The Research Methodology of H₂O Steam Influence on Formation of Nitrogen Oxides in GT Unit Combustion Chamber

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Abstract: The article is devoted to the research methodology of H_2O steam influence on formation of nitrogen oxides in GT unit combustion chamber. The authors review the influence of H_2O in "pure" form on NO_X formation. For this purpose there were conducted investigations on test combustion chamber with steam injection into the primary air flow without air-cooled flame pipe. The authors concluded that the test bench design and the equipment used in the tests allow to measure and control all the parameters that are important to solve the task set for investigation of H_2O influence on NO_X emission in combustion chamber with the variant of steam injection in the conditions that exclude additional, uncontrolled air supply into the flame pipe reaction zone.

Keywords: Influence of H₂O steam on formation of nitrogen oxides, GT unit combustion chamber, flame pipe reaction zone.

1.Introduction

While researching the process of "wet" NO_x emission suppression it is recognized that the scientists don't often take into consideration the influence of H_2O in the "pure" form on NO_x formation [3]. Consequently the experimental set up with the variant of steam injection in the conditions that exclude additional, uncontrolled inflows of air into the flame pipe reaction zone [5] was used to increase the accuracy of the process of "wet" suppression of NO_x emission [1] as well as to specify practical guidelines as for its realization.

The investigation of H_2O influence on NO_X emission in the conditions of combustion chamber with steam injection that is conducted by the scheme presented in Figure 1 was planned in the present experiment.



According to this scheme the vapor is injected into the entry section of air swirler blade channel using perforated collector ring. Consequently the ready vapor-air mixture came from the swirler into the flame pipe. For the purpose of conducting this experiment there was made a test combustion chamber with steam supply into the primary air flow without aircooled flame pipe [4]. Although it limited the maximal temperature level ion the chamber [6], it enabled to subsist the H_2O influence on NO_X formation in "pure" form.

The variable objects were used in this experiment as process operating parameters of combustion chamber that influenced on NO_X emission [2]

- air temperature at the combustion chamber inlet (T_A) ;
- isothermal value of velocity in the midlength section of flame pipe W_{inmid} ;
- excess air coefficient α ;
- heating level in combustion chamber ΔT_{cc} ;

Т

• gases temperature on exit from combustion chamber

$$T_{cp} = T_a + \Delta T_{cc}$$

The variation of these parameters enables better assessment of H_2O level of influence on NO_X emission [4].

In the test pipe that was created for this experiment the flame pipe is brought into coincidence with the frame and doesn't have an air cooling and consequently any air blows into reaction volume (Figure 2). Consequently all the air that supplies this volume comes only through the front unit of the flame pipe that is made in the form of vane swirler with 8 airfoil-section blades with flow swirl angle β =40°. The initial flow swirl is defined by the formula

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

Where d is a swirler hub diameter

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

D is a swirler outer diameter.



Figure 2: Test combustion chamber: 1-steam nozzle; 2entrance region; 3-gas fuel nozzle; 4-swirler; 5 - electrical candle connecting leg; 6 - diffuser; 7 - flame pipe frame; 8 confuser

The water steam is injected into air flow (initial flow) before the swirler through the steam nozzle 1 (with nozzle hole diameter 1 mm). The fuel gas is injected into the combustion zone using multiple-jet nozzle 3 that is located in the centre of Swirler 4 and that has an adjustable gas dispensing cap in output with 6 holes Ø1,2 mm inclined for 60° to chamber longitudinal axis.

The initial ignition of fuel-air mixture is conducted by the high voltage electrical candle that is injected into chamber. For its injection there is a connecting leg 5 that is located on diffuser 6 of the flame pipe 7.

The experiments were conducted on the bench that is showed in Figure 3. The centrifugal blower TB-259-1.12 with flow rate up to 15000 m³/h was used as an air source. The air pressure by blower was 1.12 atm. at the temperature 300-310 K.



Figure 3: Scheme of experimental bench: 1 – combustion chamber; 2 - heat-exchange unit; 3 - diaphragm; 4 experiment bay; 5 - outlet area; 6 - inspection window; 7 fuel system; 8 - steam boiler; 9 - measuring area

The bench design with surface heat exchanger with selfcontained combustion chamber allows conducting the air heating up to 500 K.

The air flow rate into the combustion chamber is regulated by rotary valve and is measured using normal diaphragm that is installed after heat-exchange unit.

The readings of diaphragm are registered using standard pressure gage and U-differential meter. Fuel-handling system consists of gas feed line to the heating air chamber as well as to test combustive chamber with corresponding shutoff and control valves [1]. The fuel discharge is measured by previously bailed measuring diaphragms and the pressure is registered by standard manometers. Pressure differential across a diaphragm is measured by U-differential meter. To receive water steam there is used the electric steam boiler that consists of two thermally-insulated cylindrical vessels with inside diameter 300 mm connected by steam and water. In each of them there were installed two heating elements with capacity 5 kW each. One of the heating elements in each vessel was connected by autotype transformer thanks to what the generator capacity regulation could be conducted stepwise, i.e. by sequential heating elements switching, and seamlessly, i.e. by autotype transformer. The steam discharge was controlled by fall of fluid level in water measuring glass tubes that are installed on vessels. At maximum generator capacity 20 kW the steam flow rate is

$$G_{ste} = 5 \text{ g/s}$$

The air temperature in front of the test combustion chamber is measured by H-A thermocouple. For gas sampling and gas flow measurement on measurement area on exit from combustion chamber there is used a movable point-like water-cooling probe and movable point-like P-P thermocouple. Their running accuracy is ± 1 mm.

