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ECOLOGICAL EFFECT OF AIR/FUEL STAGING AND FLUE GAS RECIRCULATION ON NO_X FORMATION – EXPERIMENTAL AND NUMERICAL ANALYSIS

This paper includes both experimental and modelling researches of nitrogen oxide control. The tests were carried out in a quartz combustion chamber with laboratory equipment to enable the measurement of all the thermal and chemical parameters of the process. The experimental stand was built to determine influence of the following "primary methods": air staging, reburning and flue gas recirculation on NO_x concentration reduction. The influence of simultaneous usage of the primary methods on NOx emission reduction is also studied. Numerical modelling of the combustion processes is an indispensable element of experimental research.

Работа освещает результаты как экспериментальных исследований, так и моделирования управлением содержания оксидов азота. Тесты проводились в кварцевой камере сжигания с использованием лабораторного оборудования для измерения всех термальных и химических параметров процесса. Экспериментальный стенд был построен для определения влияния основных методов – разделение воздушных потоков, дожигание и рециркуляция топочных газов – на содержание NO_x. Было изучено влияние одновременного использования основных методов сокращения выбросов NO_x. Численное моделирование процесса горения являлось обязательным элементом экспериментальных исследований.

Introduction

Combustion of fuels is the most important method of primordial energy producing and simultaneously it is a main source of toxic components polluted to the atmosphere. Nitrogen oxides are a significant threat to the environment, and combustion systems are a major source of these pollutants [1, 2].

But it is possible to limit the negative influence of toxic components on the environment. This can be done by modifying the organization of the combustion process using so-called "primary methods" [1, 2, 3].

The primary methods of NO_x reduction are the methods which its depend on the temperature process especially air staging and flue gas recirculation. The lowering of temperature during this method applying to influence on decrease of NO_x concentration [1, 2].

Experimental research of kinetics combustion process is difficult because of the complexity of the chemical reactions related with nitrogen. Numerical modeling helps engineers to optimize the operating conditions, reduce pollutant emission, investigate malfunctions in the equipment, evaluate different corrective measures and also improve the design of new boilers [4].

Most of the works deal with both experimental researches and modeling, particularly for comparative analysis. Consequence of this, the series of models of nitrogen oxides emission reduction were created. Those models involve primary methods such as fuel and air staging and combustion gasses recirculation. Based on the elements of diffusion and heat exchange combined with chemistry of process many of programs such as: FLUENT, KIVA, CHEMKIN and others have been developed. In this paper results of complex researches of separately using several primary methods are presented [3, 4].

This paper included not only experimental research but additionally the numerical modeling of NO_x reduction of primary methods.

Research

Experimental procedure

The experimental tests were carried out using laboratory stand presented in Figure 1.

The reaction chamber consists of three quartz segments each 1 m in length and 0.12 m in diameter. Individual segments are provided with measuring holes and supplying devices. The main burner is situated at the inlet into the chamber. The total length of the chamber together with the outlet is equal to 3.8 m. Natural gas was burnt in the main burner. Natural gas was also used as the reburning fuel. The amount of feeding gas, air and recirculated flue gas was measured by rotameters. Pressure fluctuations, created by the mechanical pulsation generator, were introduced into the central segment. Fluctuation frequency was determined with the use of an electronic tachometer. Flue gas composition and temperature in the individual measuring points were determined with the use of 360 Testo exhaust-gas analyser connected to the computer. Temperature was measured using separate thermoelement. The domain of the study included the following measuring cycles: fuel staging , air staging and flue gas recirculation.

All the experimental tests were carried out with the same flow parameters of natural gas and combustion air. The parameters of experimental test were as follows:

- recirculation ratio r_c equals 0.05-0.15,
- reburning fuel fraction r_b equals 0.05-0.17 in comparison to all amount of burning gas in the chamber,
- secondary air fraction r_p equals 0.11-0.26 in comparison to all amount of air introduced into combustion.

The frequency of disturbance pulsations in reburning zone was equal to 30 Hz. For all the tests temperature distribution along combustion camber was measured. Pulsation disturbances *pd* were produced in the central segment of chamber due to intensify mixing in the zone of introducing the secondary air or reburning fuel.

The pulsation disturbances were generating in the middle segment of the chamber. It intensifies the mixing of second stage air and reburning fuel.

Modeling procedure

In the numerical modeling Chemkin programme, version 3. 6.0 has been used. All calculations as a first step of procedure have been done using two applications, Equil and Premix. The model of methane combustion was extended by the reaction of NO_x formation. All the reactions and the equilibrium constants have been taken from the Miller – Bowman model, which after its modification contained 126 reactions and 28 compounds.

