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**EXPERIMENTAL REFINEMENT OF TECHNOLOGIES  
FOR ENVIRONMENTAL UPDATE OF GAS TURBINE UNITS  
APPLIED TO ELECTROGENERATOR DRIVING**

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## Abstract

The results of experimental elaboration of engineering approaches relating to environmental update of combustors for the GTK-10 10 MW, GTG-1500 1.5 MW and GT-100 100 MW gas turbine engines are presented. The combustor update was carried out by a technique of directed dosed air blow into the maximum temperature zone within the fire space.

The advantages of the technique are as follows:

- feasibility of reduction of Nox concentration in waste gases to 50 ppm;
- simplicity and adaptability to manufacture of the structure;
- no need in changing the design of the engine components and systems;
- short-time outage of the unit at update.

## Introduction

Power required by all branches of the world economy and the energy consumption at large have been on the steady rise and the environmentally unfriendly toxic emissions have been rising as well increasing twice each 12-14 years. In connection with this the problem of environmental protection against toxic pollution has been drawing the ever growing attention. In many countries the legislations putting limitations to unfriendly emissions into atmosphere have been growing more and more stringent. Improvement of environmental record has become a main trend in developments for some time past, this, in particular, pertaining to upgrading of power facilities and, more specifically, to gas-turbine engines used for electrogenerator driving.

The basic environmental challenge encountered at operating gas-turbine units is the environment pollution through hydrocarbon fuels toxic combustion products emissions. This is primarily the nitrogen oxides of the highest toxicity property whose emissions are the greatest ones followed by carbon oxide and hydrocarbons.

At present some low-emission techniques of fuel firing are known (multistage combustion, premixed combustion, catalytic burning etc.) allowing to reduce unfriendly products emissions into atmosphere with the GTU's waste gases to sufficiently low levels. Though a practical implementation of these combustion techniques

is feasible solely by creation of intrinsically brand-new and more labour-consuming combustor designs as well as through a considerable complication of the automatic control and governing systems, i.e. fresh approaches are needed in the field of GTU design as a whole which is generally associated with large expenses.

Considering a tough competition in the GTU market, actually all major firms involved in the turbomachinery equipment production reconciled themselves, to more or less extent, to these expenses and there are enough grounds nowadays to declare an advent of a fresh generation of low-emission gas turbines. In the meantime there is a large fleet of GTUs of earlier generations which are still in service. In particular, there are above 2/3rd of all gas turbines in Russia which have been in service over 15 years. At the time of these machines design, no special attention had been paid to environment protection issues; so, their environmental record is now beyond any criticism. Updating of GTU stock by replacing older production units with new generation machines has been holding on with the older GTUs depleting their life, and this process will still hold in the years to come.

Due to this, side by side with the creation of low-emission GTUs of advanced design, problem of environmental update of older design machines is now on the agenda.

## Environmental update-requirements

The problem of environmental update of gas turbine combustors, which have been still operating, differs distinctly from a problem of creation of new design low emissions GTUs. Combustor's environmental update technologies must meet a number of requirements.

Primarily, to get an environmental update economically effective, expenses on its implementation are to be low. In fact, it means that you must not introduce any changes into:

- design of solid casing;
- fuel supply and discharge systems;
- control and monitoring systems.

Secondly, field service values of an unit under update, i.e. main characteristics of an updated combustor such as:

- fuel combustion efficiency;

- hydraulic resistance;
- non-uniformity of gas temperature field downstream of combustor;
- maximum temperature of hot components' metal;
- reliability of ignition of air/fuel mixture at start-up;
- limitations of "rich" and "poor" flame turn-downs must not be inferior to those of the old design units.

Thirdly, the time of unit's outage at update carrying-out must be minimum; to attain this objective, you should provide:

- design simplicity;
- manufacture tooling;
- on-site update.

Such stringent demands make the problem of old design GTUs environmental update to be an extremely complicated one, even sometimes quite impracticable. Due to this, there have been only a few cases of environmental update of GTUs so far; and those which happened used not to be widely commercialised, remaining, essentially, within the framework of experimental explorations or individual industrial plants [1].

## Approach

It is well known that nitrogen oxide emissions lowering at hydrocarbon fuel firing may be achieved through:

- decreasing the temperature level in combustion zone;
- cutback of combustion products residence time in high temperature zone.