The E.M.F. thermocouple values are registered by potentiometer KSP-4. The combustive products analysis was conducted on chromatographs "HL analyzer $NO_X - NO$ " and "Gazohrom-3101" with periodical control using "Testoterm" device. The reduced measuring error is: NO volume ratio measuring – no more than $\pm 10\%$; (NO + NO₂) -±15%.

The exhausted area of bench has an inspection window that is located on combustion chamber flame tube head for flare observation. The values that can't be measured directly can be defined analytically [5]. Mass air discharge through test combustion chamber

$$G_A = K_{1\sqrt{\Delta P_A \cdot \rho_A}}$$

Where K_1 is diaphragm coefficient;

 ΔP_A is pressure differential across a diaphragm, mm ID S; ρ_A is an air density, kg/m³

$$\rho_A = P_{bar} + P_A^{St} / R_A \cdot (t_A + 273), kg/m^2$$

Where P_{har} is an atmospheric barometric air pressure, kg/m³; R_A is a gas constant for air, kgs·m/kg·K;

 t_A is an air temperature in front of a diaphragm, °C. Air velocity on exit from the swirler

 $W_A = G_A / \rho_A \cdot F_{sw}, m/s$ Where F_{sw} is a swirler exit section area, m².

Fuel gas consumption, kg/s

$$G_f = K_{2\sqrt{\Delta P_f \cdot \rho_f}}$$

where K_2 is a fuel diaphragm discharge coefficient; ΔP_f is a fuel gas pressure loss across a diaphragm, mm ID S; ρ_f is a gas density, kg/m³

$$\rho_F = P_{bar} + P_F^{St} / R_F \cdot (t_F + 273), kg/m^3$$

Where P_F^{St} , t_F is a static pressure and temperature of fuel gas in front of a diaphragm;

 R_F is a gas constant for methane, kgs·m/kg·K.

Excess air coefficient in test combustion chamber $\alpha_0 = G_A / G_T \cdot L_0$

where L_0 is a stoichiometric coefficient of combustible fuel, kg/kg.

Steam discharge

$$G_{ste} = F_B \cdot \rho_{wat} \cdot \Delta h / \tau, \ kg/s$$

где F_B is a steam boiler sectional area, m²;

 ρ_{wat} is a water density across saturation line, kg/m³;

 Δh is a fall of fluid level in boiler, m;

 π is a period of time during which there was a fall of fluid level inboiler, s.

For translation of *NO* and *NO*_X (mg/ m^3) values received usinggas-analyzer we can use the following formula

$$NO_X(mg/m^3) = 2.05 \cdot NO_X(ppm)$$

 $NO(mg/m^3) = 1.34 \cdot NO(ppm)$
 $NO_2(mg/m^3) = 2.05 \cdot NO_2(ppm)$

Consequently the test bench design and the equipment used in the tests allow to measure and control all the parameters that are important to solve the task set for investigation of H_2O influence on NO_X emission in combustion chamber with the variant of steam injection in the conditions that exclude additional, uncontrolled air supply into the flame pipe reaction zone.

References

- VarnatsY., MaasU., DibblR. Burning. Physical and chemical aspects, modeling, experiments, contaminants formation: translated from English – I.: FIZMATLIT, 2003. - 352 p.
- [2] Gas-turbine technologies. Problem-oriented the oretic magazine. – M.: Media-Grand, 2011. – 365 p.
- [3] Zel'dovichY.B.,Sadovnikov L.Y.,Frank-Kamenetskiy
 D.A. Nitrogen oxidation at combustion. M.: Nauka, 1947. – 146 p.
- [4] Olhovsiy G.G. Gas turbines for power engineering // Teploenergetika, 2004. No. 1. P. 38-43.
- [5] RudachenkoA.V., ChuharevaN.V., BaikinS.S. Gasturbineunits. – Tomsk: TPU Publishing, 2008. – 139 p.
- [6] SerbinS.I., MostipanenkoA.B.Analysisofmechanismsofnitr ogenoxidesformationingasturbineunitcombustionchamber. –O.: Vodoley, 2007. – 164 p.

- [7] Hrystych V.A., Tumanovskiy A.G. Gas-turbine engines and environment protection. – Kiev: Tekhnika, 1983. – 144 p.
- [8] Power engineering and environment protection / Edited by N.G.Zalogin, L.I.Kropp, Y.M.Kostrikina. – M.:Energiya, 1979. – 352 p.
- [9] Kramlich J.F., Make P.C. Modeling and measurement of sample probe effect on pollutant gases drown from flame zones//Comb. Sci. Tech- nol. 1978.
 Vol. 18. – P. 91-104.