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Research Article

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Calculations of Heat Transfer in Combustion Chambers of Gas Turbine Plants According to the Laws of Thermal Radiation of Gas volumes

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Abstract

The analysis of methods for calculating heat transfer in the combustion chambers of gas turbine plants is carried out. None of the existing methods for calculating heat transfer gives a complete and accurate picture of heat transfer in combustion chambers. The calculation method developed on the basis of scientific discovery allows one to calculate with high accuracy the density of the torch heat fluxes along the surfaces of the flame tube, organize rational heat transfer in the combustion chamber, reduce costs and time of creation of combustion chambers and increase their service life.

Keywords: Combustion Chamber, Thermal Radiation, Torch, Heat Exchange, Gas Volume, Scientific Discovery, Gas Turbine Plant

Introduction

Heat transfer by radiation is the main type of heat transfer in torch heating furnaces, fire chambers of boilers, the combustion chambers (CC) of gas-turbine installations (GTI). Thermal flows falling on the heating surface from the flare formed during combustion of gas, oil, and pulverized coal fuel by 92-98% consist of heat radiation flow and by 2-8% from convective flow [1-8]. Flame transmits 99-99.5% heat with radiation, 0.5-1% by convection [5, 9-18].

Gas turbine units have been used in power engineering for about 70 years (Figure 1). Over this period of time, the characteristics of gas turbines have changed significantly: the unit capacity has increased from 300 kW to 280-380 MW, the temperature at the turbine inlet has increased from 500 to 1400-1500°C, and the efficiency has increased from 14% to 62% in Combined Cycle Gas Turbine (CCGT). Ecological characteristics also improved significantly: the concentration of NOx decreased from 200 ppt in the 1940s to 15 ppt in the 2000s, and the specific emissions of nitrogen oxides decreased over this period from 10 to 0.1 kg / (MWh) of electricity generated [19, 20]. The specific gravity of gas turbines decreased from 10 to 1.5 kg / kW of installed capacity. It was possible to increase the temperature at the turbine inlet and the GTI efficiency after development and application: in the 1960s, nickel-based alloys, in the 1970s of cooled blades and in the 1990s of sequential gas combustion. During the 1940-1960s, various types of liquid fuels served as the main fuel for gas turbines; in the last decade, natural or liquefied natural gas, the proportion of which approaches 80% of all fuel used in gas turbines. Liquid fuel, due to its cost and increased air emissions, is mainly used in transport installations. At first, single burners were used in gas turbine sectional combustion chambers, then pre-mixed burners (the first generation of low-toxic burners [20]) were used; in the late 1980s, dry low-toxic second-generation burners were developed. In second-generation burners, gas and air were mixed after gas escaped from the openings, torch stabilization was provided by crushing the vortex and no mechanical flame stabilizer was required. Later, combustion chambers with ring burners were created, which modern gas turbines are equipped with.

Figure 1: Gas turbine power station

For the use of GTE-65 brand Power Machines at GTI, two variants of combustion chambers were compared: a sectional type of ten tubular sections with burner devices of six nozzle modules each, a flame tube and a gas collector, and a ring type of 120 preliminary mixing chambers on the frontal ring a flame tube from two shells and a pilot burner. Sectional combustion chambers (Figure 2) are more convenient for bench testing and repairs. Their main drawbacks are greater than that of ring compressor, the area of the cooled surface and the circumferential unevenness of the temperature of the combustion products. As a result of the analysis of technical and economic indicators and the experience of the previous design of the compressor stations GTE-150 and GTE-180, GTI-295 (Figure 3), the option of an annular combustion chamber was chosen. The use of a ring compressor with preliminary mixing of the fuel-air mixture in combination with the implementation of an operation algorithm in which the ratio of fuel consumption in a homogeneous and diffuse stage increases from 4: 1 to 20: 1 as the load increases with the gradual inclusion of the second-row mixing chambers into operation provide its acceptable emission characteristics on gaseous fuels [21, 22].

