Environmentally "Ecological" Injection Steam into the GT Combustion Chamber and Optimization of Means of Reducing NO_X Emissions

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Abstract: ***The article is devoted to the optimization of "ecological" injection of water steam into the gas-turbine combustion chamber for the purpose of NO_X emission reduction. The authors make a proposal concerning the optimization of steam injection into the combustion chamber using the least amount of steam. The authors conducted a test on model combustion chamber of serial type. There were described the conduction of two series of tests focused on studying the parameters of influence on output NO_X emission. There were considered the aspects that influence on the choice of the scheme for practical realization of steam injection.***

Keywords: NO_X emission reduction, optimization of steam injection, combustion chamber.

1. Introduction

The injection of water steam into the combustion zone is used for reduction emissions of "thermal" oxides of the nitrogen (NO_x = NO + NO_2) and is widely used for this purpose in gas-turbine (GT) and steam -gas CCGT) units, where there is no other mechanism for their formation due to the usage of a fuel without nitrogen being combined in it.

But the injection of the H_2O steam into the combustion zone is accompanied with deterioration of the combustion process stability and reduction of the fuel burning-out completeness at partial GT unit (CCGT unit) load rates with corresponding emission of CO and other toxic products of partial burning.

Besides, some researches [8] have proved that even at GT unit (CCGT unit) full loads (the temperature of the gases at the output from the combustion chamber is constant) after the H_2O injection into combustion chamber there are observed changes in the correlation between its components (NO and NO_2) along with the reduction of NO_x concentration and consequently the increase of its relative concentration:

$$\overline{NO_2} = \frac{NO_2}{NO_x}$$

It's well-known that the maximumal low able concentration (mac) in the near-earth atmospherically at the human breathing level is 0.6mg/m^3 and 0.085 mg/m^3 for NO_2 and consequently the actual toxicity of GT unit exhaust gases tail increases (since the $N0_2$ toxicity is considerably higher than that of *NO*

$$F_\Sigma = CNO / mac\ NO + CNO_2/mac NO_2 = CNO/0.6 + CNO_2/0.085,$$

which defines the level of the near-earth atmospheric layer pollution in the area of the gas-turbine and steam-gas units location.

The losses of injected H_2O steam in the combustion zone lead to negative consequences of injection into the combustion zone whereas the efficiency of suppression of NO_x emission in different chambers differs significantly.

Consequently there's an obvious need in optimization of the steam injection into the combustion chamber, so that the necessary level of the $N0_x$ emissions reduction be achieved at as low steam loss as possible.

The process of NO_x "thermal" formation mechanism is localized in certain areas of the flame pipe with maximally high temperatures and the availability of free oxygen.

Consequently a purposeful injection of steam into this zone could facilitate the reduction of expenses while providing the target level of the $N0_x$ emission reduction. But a practical solution of this problem is complicated by the instability of the thermal and concentration fields in the combustion pipe [10]. Such instability which depend upon either mode parameters of the working process, and structural particularities of the combustion chamber front construction, i.e. the scheme of fuel injection and the way its mixture with the air is organized and stabilization of the combustion is achieved [5].

The problem is further complicated with the fact that the formation of NO_x components take place both in the flame zone ("fast" NO_X), and beyond it. Additionally and regardless of which part of them is formed in a given area, the maximum temperature zones of in the jet and those of the maximum level of NO_x local concentration usually don't coincide [6].

The described thermal-emissive situation in the jet and the lack of information about conditions influencing upon it in a real-world combustion chamber, don't allow to predict an optimal scheme for the injection of an "ecological" (the part of steam aiming at improvement of GT unit ecological characteristics as opposed to the "energy-proposed" injection aimed at GT unit, CCGT unit power capacity increase) steam into the flame pipe of the combustion camera [9]. Therefore, within this research the problem have been solved in an experimental way.

In order to make the achieved results being of a direct practical interest, the experiments were conducted using a natural combustion chamber of the serial type [7], shown in Figure 1.

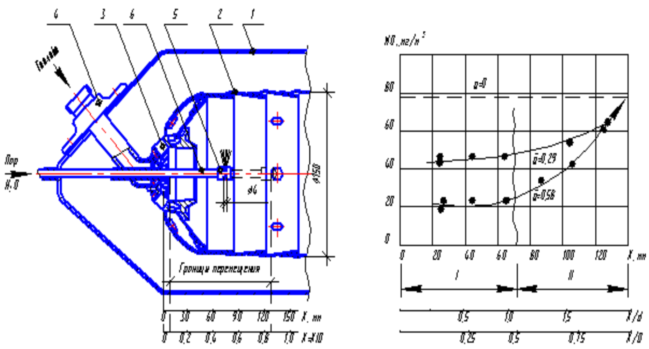

Figure 1: Scheme of a natural combustion chamber with a movable steam dispenser: 1-body; 2-flame pipe; 3 - swirler; 4-fuel injector; 5-steam dispenser; 6-movable steam collector; the influence of steam inlet location along the combustion chamber axis on NO_X formation

For optimization of schemes of steam injection into its reaction compartment, there were conducted 2 series of experiments, by which the influence upon NO_x output emission has been analyzed:

a) location of thesteam inlet along the flame pipe axis;

b) its location in the intersection of the mixture formation area of the front unit.

