Consideration of Expediency of Water Injection Application into gas-Turbine Combustion Chamber of GTP as NO_X Emission Reduction Method

Dr. Hesen Bab[1], Dr. Mustafa Sahoub[2], Dr. Shaban Ebrahim[3], Dr. Khaled Elozi[4]
[1,3] Department of physics , Faculty of Scienec , Alejelat- Zawia University, Libya.
[2,4] Department of physics , Faculty of Scienec ,Zawia University,

Abstract:

This article is concerned with consideration of expediency of water injection application into gas-turbine combustion chamber of GTP as NO_X emission reduction method.

Different methods of nitrogen oxides concentration reduction and their consequences are considered, as well as method of fighting pollutants by means of water and methods of supply thereof into reaction combustion zone. The Process of water injection and its results are described. A conclusion is made that the effect depends considerably on water injection system efficiency and correct choice of water injected dosage. Also the article contains a thesis about possible influence of chemical reaction rate – combustion reaction kinetics on nitrogen concentration reduction. Three variants of water injection into combustion zone designed for this purpose nozzle are considered. Process of water preparation for injection is described. A conclusion is made on inexpediency of operations conduction in the line of water injection application (into combustion chamber) as NO_X emission reduction method.

Key words: water injection, gas-turbine combustion chamber of GTP, NO_X emission reduction method, nitrogen oxides reduction.

1.Introduction.

Fuel-gas emissions, formed as a result of hydrocarbon fuels combustion, include highly toxic nitrogen oxides NO_X (sum of oxides NO and NO_2), carbon monoxide CO, sulfur oxides SO_X, (sum of oxides SO_2 and SO_3), unburned hydrocarbons and products of their incomplete oxidation (ketones, aldehydes), different chemical combinations, including carcinogens, such as benz(a)pyrene $C_{20}H_{12}$, components of the so called “solid aerosol particles”.

All pollutants of fuel gases may be conditionally divided into two groups:

- substances, formation of which depends on high-temperature processes of fuel combustion – NO_X, SO_X, CO;

- substances, formation of which depends primarily on fuel chemistry and process of preparation thereof, and only secondarily - on high-temperature processes of fuel combustion – SO_3, aerosols.

High-temperature parameters of fuel combustion predefine methods of fuel gases pollutants fighting: thus, for the purposes of nitrogen oxides concentration reduction a recirculation of fuel gases, fuel temperature increase, flare cooling speed variation, two-stage combustion, combustion zone distribution and catalytic fuel additives are applied successfully [4].

It's possible to achieve reduction of NO_X and SO_X emission at fuel combustion till the **mac** level only with taking several measures simultaneously [1].

Consequence of such methods application is nitrogen oxides concentration reduction in fuel pollutants up to 500÷700 mg/m^3 and lower, and at combustion of fuel oil and natural gas – up to 150÷200 mg/m^3. However in order to achieve such results it's necessary to give up technical and economic expediency, whereas application of "furnace" methods leads to heavy expenses of fuel gases recirculation – more than 8÷12%.

Achievement of marginal excess air at combustion is to be accompanied by reliable work of furnace units' automation or application of specialized systems for fuel combustion processes maintenance under standard conditions.

Whereas the significant part of energy carriers (both liquid and solid) contains a certain number of liquid (the so called "watered fuels") the most frequently used method to fight pollutants is still water injection as additive.

There are two ways of H_2O supply into reaction combustion zone[7]:

– water or vapor injection;

– application of water-fuel emulsions.

At water or vapor supply temperature in combustion zone is decreased as inert diluent of combustible mixture with rather high heating capacity.

Thus, for example, heating capacity of water vapor is almost twice higher than air heating capacity and the latter's increase by 1% (at fixed initial temperature of air-fuel mixture) should decrease combustion temperature, theoretically, approximately by 21K.

When H_2O is injected into a combustion chamber by drops the effect may be even more due to additional heat absorption for liquid evaporation. Water may be injected into a combustion zone through flame tube head, through specially designated to this purposes nozzles or introduced with fuel in a form of water-fuel emulsion.

These variants are demonstrated in terms of combustion chamber GTE-150 [6] in Fig. 1.