In a GTU combustor, these conditions are met given:

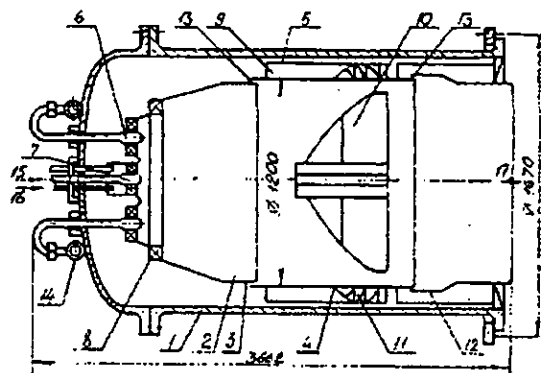
- increase in excess air coefficient in primary zone;
- increase in air velocity in primary zone.

At the same time, a simple air redistribution between combustor elements aiming to increase the excess air coefficients in primary zone results typically in:

- degrading of fuel combustion efficiency;
- considerable increase in CO emissions;
- increase in combustor hydraulic resistance.

These undesired concurrent phenomena may be avoided by using a technique of local air blow-in dosing into the combustor's high-temperature firing space zones, said technique being developed by the paper's authors [2,3], the very essence of said technique is in:

- additional air supply only into local zones of firing space having the highest temperature gradients;
- strict dosing of additional air supply aiming to avoid high-temperature  $\text{NO}_x$  generating zones and, at the same time, not allowing combustion reaction "freezing".



GTK-10 TYPE COMBUSTOR TECHNICAL DATA

Component	Technical Data
1. Casing	
2. Dome	
3. Liner	
4. Mixer	
5. Burner	
6. Screen	
7. Pilot Burner	
8. Swirler	
9. Annular channel	
10. Mixer window	
11. Guide vanes	
12. Joined lines	
13. Slot	
14. Fuel collector	
15. Pilot fuel	
16. Ignition fuel	
17. Exhaust gas	
	• fuel type: natural gas
	• air flow rate, kg/sec: 84.1
	• fuel flow rate, kg/sec: 0.868
	• air parameters at combustor inlet:
	- pressure, kg/cm <sup>2</sup> : 4.4
	- temperature, °C: 405.0
	• gas temperature downstream of combustor, °C: 780.0

FIG. 1 GTK-10 TYPE

Regardless of the technique simplicity and obvious expediency, to implement this successfully, one needs carrying-out special investigations into each specific type of its application and experimental refinement of an updated combustor as well. The basic targets of said researches are:

- identification of location and dimensions of high-temperature zones in a combustor;
- provision of appropriate direction and depth of additional air jet penetration into hot gas stream;
- determination of optimum additional air flow.

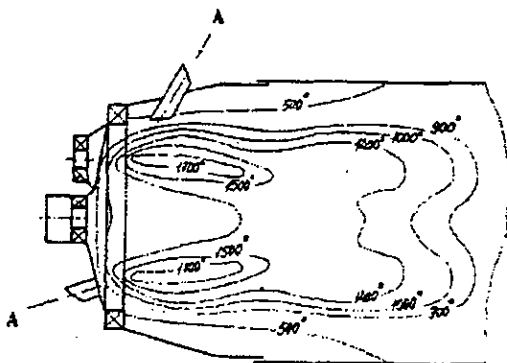
## GTK-10 combustor modification

In 1990-95, the authors developed and commercialised a technology of environmental update of GTK-10 type gas-pumping unit at the RAO "GAZPROM" compressor stations; the power of said unit being 10MW and it was produced by the "Nevsky Zavod" (St.Petersburg) [4,5,6,7].

GTK-10 combustor (see Fig.1) is a typical full-size combustor with a separate cylindrical casing joint on the underside to a turbine casing. The combustor dome includes 7 register burners, 6 thereof constitute an annular row and one is the pilot one located along the combustor axis. Outside, the annular burner row encircles

a blade air swirler of a large diameter intended mainly for liner cooling. Mixer is the annular channel formed by the liner and screen closed on one end and communicated with the firing space through mixer windows provided in the liner opposite one another.

The combustion zone structure (configuration and sizes, fuel burn-out and temperature field sizes and configurations of the reverse-flow zone) are primarily functions of burner flames interactions and also an interaction of the burner flames with the annular and opposite-twisted air jet outflowing from the larger swirler.



