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The Efficiency of Reduction of Environment Pollution by Toxic Nitrogen Oxides Using Fuel Combustion Mixture Moisturisation

Hesen Bab[1], Khaled Elozi[2], Naser Albishti[3], Shaban Ebrahim[4]

[1, 3, 4]Department of Physics, Faculty of Science, Alejelat, Zawia University, Alejelat, Libya

[2]Department of Physics, Faculty of Science, Zawia, Zawia University, Az Zawiyah, Libya

Abstract: ***The article is dedicated to the problems of efficiency of reduction of environment pollution by toxic nitrogen oxides using fuel combustion mixture moisturisation. There were analyzed the ways of nitrogen oxides concentration reduction in combustion products as well as in the gas-turbine combustion chamber. There was described the method of usage of water steam injection ("ecological" and "energetic"). There was made a conclusion that the results can be achieved taking into consideration the real content of steam gases at "ecological" steam injection into the combustion chamber.***

Keywords: Pollution reduction, nitrogen oxides, water steam injection, combustion products.

1. Introduction

The abatement of atmosphere pollution by toxic combustion products is one of the most important problems of the modern world. It has been known that combined heat and power units capacity is regulated by the combustion products temperature (GT unit, CCGT unit, ICE). The high-load modes presuppose preference of nitrogen oxides NO and NO2 to other combustion products as they have higher toxicity and make up more than 35% of the total urban air pollution [7].

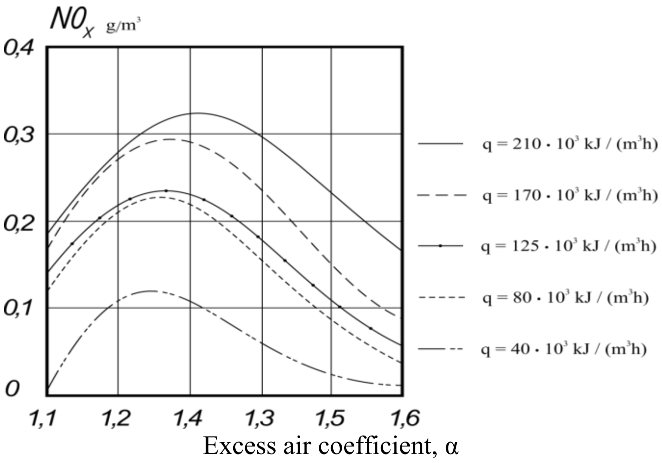

Figure 1: Combustion chamber exit nitrogen oxide concentration depending on the excess air coefficient change in the combustion area due to different thermal stresses [1]

In fact one-time maximum allowable concentration (mac) in community air bottom layer (on the breathing layer) makes up

$$macNO_2 = 0.085 \text{ mg/m}^3$$
$$macNO = 0.6 \text{ mg/m}^3$$

Preservation of the environment problems concern prompted the international community on signing the International Convention in 1988 relating to nitrogen oxides atmospheric emission reduction.

The chain scheme that fulfills the atmospheric nitrogen "thermal" oxidation [2] that is the main mechanism of nitrogen oxides composition regardless of the fact that there is no "untreated" nitrogen within combustible natural gas and oil distillates is depicted below

$$O_2 = 2O$$
$$N_2 + O = NO + N$$
$$N + O_2 = NO + O$$

As a result of oxidation reaction duration we receive nitrogen monoxide *NO* at the output. Upon the existence of additional nitrogen in the reaction zone the oxidation will continue and the nitrogen monoxide will transform into nitrogen dioxide NO_2.
The main oxidizer of *NO* in atmospheric air [5] is ozone and if it is not present in the reaction zone or in the case of limited *NO* oxidation reaction rate by molecular oxygen only the part of *NO* within combustion chamber and exhaust gas conduit is oxidized to NO_2.

Consequently regarding the real ground-level pollution from the stack flue we can make a conclusion about the nature of flue gases that contain both NO_2 and *NO*. Traditionally the assessment of flue gases pollution by nitrogen oxides is expressed by the sum

$$NO_x = NO + NO_2$$

Consequently the irrationality of such traditional assessment is obvious. Really *NO* is reduced to NO_2 and excepted

$$macNO_x = macNO_2$$

Therefore the toxicity level (factor) [5, 6] of the nitrogen oxides notional amount

$$F_{NOx} = NO_X / mac$$

$NO_X = NO_X / 0.085$

far exceeds its real value

$F_{NO+NO2} = NO/mac_{NO} + NO_2/mac = NO/0.6 + NO_2/0.085$

that leads to groundless restriction of the built generating capacity concentration as well as to the excess height increase of valuable stack flue [5]. The determination of real correlation of NO and NO_2 in gases that come out of stack flue will help to resolve differences between theoretic and actual values of toxicity level.