As kinetic calculations show, when burning poor homogeneous mixtures of natural gas and air at temperatures t_g = 1400 ... 1500°C, pressures of 1.5...2.0 MPa and residence time τ_{rt} = 20 ... 30 ms, it is possible to reduce NOx emission to 3 ... 8 rpm. To solve this problem, over the past 10–15 years, gas turbine companies have been intensively creating combustion chambers with the organization of burning pre-mixed air-fuel mixtures with a coefficient of excess air in the combustion zone α = 1, 9 ... 25 [23]. With the introduction of this method of burning in compressor almost all the leading gas turbine companies without water or steam injection, nitrogen oxide concentrations of not higher than 8 ... 25 ppt were obtained at operating conditions. In most of the compressor stations, two or more independently adjustable fuel supply stages are provided during start-up and loading of gas turbines, air bypass along the compressor circuit.

The main problem in creating low-toxic compressor is the provision of a stable combustion regime without disruptions, breakthroughs, and pulsations of the torch. They can be avoided during the design of the spacecraft using modern calculation methods, experimental results and operating experience. As a result, a balance of sizes, parameters and indicators is achieved. To maintain this balance when changing modes, sensors are installed, the signals from which are fed to the automated control system of the gas turbine. This compromise in the organization of the process of burning natural gas explains the difference in NOx concentrations that can be achieved; it has already been actually received by the leading foreign companies GE, Simens, Alstom for stationary gas turbines. The term of industrial operation of low-toxic CS is 30 ... 50 thousand hours [24].

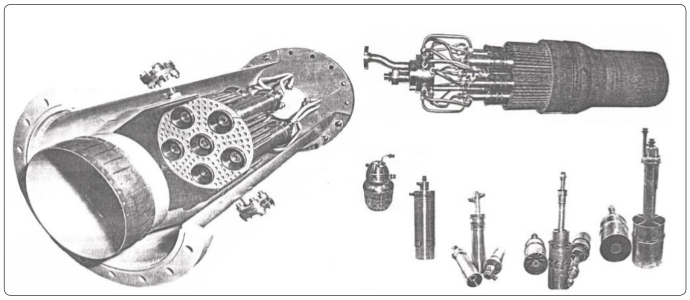


Figure 2: Combustion chambers of gas pumping units of various capacities

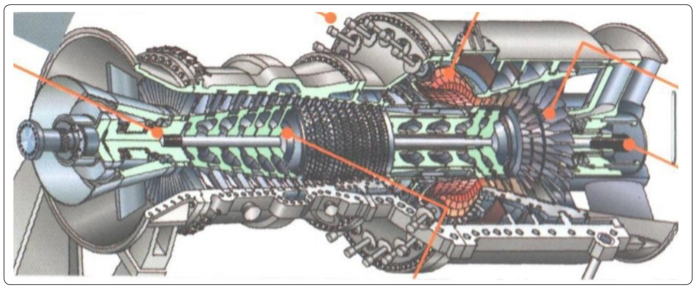


Figure 3: Gas turbine unit with a capacity of 295 MW

Details of the combustion chambers are the most important units of gas turbines, the reliability and operation of gas turbines as a whole largely depend on the degree of their perfection. Statistics show that approximately 25% of failures of the main parts and components of gas turbines are in combustion chambers [25]. The resource and reliability of the flame tubes and transition pipes is determined by the level and uniformity of heating of their walls. At a temperature of 900°C and more, the loss in the scale is 0.05 - 0.1 mm per year. Taking into account the properties of modern materials, to ensure the resource of flame tubes, it is necessary that the local wall temperature does not exceed 900... 950°C with gradients of not more than 50°C / mm. Fulfillment of these requirements at high operating temperatures and limited air flow is a very difficult task, for which convection-film cooling is used in gas turbines.