The modeling procedure needed to prepare input file contains the conditions of experiment: mass flux, pressure, temperatures profile and

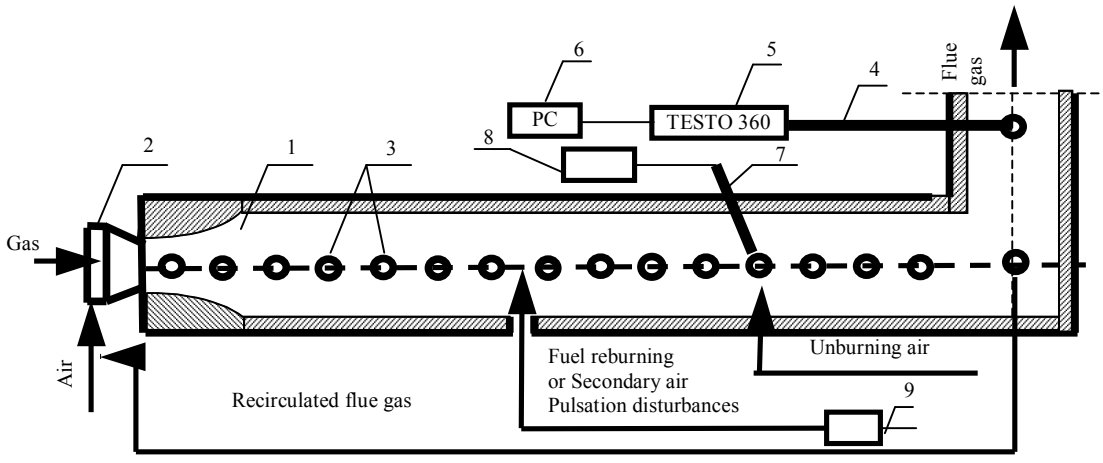


Fig.1. Laboratory for combustion tests : 1 – quartz chamber, 2 – burner, 3 – measurement points, 4 – probe, 5 – 360 Testo exhaust-gas analyzer, 6 – PC computer, 7 – PtRh-Pt thermocouple, 8 – measuring card, 9 – pulsation generator

proper calculation grid.

The following quantities have been used:

- mass flux 2.8-3.9 g/m^{2}s,
- the temperatures profile taken from the initial experimental tests,
- the substrates calculated by Equil as a fraction rate,
- estimated products of combustion calculated by Equil as a fraction rate.

The scheme of modeling chamber presented in Figure 2.

