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# EXPERIMENTAL STUDY OF COMBUSTION PROCESSES IN A BURNER OF A COMBUSTION CHAMBER OF A GAS TURBINE PLANT

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**Abstract.** The article presents an experimental study of combustion processes in a two-tier burner of a combustion chamber of a gas turbine installation. Gorenje The main attention is paid to the analysis of combustion characteristics, such as temperature, concentration of combustion products and process stability under various operating modes of the gorenje. During the experiment, measurements were carried out at different points of the combustion chamber, which made it possible to identify the influence of the design features of a two-tier burner on combustion efficiency and reduction of emissions of harmful substances. The results of the study can be used to optimize combustion processes in gas turbine plants, increase their energy efficiency and reduce environmental impact.

**Key words:** micro-flame burning, nitrogen oxide, gas turbine plant, combustion chamber, two-tier burner.

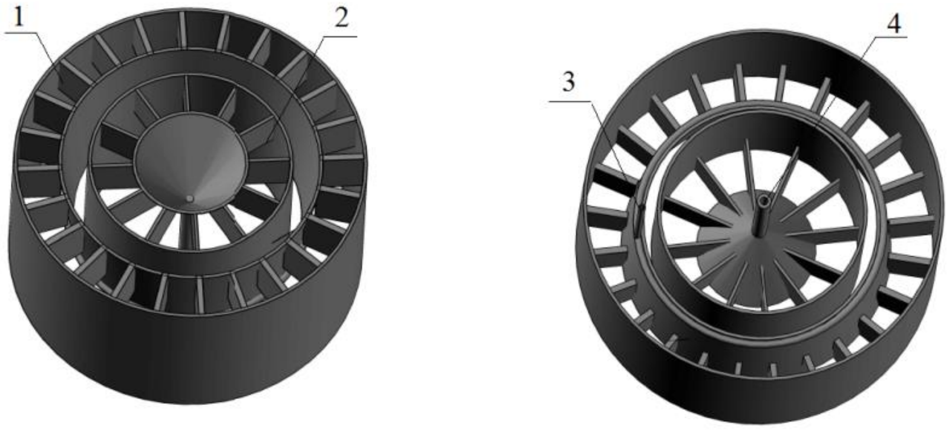
## *Introduction*

The trend of high energy development leads to the design of new efficient energy-intensive installations. The Energy Development Strategy of Kazakhstan 2030 provides for the construction of combined-cycle (CC) and gas turbine plants (GTP) operating on pipeline gas. Additionally, new power blocks must meet the increasingly stringent annual requirements for harmful emissions [1,2]. The combustion chambers of first-generation gas turbine units represented a fuel combustion system relying solely on a diffusion mechanism. Prior to the introduction of strict nitrogen oxide emission regulations, combustion chambers were designed such that the air-to-fuel ratio in the combustion zone was close to the stoichiometric value.

The objective of this work is to determine the performance characteristics of a burner in the combustion chamber of a gas turbine unit and to investigate the formation of $NO_x$ in the two-level burner under different combustion modes.

## *Materials and research methods*

Existing simple centrifugal injectors in the GTU combustion chamber have high nitrogen oxide emission rates. We propose using two-level burners in the GTU combustion chamber [3,4]. In this two-level burner, the method of fuel combustion is microflame, i.e., the separation of a single flame into individual microflames and separate tiered combustion. This is made possible by the distributed supply of fuel and air, and by the radial sectioning of the fuel-air mixture combustion organization. Microflame combustion implies a combustion process consisting of many small flames. The burner is designed to operate with either one type of fuel or for the simultaneous combustion of liquid and gaseous fuels. The burner can function under various modes, with different zones operating at different modes: the inner and outer zones. Special attention is paid to fuel distribution in the two-level burner. By managing the zones, the output of toxic substances can be regulated. An isometric view of the two-level burner device is presented in Figure 1.



*а)* Front view *б)* Rear view

1 – outer tier; 2 – inner tier; 3 – fuel pipe of the outer tier; 4 – fuel pipe of the inner tier
Figure 1. Isometric view of the two-level burner

In the studied burner, compressed air is supplied from a fan or compressor, passing through stabilizing tubes. The air flow acquires almost uniform velocity across the entire section and is fed through the measuring zone into the diffuser of the front device with the burner. Fuel enters the burner through the supply pipeline from the gas pipeline. In the burner device, the fuel is pre-mixed with air and fed into the combustion zone. The bulk of the air in the two-level burner enters the combustion zone through the front device. The installation scheme for testing is shown in Figure 2.