A - dozed oriented supply of additional air

FIG. 2 FLAME TEMPERATURE FIELD OF AN INITIAL DESIGN GTK-10 COMBUSTOR AND DIRECTION OF ADDITIONAL AIR JETS SUPPLY

On the basis of researches, the gas temperature fields within the combustor fire space (see Fig.2) and through accurate three-dimensional localization of high-temperature zones, the directions of additional air jets were identified to reduce  $\text{NO}_x$  emissions.

In the process of experimental refinement of updated combustors, the diameters and amount of air-guide branch pipes, the length of branch pipe areas protruding into the fire space, their cooling systems and other design details were elaborated.

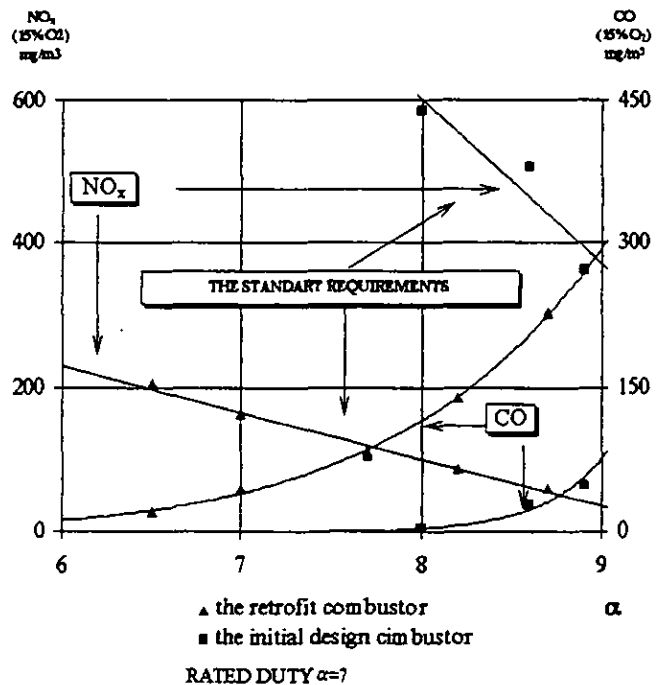


FIG. 3  $\text{NO}_x$  AND CO EMISSION AS FUNCTION OF EXCESS-AIR COEFFICIENT

The results of updated GTK-10 combustor tests demonstrated that  $\text{NO}_x$  emissions level was reduced by 6 times with no considerable increase in CO emissions (see Fig.3). Other characteristics of updated combustors not associated with the exhaust toxicity proved to be not inferior to those of an old design combustor (see Table 1).

COMPARISON OF OLD DESIGN AND UPDATED GTK-10 COMBUSTOR CHARACTERISTICS

Table 1

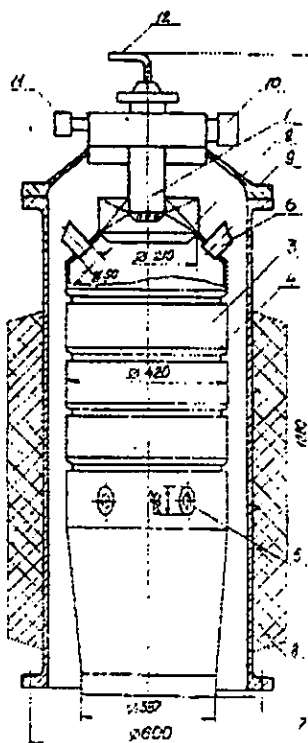
CHARACTERISTICS	OLD DESIGN	UPDATED COMBUSTOR
$\text{NO}_x$ concentrations in combustion products in terms of $\text{NO}_x$ at 15% $\text{O}_2$ measured on test rig at rated duties, $\text{mg}/\text{Nm}^3$	850.00	138.00
CO concentration (at 15% $\text{O}_2$ ) at rated duty	10.00	93.00
Fuel combustion efficiency at rated duty	0.99	0.99
Relative hydraulic resistance, %	2.85	2.90
Relative nonuniformity of gas temperature field downstream of combustor $(T_{\text{max}} - T_{\text{mean}}) / (T_{\text{mean}} - T_{\text{air}})$ , %	19.00	11.00
Maximum temperature of liner metal, $^{\circ}\text{C}$	high	high

High efficiency, reliability, simplicity and adaptability to manufacture provided by the proposed approach have inevitably led to its fast commercialisation. By now over 250 units have been updated. Some of these have already clocked up over 3 years in service [8].