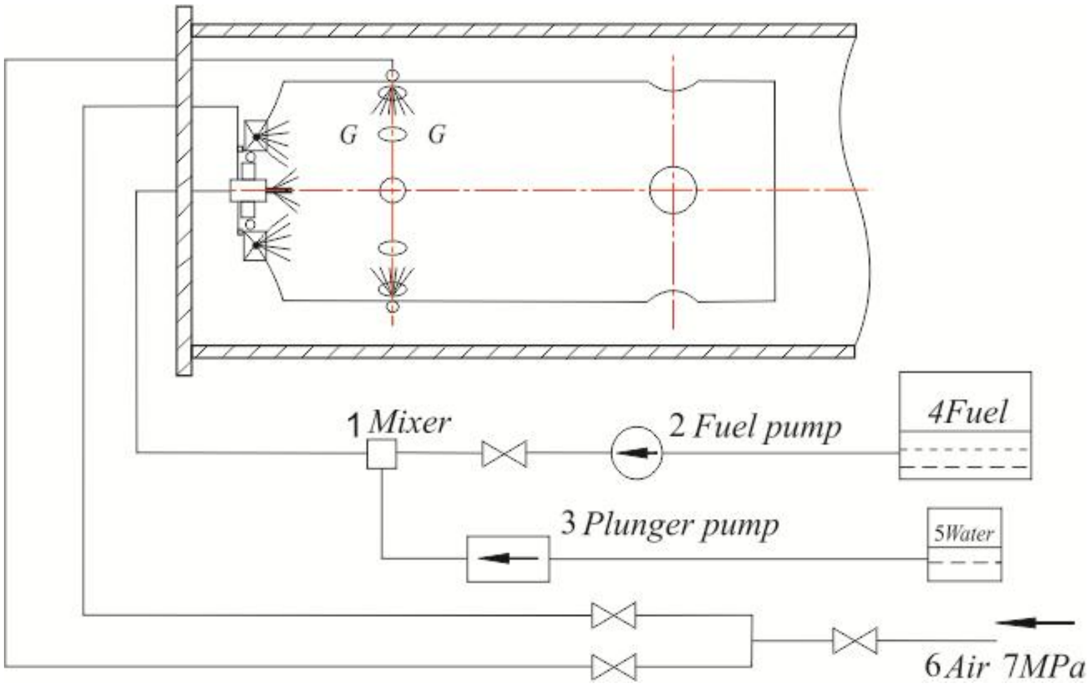

Figure 1. Scheme of possible water admissions into combustion chamber

When water is injected through flame tube head of combustion chamber at relative quantity of water, equal to

$$\frac{G_{H_2O}}{G_{fuel}} = 1,6$$

NO_X emission reduction may achieve almost 5-fold meaning (Figure2).

NO_X emissions were successfully reduced by 50% in combustion chambers with such water injection, when the latter was consumed in amount 35 % of fuel consumption, but simultaneously it was found out that the effect significantly depended on efficiency of water injection system and correct choice of injected water dosage. Indeed, the effect of neutralization reduces significantly in case of injection of decreased amount of water. When the injection is too high there is a phenomenon of “freezing”, when concentrations of *NO* and *CO* become constant, i.e. remain unchanged, what is even more undesirable.

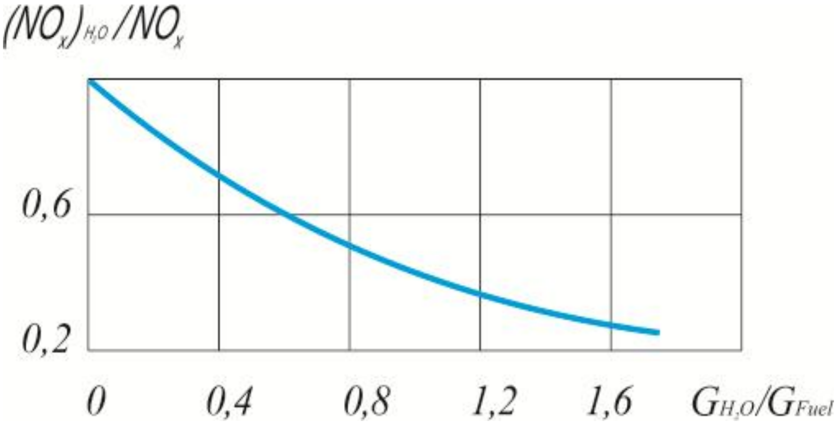

Figure 2. ***NO_X*** **emission reduction in gas-turbine combustion chamber GT-100 at water injection through flame tube head**

Figure 3 demonstrates experimental data, displaying influence of water on a process of fuel combustion in a variant of water-fuel emulsion injection, received in combustion chamber GTE-150 with further air injection. As is evident, entry of emulsion with water content 10÷15% under such conditions reduced *NO* concentration by 20÷30%.