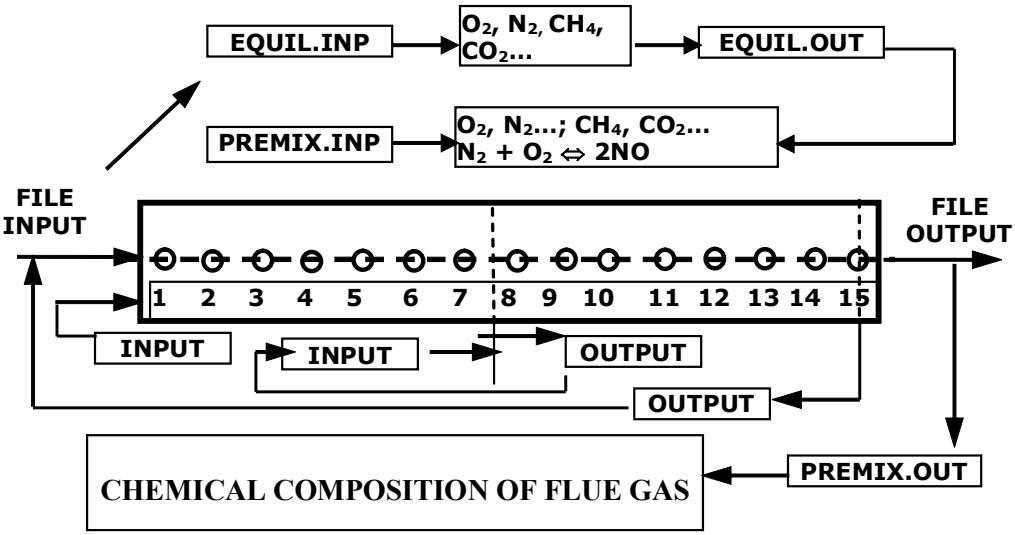


Fig.2. Scheme of modeling chamber

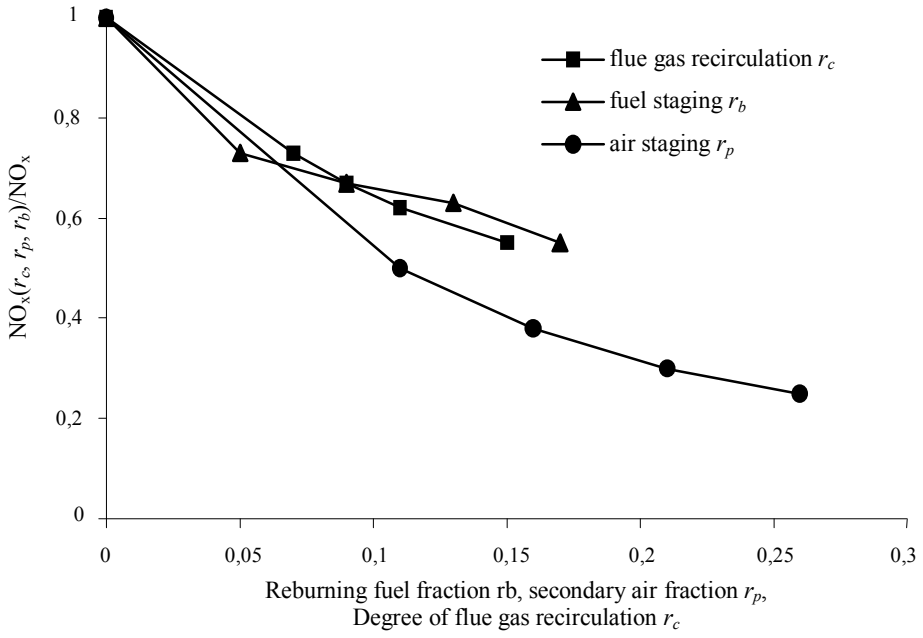


Fig.3. The impact of primary methods on NO_x concentration

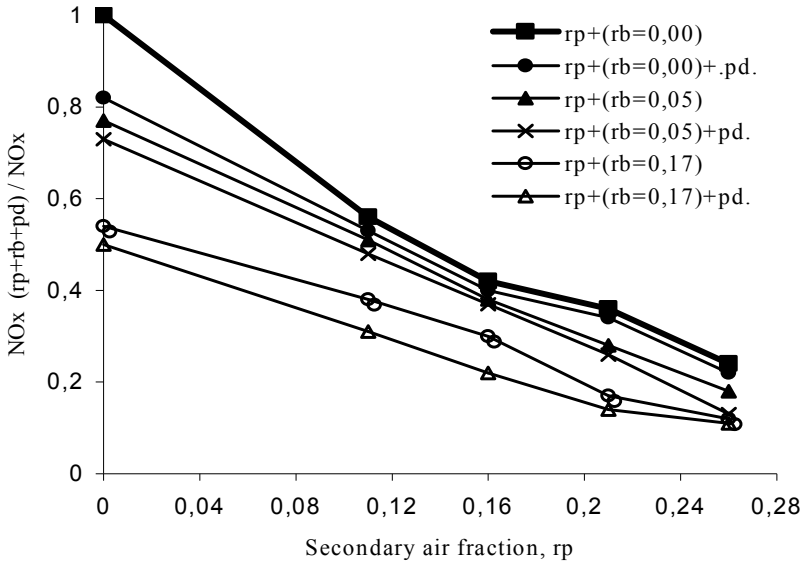


Fig.4. The impact of the air staging, reburning and pulsation disturbances (*pd*) on reduction in NO_x concentration $\frac{NO_x\ (r_p + r_b + pd)}{NO_x} = f(r_p)$

Results

Results of the experimental and numerical researches are presented in Figs. 3, 4.

The experimental tests showed that the highest efficiency was for the test with air staging. The final effect of NO_x reduction equals 71 %.

The simultaneous application of primary methods causes additional increase in NO_x reduction in the certain systems. The highest efficiency was achieved by application of air staging and reburning (Fig.4) assisted by pulsation disturbances of reacting substances. The obtained final effect of NO_x reduction was equal to 89 %. An increase in NO_x reduction, in 14 % in comparison to fuel staging and in 44 % in comparison to reburning, was achieved.

CONCLUSIONS

On the basis of conducted experimental and modeling research the following statements and conclusions were formed:

- Each of the tested prime methods of reduction of NO_x concentration in the combustion process is unique and leads to the decrease of NO_x concentration in specific scope.
- Among the prime methods tested the highest effectiveness in NO_x reduction amounting to 71 % was obtained by the use of air staging.
- The simultaneous application of primary methods causes additional increase in NO_x reduction in the certain systems.
- The results verification of the modelling research based on the conducted experiments showed high conformity of results.

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