The emission of primary ("thermal") monoxide NO depends on the temperature in combustion chamber reaction volume that is expressed in exponential model.

Therefore to reduce the nitrogen oxides concentration in combustion products it is necessary to reduce the temperature in combustion chamber reaction volume.

Regarding the process of NO full oxidation to NO_2 it is important to note that in conditions of combustion chamber and gas pipe the most important is such reaction

$$NO + HO_2 \rightarrow NO_2 + OH$$

where$NO_2$is a peroxide radical the concentration of which (and thus the NO_2 formation reaction rate) depends on the concentration and temperature fields running mode in reaction volume.

Concentration and temperature fields in reaction volume depend on the mixture formation means and stabilization of combustion in combustion chamber as well as on the applied method of NO_X emission reduction.

The abovementioned theses were examined for the case of gas turbine combustion chamber usage and there was applied the widespread scheme of mixture formation and combustion stabilization (gas fuel) by swirling the air fuel stream in the reaction zone.

The intensity of air fuel stream (primary - Ω_0) depends on swirler geometric characteristics [4]

$$\Omega_0 = tg\beta \cdot \left(1 + \frac{\overline{d}^2}{1+\overline{d}}\right)$$

where

$$\overline{d} = \frac{d}{D}$$

To reduce the NO_X emission in studies there was used the water steam injection (H_2O) into the combustion chamber as the most economically effective method. Such assertion found its argumentation in the works of ABB company [3] confirming that under medium GTunit loads the steam injection into the flare is an optimum decision for NO_X emission reduction.

The schemes of steam injection into the flare under the excepted mixture formation scheme:

- With under-fire air;
- With fuel gas.

The combustion chamber test model that presupposes possibility of using both these schemes is shown on figure 2.

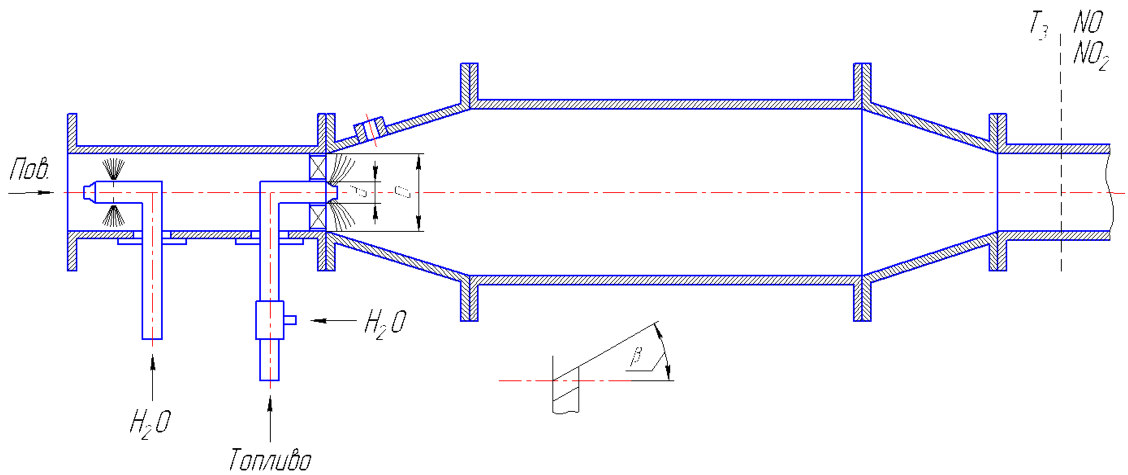

Figure 2: The scheme of test combustion chamber

However our studies showed that the method of steam injection into the flare is of no consequence as modern combustion chamber is characterized by the primary zone swirling intensity

$$\Omega_0 > 0,9 \div 1,0$$

However the most convenient from the point of view of combustion chamber operating mode regulation is the steam injection into the combustion air. That's why the most important studies were conducted according to this scheme. Unlike "energetic" steam injection into the combustion chamber the main purpose of which is the GT unit power augmentation the "ecologic" injection presupposes the regulation of NO_X emission [4]. For GTunit power reduction mode where the steam injection into the combustion chamber reduces the temperature not only in local zones of NO composition at the output from combustion chamber (T_3 is average temperature level)

$$\alpha = G_{ste}/G_{fuel}$$
$$L_o = \text{const}$$

WhereL_o is a stoichiometric fuel coefficient.