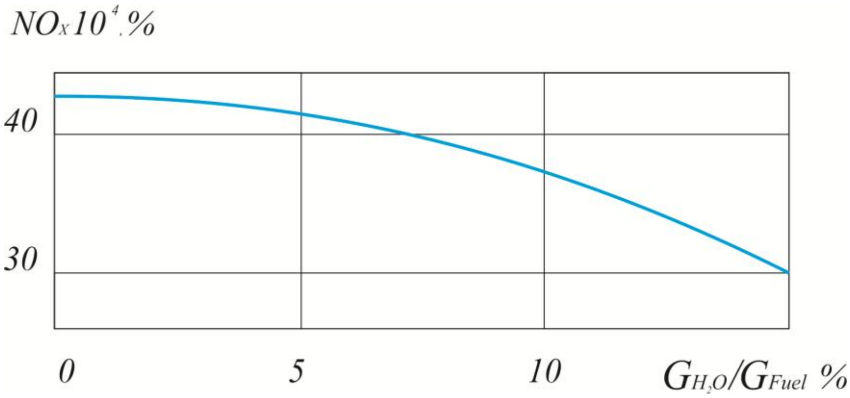

Figure 3. Dependence diagram $NO_X=f(G_{H_2O}/G_{Fuel})$ at water injection in a form of water-fuel emulsion

Other researches results demonstrated possible reduction of nitrogen oxides concentrations by 25÷50% at application of 10% water-fuel emulsion (G_{H2O} =10%) during operations with liquid and gaseous fuel [8].

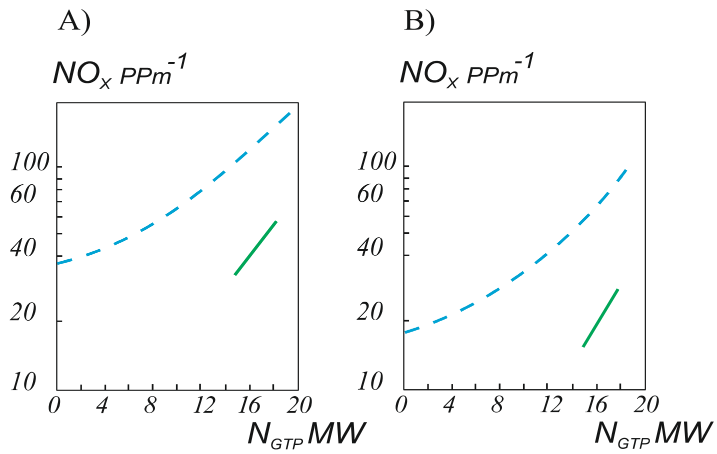

Figure 4. Influence of water injection on NO_X emission when working with liquid (*A*) and gaseous fuel (*B*): .... without water injection;
——— with water injection

It is clearly that cooling of combustion flare may not reduce so significantly nitrogen oxides concentrations. It is possible that this process is influenced by a rate of chemical reactions – kinetics of combustion reactions allows such assumption [5].

Indeed, under conditions of high temperatures and availability of water vapors the developed atomic oxygen primarily will react with carbon

$2H_2O + 2C + O \rightarrow 2H_2 + CO + CO_2$ Due to the fact that oxygen will react with nitrogen much more difficult, the concentration of atomic oxygen, which could be included into nitrogen oxides, forming the latter, reduces significantly [2].

Summarizing the above, it’s possible to notice that water supplied into the reaction zone is not so much coolant as chemical reagent, being a resource of active radicals *OH* and *H*, influencing significantly on processes of formation of *NO* and *CO*.