## GTG-1500 combustor modification

Further researches performed by the authors were aimed at propagation of successful experience of NO<sub>x</sub> emissions reduction technique to other types of combustors.

For the time being some activities within the framework of a conversional program are carried out at the "Proletarsky Zavod" (St.Petersburg) aimed at design upgrading of GTG-1500 185 MW gasgenerator. As a baseline machine, a marine turbogenerator is employed. One of the main targets of these activities is combustor updating enabling to switch it over from liquid to gaseous fuel and to improve its environmental record as well.



1. Gas burner
2. Air blade swirler
3. Liner
4. Liner cooling system
5. Mixer
6. Air-guide brass pipes for NO<sub>x</sub> emissions reduction
7. Casting
8. Thermal insulation
9. Casting cover
10. Main fuel supply
11. Pilot fuel supply
12. Electric cable for igniter

### TECHNICAL DATA

- number of combustors - 1
- fuel type - natural gas
- air parameters at combustor inlet:
  - pressure, kg/cm<sup>2</sup> - 6.25
  - temperature, °C - 255
- airflow rate per combustor, kg/sec - 10.8
- fuel flow rate per combustor, kg/sec - 0.157
- gas temperature downstream of combustor, °C - 843
- excess-air coefficient - 4.4

FIG. 4 GTG-1500 TYPE COMBUSTOR

Refinement of full-scale GTG-1500 combustor (see Fig. 4) was carried out using a fire test bed with pressures close to atmospheric ones. On the 1st stage of tests, the gas burner design was upgraded and the old design combustor characteristics with gaseous fuel firing were identified. The 2nd stage of tests was aimed at NO<sub>x</sub> emissions lowering.

The main results of GTG-1500 combustor test rig refinement are shown in Fig. 5 and Table 2. The data obtained indicated in particular, that through the local dosed air blow-in the nitrogen oxide concentrations in combustion products from the combustors of this type can be lowered as much as 2-3 times with an acceptable level of carbon oxide emissions and fuel combustion efficiency maintained.

## COMPARISON OF OLD DESIGN AND UPDATED GTG-1500 COMBUSTOR CHARACTERISTICS

Table 2

CHARACTERISTICS	OLD DESIGN	UPDATED COMBUSTOR
NO <sub>x</sub> concentrations in combustion products (in terms of NO <sub>2</sub> at 15% O <sub>2</sub> ) measured on test rig at rated duties, mg/Nm <sup>3</sup>	145.00	32.00
NO <sub>x</sub> concentrations in combustion products (in terms of NO <sub>x</sub> at 15% O <sub>2</sub> ) in terms of full-scale pressure, mg/Nm <sup>3</sup>	313.00	90.00
CO concentration (at 15% O <sub>2</sub> ) at rated duty	13.00	200.00
Fuel combustion efficiency at rated duty	99.90	99.90
Relative non-uniformity of gas temperature field downstream of combustor (T <sub>max</sub> -T <sub>mean</sub> )/(T <sub>mean</sub> -T <sub>air</sub> ), %	12.00	9.00
Relative hydraulic resistance, %	12.30	2.34
Maximum temperature of liner metal, °C	585.00	600.00
Combustion stability:		
- "rich" flame-out (min, not above)	2.00	2.00
- "lean" flame-out (max, not below)	30.00	30.00
-vibration combustion duties	no	no
Reliability of air/fuel mixture ignition at startup of initial design combustion system	high	high