That's why "ecologic" injection of the steam into the combustion chamber (as opposed to "energetic") presupposes such regulation that together with the change of G_{ste} realizes the corresponding correction α to support the constant (T_3) that responds to turbine load.

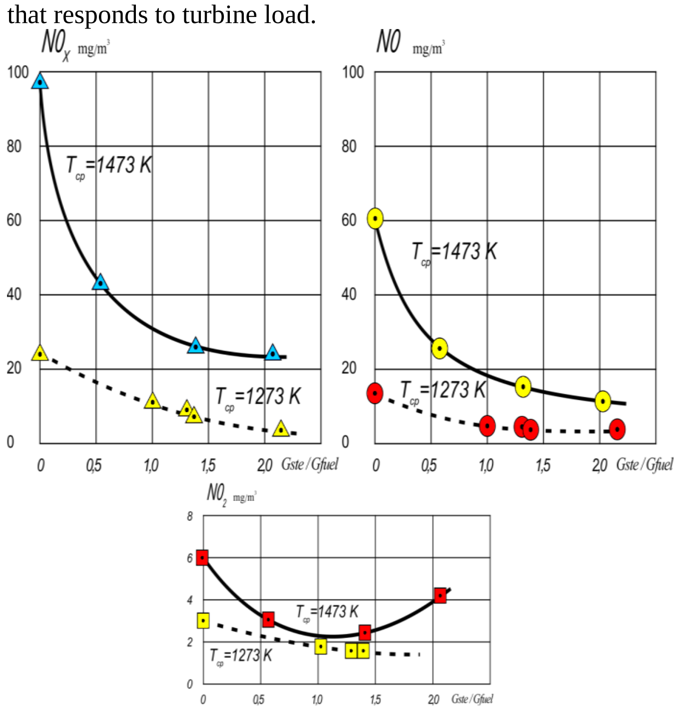

Figure 3: The influence of T_{cp} on the dependence of NO_X components concentration from *Gste/Gfuel*

All the changes of *NO* (the incident in the course of T_{cp}reduction and G_{ste}/G_{fuel} rising) reproduce the plots - NO_X. From the levels of concentration the defining role of *NO* in the sum NO_X is obvious. When it comes to dioxide NO_2 its concentration somehow depends on T_{cp} (declines when it declines) as it is seen in figure 3 although it poorly depends on steam mass ratio. The latter results in the fact that in the course of steam supply to the chamber along with the *NO* and NO_X concentration reduction there happen the increase of nitrogen dioxide NO_2 abundance ratio in combustion products. Visual comparison of NO_X toxicity level assessment and nitrogen oxides (NO + NO_2) actual composition is shown in Figure 4.

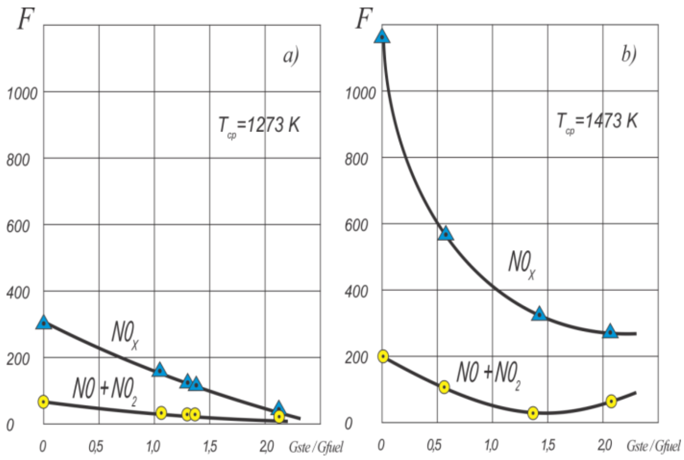

Figure 4: Nitrogen oxides toxicity factors (levels) in the course of steam supply to the combustion chamber under fire air

Basing on the assertion (for real gas)

$$NO_2 < NO_X$$

we can state that

$$F_{NO+NO2} < F_{NOX}$$

Herewith the converse of dependences

$$NO_X = f(G_{ste}/G_{fuel})$$

And

$$NO_2/NO_X = f(G_{ste}/G_{fuel})$$

provides almost constant value $F_{NO\,+\,NO2}$.

These dependences had such nature at other values T_3 as well. Consequently we can achieve considerable increase of gas turbine capacities concentration and reduction of the cost for exhaust stack construction in the course of "ecologic" steam injection into the combustion chamber.

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