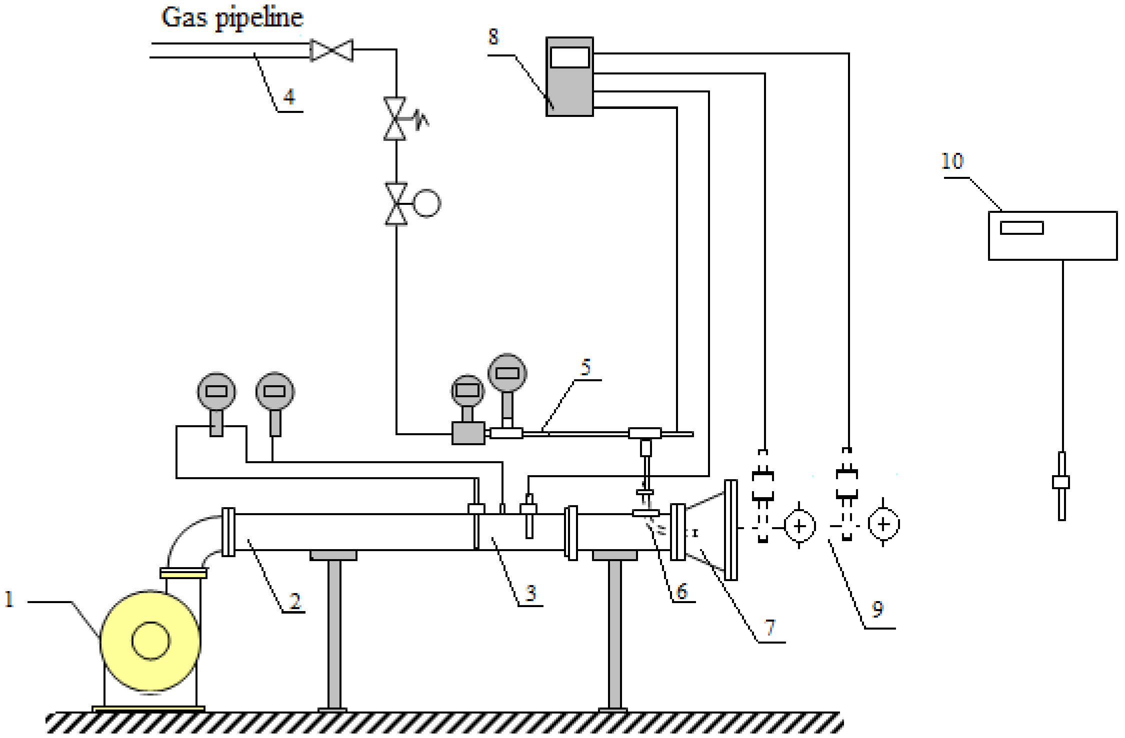


Figure 2-Experimental stand

1 – fan; 2 – stabilizing tube; 3 – measuring section at air inlet; 4 – gas pipeline; 5 – measuring section for fuel supply; 6 – fuel supply pipe; 7 – diffuser of the front device with the burner; 8 – multi-channel meter; 9 – measuring section behind the diffuser; 10 – gas analyzer

To determine the performance characteristics of the GTU combustion chamber burner, the air flow rate, fuel flow rate, temperature, and pressure at the inlet and outlet of the burner, as well as the concentration of harmful emissions, are measured. Measurements were conducted under different modes and conditions: 1) fuel supplied to the inner tier; 2) fuel supplied to the outer tier; 3) both tiers operating simultaneously. The study also examined flame blow-off at different air flow velocities. Liquefied propane was used as the gaseous fuel.

The overall excess air coefficient is determined by the formula:

$$\alpha = 3600 \cdot \frac{G_\text{в}}{G_\text{т} \cdot L_0}, \tag{1}$$

where $G_\text{в}$ – is the air flow rate in kg/s; $G_\text{т}$ – is the fuel flow rate in kg/h. $L_0$ is the stoichiometric coefficient, kg/kg, кг/кг [5].

***Research results***

The results of the experiments during stable combustion and blow-off at different air speeds under different modes are presented in the tables and figures below. In Tables 1 and 2 and in Figures 3 and 4, the results during the operation of the inner tier are shown.