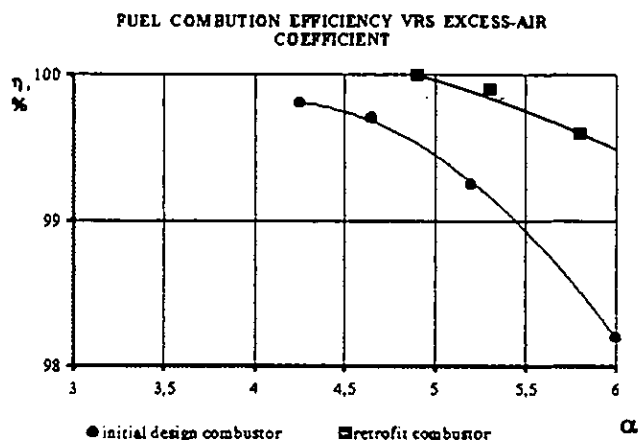
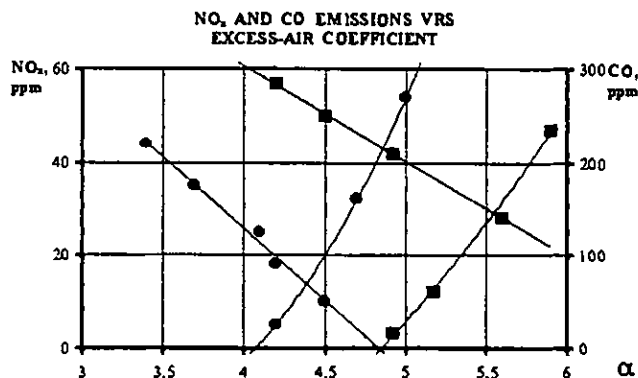
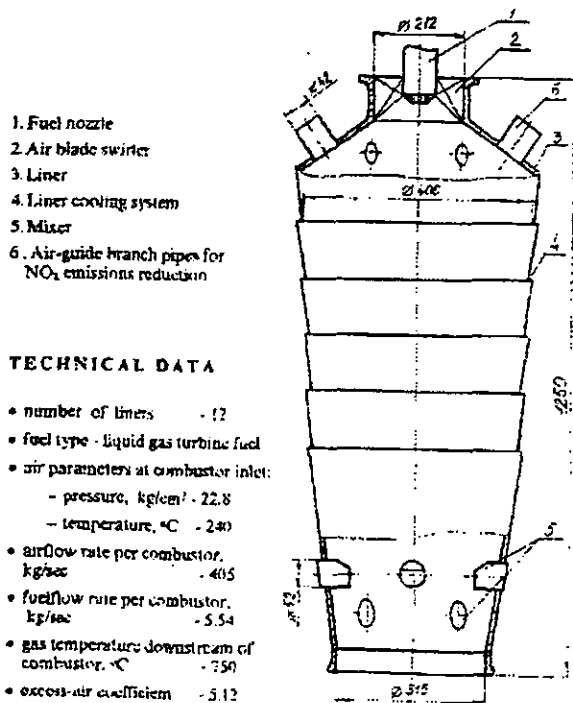


FIG. 5 GTG-1500 GAS TURBOGENERATOR COMBUSTOR RIG TEST RESULTS

At present some preparatory works are being carried out in view of the field tests of combustor operating as part of an engine. The start of tests is scheduled to take place in the 4th quarter this year.

### GT-100 combustor modification

The high pressure combustor of a power GT-100 "Leningrad Metal Works" (St.Petersburg) production turbine plant consists of 12 cylindrical liners located circumferentially in a common turbine casing. In terms of the operating process organization liner design and sizes (see Fig.6), this combustor is fairly similar to the above-described GTG-1500 combustor. The only distinction is the working media parameters.

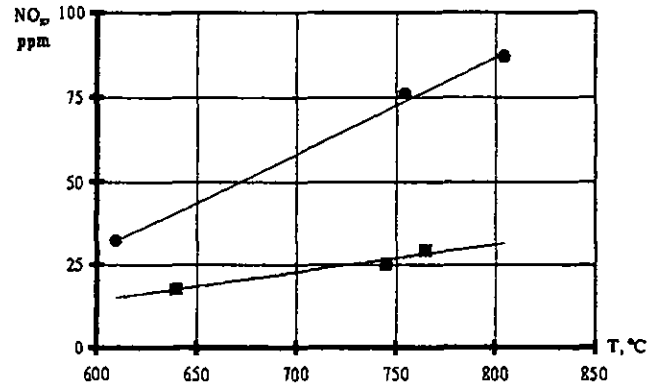


#### TECHNICAL DATA

- number of liners - 12
- fuel type - liquid gas turbine fuel
- air parameters at combustor inlet:
  - pressure, kg/cm<sup>2</sup> - 22.8
  - temperature, °C - 240
- airflow rate per combustor, kg/sec - 405
- fuel flow rate per combustor, kg/sec - 5.54
- gas temperature downstream of combustor, °C - 750
- excess-air coefficient - 5.12

As it follows from the data presented, the NO<sub>x</sub> concentration in waste gases at combustor update was reduced by 2.4 times. The other characteristics of the combustor in the meantime have not actually changed.