An effective method of increasing the service life of parts of a hot tract is electron beam and plasma spraying of a protective coating on their internal surfaces. The most effective is the plasma spraying of a ceramic thermal barrier coating. The coating consists of a metal CrNiAlY substrate and a ceramic ZrO_2 protective layer and can significantly reduce gas corrosion and increase the resource of gas path components by 50%.

Problem of heat transfer calculation in combustion chambers

Working processes in GTI combustion chambers, gas-turbine engines (GTE, figure 4) are characterized by a variety of simultaneously occurring and interconnected physical and chemical processes in a turbulent gas stream with a complex aerodynamic structure. Mathematical description of all processes taking place in the combustion chamber is an unsolvable task for calculation of its characteristics, despite development of mathematical methods of numerical solution of the system of differential equations of heat mass exchange and gas dynamics [26].

a b

Figure 4: NK-37 gas turbine engine with a capacity of 25 MW, efficiency 36% (a) and gas turbine power station GTE-25 / NK based on the gas turbine NK-37 (b)

The system of differential equations for the transfer of scalar and vector quantities by a moving turbulent gas flow in the presence of heat and mass flows, chemically reacting homogeneous fuel-air mixture, continuity and state equations has the following form [26]:

$$\left.\begin{aligned}&\frac{\partial \rho\psi_i}{\partial t}+div\left(\rho W\psi_i-\frac{\mu_{iT}}{A_i}grad\psi_i\right)=S\psi_i\\&d\left(\rho WF\right)=0;\ f\left(\rho,p,T\right)=0\end{aligned}\right\}\qquad(1)$$

where ρ, p, T - density, pressure, gas temperature; W is the gas flow velocity vector; μ_{iT}- dynamic coefficient of turbulent viscosity of the gas; F is an element of surface area; ψi - concentrations of reaction products, are functions of the Prandtl number, Schmidt number, specific heat of combustion and mass rate of the chemical reaction.

Integration of equation (1) is carried out by first performing transformations for the steady-state combustion process in a moving gas stream. As a result of solving equation (1), data are obtained on the temperature and pressure fields in the combustion chambers and the emission of pollutants.

The law of thermal radiation of solid fuel for calculating heat transfer in furnaces was discovered experimentally by Stefan in 1879 and theoretically substantiated by Boltzmann in 1884. At that time, at the end of the 19th century, in the furnaces of steam boilers of steam locomotives, steamboats, and power plants, the burning of solid fuels, coal, peat, shale, and firewood on the grates of power plants was intensively used. The law, discovered by Stefan, Boltzmann, allows one to calculate the heat transfer by radiation in furnaces and furnaces operating on solid fuel. Since the middle of the 20th century, in connection with the growth of gas, oil, coal production in power plants, furnaces and combustion chambers, torch burning of gaseous, liquid, and pulverized fuels has been intensively used. In the 1950s and 90s, ten methods for calculating heat transfer in flare furnaces and combustion chambers were developed, based on the law of thermal radiation of Stefan-Boltzmann solids, since the laws of thermal radiation of gas volumes of flares were not discovered.

However, none of the existing methods for calculating heat transfer by radiation zonal, numerical, Pl - approximations, Monte Carlo, Schwarzschild-Schuster, Eddington, Chandrasekar, spherical harmonics - does not allow to have a complete picture of heat transfer in the compressor station of gas turbines, furnaces of steam boilers of power plants, flare heating furnaces. The above methods are based on the Stefan-Boltzmann law, the fundamental law of physics and energy, the law of thermal radiation of solids, solid fuels, coal, peat and shale. However, the radiation of gas volumes of compressor, furnaces, does not obey the Stefan-Boltzmann law and the calculation error is 70-90% or more [5- 8]. Currently available articles, textbooks, and monographs of Russian and foreign scientists do not have a complete picture of heat transfer in a compressor, there is no data on the magnitude and distribution of heat fluxes of radiation on the surface of a flame tube, on the surfaces of burner devices.