Table 1. Results of stable combustion

| **ω, m/s** | **Vд, m$^3$/h** | **Gт, kg/h** | **Gв, kg/s** | **α** |
|---|---|---|---|---|
| 2 | 1,44 | 2,6683 | 0,032 | 1,877097 |
| 3 | 1,56 | 2,8907 | 0,048 | 2,599057 |
| 4 | 1,8 | 3,3354 | 0,064 | 3,003355 |
| 5 | 2,04 | 3,7801 | 0,08 | 3,312524 |
| 6 | 2,4 | 4,4472 | 0,095 | 3,343579 |

Table 2. Results during flame blow-off

| **ω, m/s** | **Vд, m$^3$/h** | **Gт, kg/h** | **Gв, kg/s** | **α** |
|---|---|---|---|---|
| 2 | 0,66 | 1,223 | 0,032 | 4,09548 |
| 3 | 0,9 | 1,6677 | 0,048 | 4,50503 |
| 4 | 1,2 | 2,446 | 0,064 | 4,09543 |
| 5 | 1,5 | 2,7795 | 0,08 | 4,50503 |
| 6 | 1,62 | 3,0019 | 0,095 | 4,95345 |

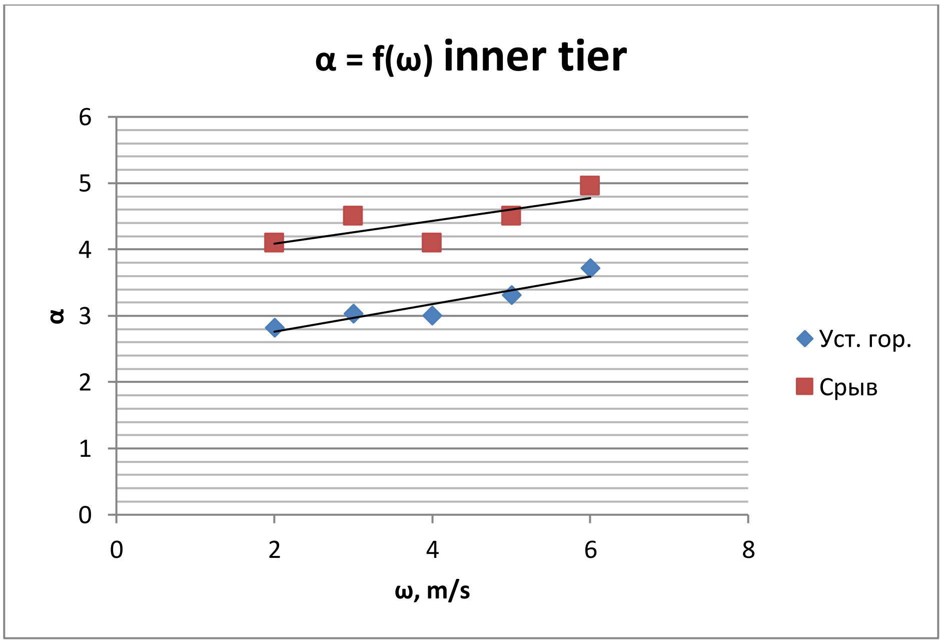
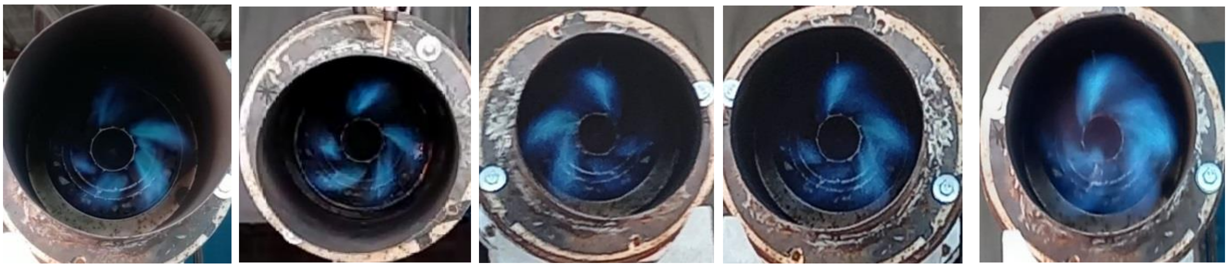


Figure 3- Dependence of excess air coefficient on air flow velocity during operation of the inner tier



2 m/s 3 m/s 4 m/s 5 m/s 6 m/s

Figure 4- Snapshot of the combustion process in the inner tier under different modes

In the conducted experimental studies, the excess air coefficient for the inner combustion tier varied in the range $\alpha = 1{,}87 \div 4{,}95$; on average, the fuel consumption during blow-off was 63% less than that during stable combustion.

