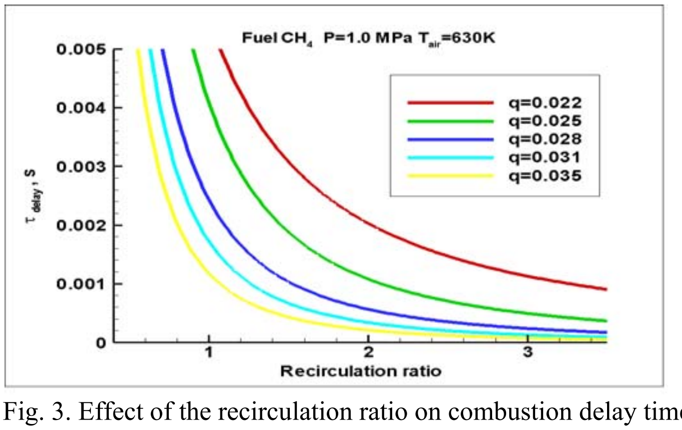


Fig. 3. Effect of the recirculation ratio on combustion delay time for various fuel/air ratios q. Combustion pressure is equal to 1.0 MPa.

**References**

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