NO<sub>x</sub> EMISSIONS VRS GAS TEMPERATURE DOWNSTREAM OF COMBUSTOR



FUEL COMBUSTION EFFICIENCY VRS EXCESS-AIR COEFFICIENT

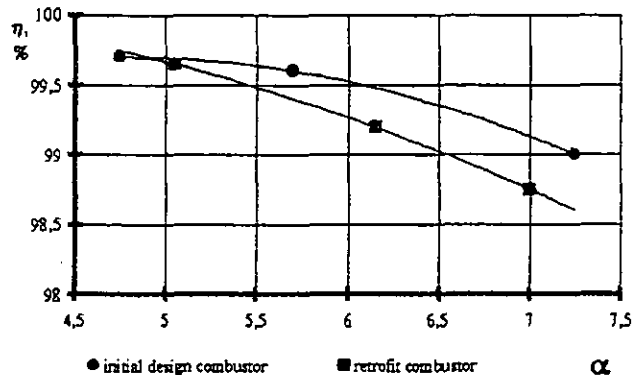


FIG. 7 GT-100 GAS TURBOGENERATOR COMBUSTOR RIG TEST RESULTS

A high air/fuel mixture ignition reliability at startup should be particularly marked, this being the same as featured by the old design combustor, and also a sufficiently high fuel combustion efficiency. Thus, the test results indicated that NO<sub>x</sub> emissions reduction technique under discussion is fairly applicable to combustors with liquid fuel firing.

As the next stage of the GT-100 gasgenerator environmental update, the integrated field tests of high pressure combustor operating as part of the unit will be carried out. Preparations for this are now in full swing.

### Summary

Summarizing the data obtained, it is well-grounded to declare that the NO<sub>x</sub> emissions reduction technique through location of air dosed blow into high-temperature fire space zone may be successfully utilized as applied to single-burner combustors [9,10] operating both with gaseous and liquid fuels.

FIG. 6 GT-100 TYPE COMBUSTOR

A more substantial distinction is that the GT-100 combustor is of dual fuel type. So there were some anticipations as to plausibility of air blow into the fire zone head region deteriorating the fuel atomization process and causing the drops evaporation which is likely to result in combustion efficiency degradation and emergence of problems associated with air/fuel mixture ignition at a startup.

The test development of the high pressure GT-100 combustor environmental update was carried out using full-scale models at pressures close to atmospheric one. Principal results of this work are presented in Fig.7 and in Table 3.

The advantages of the technique under discussion are as follows:

- feasibility of reduction of NO<sub>x</sub> concentrations in waste gases up to 50 ppm (at 15% O<sub>2</sub> in terms of NO<sub>x</sub>) without a marked increase in CO concentration and degrading the fuel combustion efficiency.

Design simplicity and adaptability to manufacture:

- absence of any changes of the components and engine systems design (besides combustor proper);
- low cost;
- short time of unit's outage for update.

**COMPARISON OF OLD DESIGN AND UPDATED GT-100 COMBUSTOR CHARACTERISTICS**

Table 3

CHARACTERISTICS	OLD DESIGN	UPDATED COMBUSTOR
NO <sub>x</sub> concentrations in combustion products (in terms of NO <sub>2</sub> at 15% O <sub>2</sub> ) measured on test rig at rated duties, mg/Nm <sup>3</sup>	204.00	88.00
NO <sub>x</sub> concentrations in combustion products (in terms of NO <sub>x</sub> at 15% O <sub>2</sub> ) in terms of full-scale pressure, mg/Nm <sup>3</sup>	620.00	259.00
- recalculated using relationship (16p-0.23)/(6p+0.77)	13.00	200.00
Fuel combustion efficiency at rated duties, %	99.70	99.60
Relative hydraulic resistance, %	3.00	3.00
Relative non-uniformity of gas temperature field downstream of combustor (T <sub>max</sub> -T <sub>mean</sub> )/(T <sub>mean</sub> -T <sub>air</sub> ), %	15.00	15.00
Maximum temperature of liner metal, °C	750.00	750.00
Combustion stability:		
"rich" flame-out	no	no
"lean" flame-out	15.00	14.00
vibration combustion duty	no	no
Reliability of air/fuel mixture ignition at startup	high	high

A deficiency of the technique is some increase in CO emissions and degradation of combustion efficiency under fractional loads duties which is an indispensable trade-off for NO<sub>x</sub> concentration lowering at rated duties given strict air and fuel supply systems and monitoring systems retaining prerequisites are met.

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