In Tables 3 and 4 and in Figures 5 and 6, the results of combustion studies during the operation of the outer tier are presented.

Table 1. Results of stable combustion

| **ω, m/s** | **Vд, m$^3$/h** | **Gт, kg/h** | **Gв, kg/s** | **α** |
|---|---|---|---|---|
| 2 | 0,96 | 1,7789 | 0,032 | 2,81565 |
| 3 | 1,08 | 2,0012 | 0,048 | 3,75419 |
| 4 | 1,2 | 2,2236 | 0,064 | 4,50503 |
| 5 | 1,32 | 2,446 | 0,08 | 5,11936 |
| 6 | 1,44 | 2,6683 | 0,095 | 5,57263 |

Table 2. Results during flame blow-off

| **ω, m/s** | **Vд, m$^3$/h** | **Gт, kg/h** | **Gв, kg/s** | **α** |
|---|---|---|---|---|
| 2 | 0,3 | 0,5559 | 0,032 | 9,01007 |
| 3 | 0,36 | 0,6671 | 0,048 | 11,2626 |
| 4 | 0,42 | 0,7783 | 0,064 | 12,8715 |
| 5 | 0,6 | 1,1118 | 0,08 | 11,2626 |
| 6 | 0,6 | 1,1118 | 0,095 | 13,3743 |

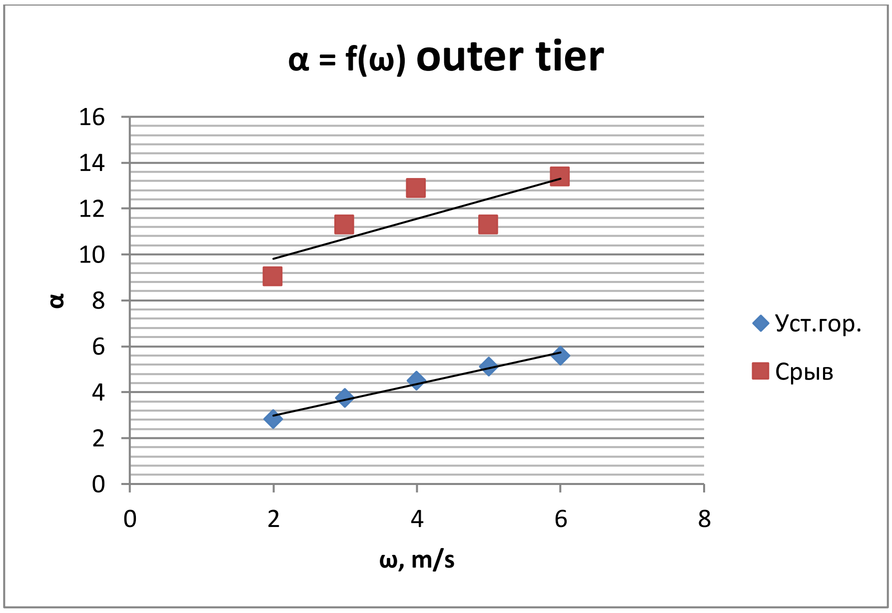
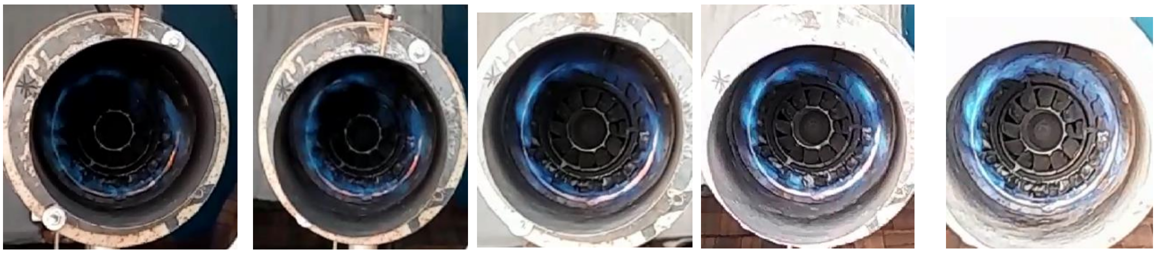


Figure 5- Dependence of excess air coefficient on air flow velocity during operation of the outer tier



2 m/s 3 m/s 4 m/s 5 m/s 6 m/s

Figure 6- Snapshot of the combustion process in the outer tier under different modes

In the conducted experimental studies, the excess air coefficient for the outer combustion tier varied in the range $\alpha = 2{,}81 \div 13{,}37$; on average, the fuel consumption during blow-off was less than the fuel consumption during stable combustion.