Changes of the steam inlet location along the burning pipe were done by means of a movable steam dispenser [4], shown in the chamber area in Figure 1. The results of this experiment have proved the need for steam injection within the area recirculation behind the stabilizer located as closely as possible to the front unit intersection with the combustion chamber.

The variants of steam injection at the cross-section of this unit are shown in Figure 2.

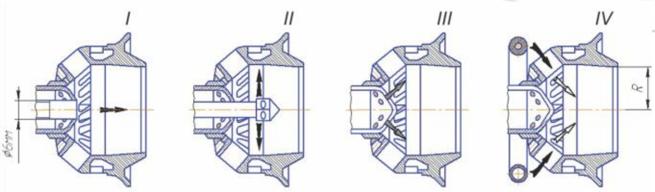

Figure 2: Variants of steam injection at the cross-section of the front unit: –steam injection; – steam-gas mixture; – steam-air mixture

The given schemes differ not only by the relative radius of inlet location (R) but also by the way of steam injection into the reaction area in the form of steam ,steam-fuel and steam-air mixtures.

The excepted variants of steam injection into the flame pipe required the corresponding organization of steam supply. As to the variants I and II, here the steam was injected directly from the steam boiler by self-supporting steam line equipped with regulation valve and flowmeter. In variant III the steam was previously mixed with fuel gas (natural gas) in volume mixer. Adjustable gas and steam supply allowed individual adjustment of content as well as the discharge of steam-gas mixture supplied into fuel injection valve. In variant IV the steam is injected into the entry section of air swirler blade channel using perforated collector ring. Consequently the ready steam-air mixture came from the swirler into the flame pipe.

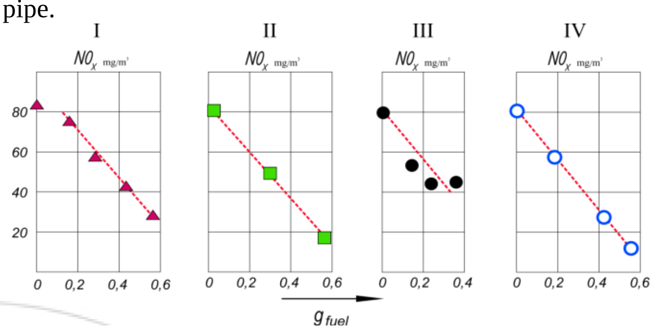

Figure 3: Results of the test chamber with different variants of steam injection *(T_{air} = 537 K ;W_{air} = 17.7-18 m/s; T_{cp} = 1400-1473 K)*

For all the studied variants the comparison of obtained results is shown in Figure 4 in the coordinates $NO_x = f(G_{ste})$.
From this figure we see that for the variants II-IV of steam injection the influence of H_2O steam on NO_X emission is significant. The variant 1 differs by its somewhat less intensive influence of steam on NO emissions that conforms to the previous conclusion as to practicability of injection of the “ecological” steam into the center of the recirculation zone.

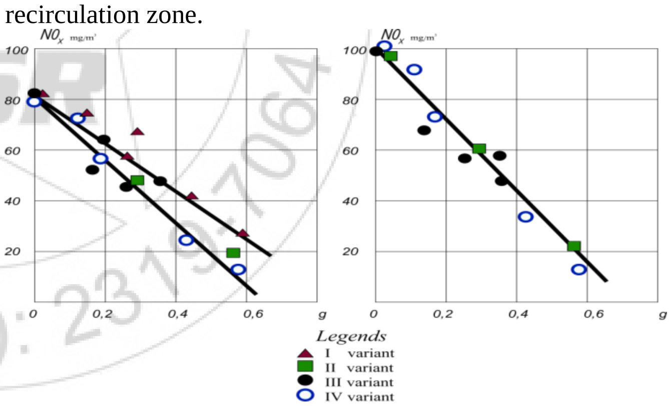

Figure 4: Influence of the scheme (the variant) of the steam injection at the cross-section of the front unit of the combustion chamber on the dependency of the nitrogen oxides concentrations upon steam relative composition.

Steam injection in the form of a concentrated axial stream, the range of which is along the recirculation zone [1]:

$$l_{str} \approx 22.5d * W_{str}/ W_{rec}$$

where *d* is a diameter of the stream;
$W_{str}$and W_{rec} are the velocities of the steam stream and the recirculation stream correspondingly.

The recirculation stream removes the area of vapor diffusion of the flame pipe cross-section from the front unit. As to the II-IV variants, they provide practically similar result - under the conditions of the studied combustion chamber, - which can be explained by the utterly high intensity of the weight exchange in the primary zone of the chamber. For all of them: in accordance with Fig. 3, the intensity of the suppression ofNO_x emissions by steam (in the tested modes) can be described by a general relation:

$$NO_x = NO_x/(NO_x)_{Gste=0} \approx 1 — 1.34 * G_{ste}/G_{fuel}$$

However it should be noticed that the scheme (the variant) for the practical realization of the steam injection should be chosen with taking into consideration all other aspects of the problem: manufacturability of steam injection execution, functional reliability, facilities providing control at variable modes etc. [3] In this aspect, the IV variant has an advantage, being the simplest in the terms of design and suitable for GT unit control.

In the conducted studies, no themes similar to H_2O influence on CO emissions and other pollutants have been registered, since in modern GT units (CCGT units) injection of "ecological" steam is realized at the high load mode only, but under the partial one is even forbidden [2].

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