Throughout the 20th century, before the author discovered the laws of thermal radiation of gas volumes of flares, there was no information about the following processes occurring in the (GTE) gas turbine engine (Figure 5): about the size and distribution of heat fluxes of radiation from the gas volume of the torch over the surface of the flame pipe; about the location in the flame tube of the local maximum heat fluxes of the flare radiation for organizing effective cooling of this local surface; on the effect on the service life of flame pipe of the power distribution of the gas volume of the torch along the length of the compressor; on the distribution of the radiation power of the torch in the volume of the flame pipe compressor; on the magnitude of the heat fluxes incident on the surface of the flame tube and on the limiting heat flux at which deformation and destruction of the flame tube occurs; on the distribution of torch radiation fluxes along the burner device of the compressor station.

Thus, over the 20th century, the gas volume of the torch in the gas turbine compressor station, gas turbine engine, remained a “black box”. The solution to the problems of calculating heat transfer in the gas turbine compressor station, gas turbine engine is at an impasse. Data on local heat transfer in the gas turbine compressor station and gas turbine engine are obtained by months-long, expensive, labor-intensive experimental studies of heat transfer, since none of the existing calculation methods gives a complete picture of the heat exchange of the gas volume with the heating surfaces of the compressor station. The lack of accurate calculation data was compensated by the results of numerous, expensive, time-consuming, long-term experimental studies of the technical operating modes of gas turbine engines. For example, development, experimental research and the creation of gas turbine engines for airplanes take up to 10 years. Most of the time, due to the lack of accurate calculation methods, is occupied by tests at the experimental test benches of gas turbine engines and its individual components: a combustion chamber, gas turbine and compressor. Testing of the combustion chambers is carried out until they are completely destroyed, followed by correction of the design of the compressor, cooling of the flame tube, replacement of individual parts, components and material for their manufacture. During testing, up to 50 full-size prototypes of gas turbine engines are created and destroyed. The costs of creating a gas turbine engine range from 1.5 to 4 billion dollars.

The laws of thermal radiation of gas volumes and methods for calculating heat transfer in combustion chambers

In 1996-2001, the author discovered the fundamental laws of physics and energy, the laws of thermal radiation of gas volumes of flares, the laws of thermal radiation of cylindrical gas volumes [9-12]. Cylindrical gas volumes fit into the torches of furnaces, combustion chambers in the mathematical modeling of their thermal radiation. In order to comply with centuries-old scientific traditions and copyright laws of thermal radiation of gas volumes in a diploma for scientific discovery, articles, textbooks, similar to the laws of radiation of solids, the laws of Stefan-Boltzmann, Planck, Wien, are named after the author who discovered them, the laws of Makarov [13-15]. Based on a scientific discovery, a new concept for calculating heat transfer in flare furnaces and gas turbine engine was developed.

With the discovery by the author of the laws of thermal radiation of gas volumes and the development on their basis of the methodology for calculating heat transfer in flare furnaces and combustion chambers, it became possible to calculate the complete heat transfer picture in the gas turbine engine, (Figure 6), organize rational heat transfer in the gas compressor and significantly reduce the costs of experimental research and testing, to increase the life of the compressor.

The open laws of thermal radiation of gas volumes, the developed methodology for calculating heat transfer in the compressor station of gas turbine engine, examples of calculation of heat transfer in the compressor station are described in the monograph of the author

"A. Makarov Heat transfer in electric arc and flare metallurgical furnaces and power plants. St. Petersburg: Doe, 2014, 384 p.", which is recommended by the UMO for education in the field of metallurgy of the Ministry of Education and Science of the Russian Federation as a textbook for university students [15]. The mathematical record and the formulation of the laws of thermal radiation of cylindrical gas volumes, the Makarov laws, which simulate the compressor torch in calculations, are presented in table 1.