In Tables 5 and 6 and in Figures 7 and 8, the results of combustion studies during simultaneous operation of both tiers are presented.

Table 1. Results of stable combustion

| **ω, m/s** | **Vд, m$^3$/h** | **Gт, kg/h** | **Gв, kg/s** | **α** |
|---|---|---|---|---|
| 2 | 1,44 | 2,6683 | 0,032 | 1,877097 |
| 3 | 1,56 | 2,8907 | 0,048 | 2,599057 |
| 4 | 1,8 | 3,3354 | 0,064 | 3,003355 |
| 5 | 2,04 | 3,7801 | 0,08 | 3,312524 |
| 6 | 2,4 | 4,4472 | 0,095 | 3,343579 |

Table 2. Results during flame blow-off

| **ω, m/s** | **Vд, m$^3$/h** | **Gт, kg/h** | **Gв, kg/s** | **α** |
|---|---|---|---|---|
| 2 | 0,42 | 0,77826 | 0,032 | 6,435761 |
| 3 | 0,6 | 1,1118 | 0,048 | 6,757549 |
| 4 | 0,66 | 1,22298 | 0,064 | 8,190969 |
| 5 | 0,72 | 1,33416 | 0,08 | 9,385485 |
| 6 | 0,78 | 1,44534 | 0,095 | 10,28794 |

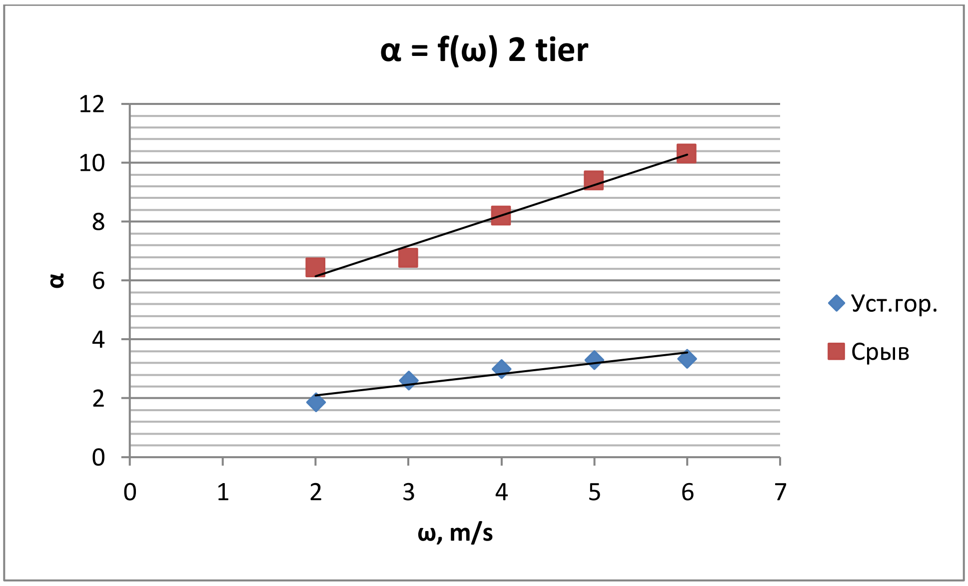


Figure 7- Dependence of excess air coefficient on air flow velocity during operation of both tiers simultaneously

2 м/с 3 м/с 4 м/с

Figure 8- Snapshot of the combustion process in both tiers under different modes

In the conducted experimental studies, the air excess coefficient $\alpha$ varied in the range of 1.87 to 13.37. Within this range of the air excess coefficient, the combustion efficiency reaches $\eta \geq 0.98$. According to the experimental results, nitrogen oxide emissions in the combustion chamber also decrease and depend on the distribution of $\alpha$ values across the stages, as well as the degree of flow swirl in the upper and lower stages. The study [3] presents the results of the investigation of a dual-stage burner when burning liquid fuel. The dependence of NOx emissions on the air excess coefficient $\alpha$ when burning a lean fuel-air mixture is shown in Figure 9.