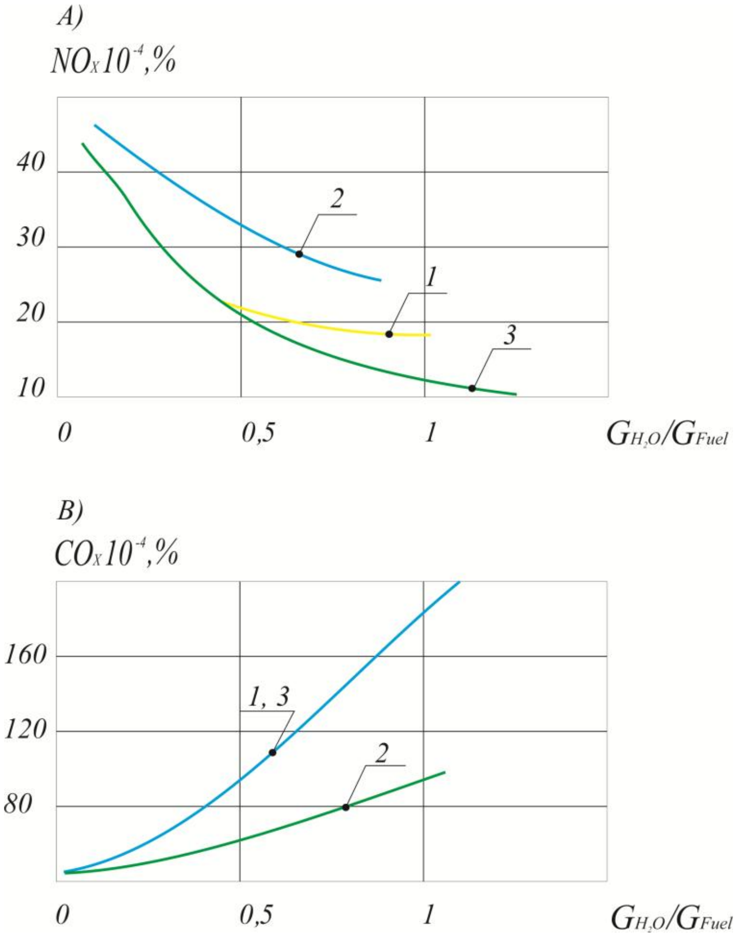

Figure 5. Dependence diagrams of emission of NO_X (*A*) and *CO* (*B*) on supplied into reaction zone water at different variants of injection: 1 – injection through flame tube head; 2 – injection through side outlets of flame tube walls; 3 – simultaneous supply by two first variants

Water injection into combustion zone by designated to this purposes nozzles may be carried out in three ways:

- through air swirler of flame tube head;
- through the first row of side outlets of flame tube;
- two ways simultaneously.

The results received on NO_X emission reduction are demonstrated in Fig. 5. It's obvious that the greatest nitrogen oxides emission reduction (3÷4 times) is achieved at application of the third variant of water supply.

Literature sources contain a lot of other examples, but they all testify that along with significant reduction of NO_X emission water injection results in a number of side, negative effects, influencing significantly on other characteristics of combustion chambers and GTP in general.

First of all it concerns decrease of intensity and completeness of combustion, which may result in fuel incomplete burning. According to the Figure 5 – б, the main products of such incomplete burning is carbonic oxide (CO), which is also included into toxic pollutants of combustion products.

Due to heat input into water evaporation in combustion chamber, in GTP (CCGP) specific fuel input increases.

Due to corrosion and possibility of salt deposits stability of combustion and combustion chamber and turbine resource reduce (combustion chamber resource reduction may be 2÷4-fold) [3].

Application of water injection requires thorough preparation thereof which is according to current requirements is rather complicated.

In order to meet the requirements water, first of all, is to be processed in 3-stage filters with activated coal, then it is supplied into zeolite softeners where lime carbonate, silicone-acid magnesium and calcium sulphate are removed, after this water is filtered through three filters with perforated meshes with width 5 µm and then pumped through two stages of reverse osmosis plants (ROP).

From these ROPs water is supplied by means of pumping into collecting tank through a system of 3-stage deionization of mixed-type effect. And only after this it's supplied into de-aerator of injectable water.

Such system of water preparation, notwithstanding its quality and reliability, is economically unprofitable.

Conclusion:

All the above affords grounds for drawing conclusion on inexpediency of operations conduction in the line of water injection application (into combustion chamber) as NO_X emission reduction method.

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