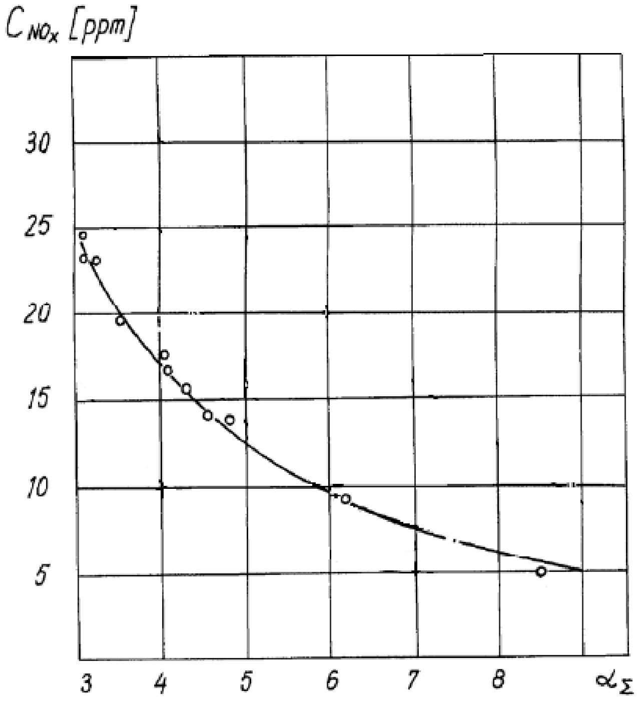


Figure 9- Dependence of nitrogen oxide concentrations on the air excess coefficient

***Conclusion***

It is recommended to use multi-stage burners and the microflame combustion method in the design and modernization of gas turbine combustion chambers to improve energy performance and reduce environmental impact.

The efficient reduction in the $NO_x$ emission in processes of lean premixed combustion of liquid fuels is possible to be controlled by the adequate flow swirling by inlet and exit vortex generators.

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## ГАЗ ТУРБИНАЛЫ ҚОНДЫРҒЫНЫҢ ЖАНУ КАМЕРАСЫ ОТТЫҒЫНДАҒЫ ЖАНУ ПРОЦЕССТЕРІН ЭКСПЕРИМЕНТАЛДЫ ЗЕРТТЕУ

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**Аңдатпа.** Мақалада ұсынылған эксперименттік зерттеу процестер жану двухъярусной шілтерде жану камерасының газ-турбиналық қондырғылар. Негізгі назар талдау сипаттамаларын және жану сияқты, температурасы, концентрациясы жану өнімдерінің және тұрақтылық үрдістің жұмыстың әртүрлі режимдері кезінде қыздырғыштар. Эксперимент барысында жану камерасының әртүрлі нүктелерінде өлшеулер жүргізілді, бұл екі деңгейлі оттықтың құрылымдық ерекшеліктерінің жану тиімділігіне және зиянды заттар шығарындыларының төмендеуіне әсерін анықтауға мүмкіндік берді. Зерттеу нәтижелерін газ турбиналық қондырғылардағы жану процестерін оңтайландыру, олардың энергия тиімділігін арттыру және қоршаған ортаға әсерін азайту үшін пайдалануға болады.

**Түйін сөздер**: микрофакельді отын жағу, азот оксиді, газ турбиналы қондырғы, жану камерасы, екі деңгейлі оттық.

## ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ПРОЦЕССОВ ГОРЕНИЯ В ДВУХЪЯРУСНОЙ ГОРЕЛКЕ КАМЕРЫ СГОРАНИЯ ГАЗОТУРБИННОЙ УСТАНОВКИ

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**Аннотация.** В статье представлено экспериментальное исследование процессов горения в двухъярусной горелке камеры сгорания газотурбинной установки. Основное внимание уделено анализу характеристик горения, таких как температура, концентрация продуктов сгорания и стабильность процесса при различных режимах работы горелки. В ходе эксперимента проведены замеры в разных точках камеры сгорания, что позволило выявить влияние конструктивных особенностей двухъярусной горелки на эффективность сгорания и снижение выбросов вредных веществ. Результаты исследования могут быть использованы для оптимизации процессов сгорания в газотурбинных установках, повышения их энергетической эффективности и уменьшения воздействия на окружающую среду.

**Ключевые слова:** микрофакельное сжигание, оксид азота, газотурбинные установки, камера сгорания, двухъярусная горелка.