Figure 5: Marine gas turbine engine M75RU, with a capacity of 5.7-10.3 MW, efficiency 33-35% (a) and its application on the drilling platform (b)

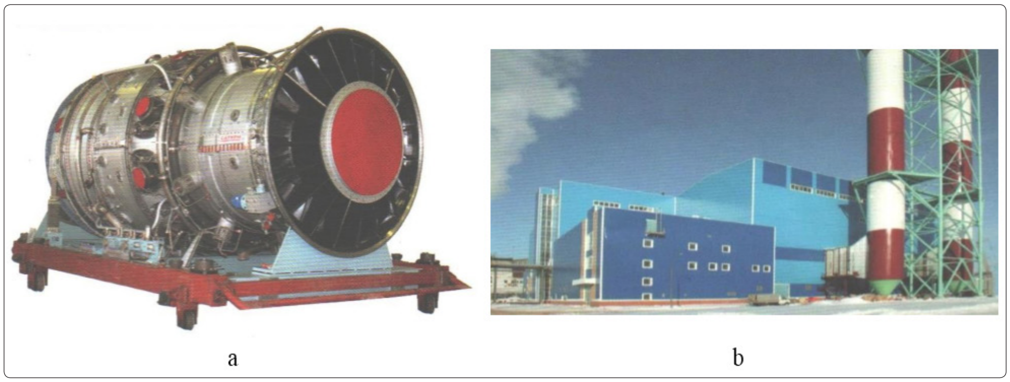


Figure 6: GTD-110 gas turbine engine with a capacity of 115 MW, efficiency 36% (a) and its practical use at the combined cycle power plant PGU-495, with a capacity of 495 MW, efficiency 52-58%

In the table 1, the following notation is used: q is the density of the flux of thermal radiation incident from the cylindrical gas volume (CGV) at the design site (DS), kW / m^2; φ is the angular emissivity (fraction of radiation) of the CGV on the DS; P is the radiation power of the CGV, kW; k is the absorption coefficient of CGV; l - the average path length of the rays from all atoms of the CGV to the DS, m; F is the surface area of the DS, m^2; indices indicate the numbers of gas volumes from 1 to n.

Based on the open laws of thermal radiation of cylindrical gas volumes, a method for calculating heat transfer in flare furnaces and gas turbine combustion chambers has been developed. According to open laws, cylindrical gas volumes are inscribed in the gas volumes of the combustion chambers, the radiation of which in the calculations is modeled by the equivalent radiation of their cylindrical axis of symmetry (see Law V, Table 1) [15-18]. The calculation procedure, the formulas for calculating heat transfer in the gas turbine engine, gas turbine engine are set out in table 2.

Table 1: Mathematical record and formulation of the laws of thermal radiation of cylindrical gas volumes, which are used to simulate torches

Law number	Mathematical record of the law	Formulation of the law
I	$q_{FdF} = \frac{\varphi_{F_0dF} \cdot P_F \cdot e^{-kl}}{F_0} = \frac{\varphi_{F_0dF} \cdot P_F}{F_0 \cdot e^{kl}}$	The density of the thermal radiation flux incident from the cylindrical gas volume to the design site is directly proportional to its power, angular coefficient of radiation and inversely proportional to the absorption coefficient, the average path length of the rays from atoms of volume to the site and the area of the site.
II	$l_1 = l_2 = l_3 = \ldots = l_i = \left(\sum_{i=1}^{n} \frac{l_i}{n} \right) = l$	Mean length of beam path from quadrillions of radiating atoms of volume to design site is equal to arithmetic mean distance from symmetry axis to site.
III	$\varphi_{F_1dF} = \varphi_{F_2dF} = \varphi_{F_3dF} = \ldots = \varphi_{F_idF}$	Angular coefficients of emission of coaxial cylindrical gas volumes to the design site are equal.
IV	$q_{F_1dF} = q_{F_2dF} = q_{F_3dF} = \ldots = q_{F_idF}$	Radiation flux densities of coaxial cylindrical gas volumes per design area are equal.
V	$q_{F_1dF} = \sum_{i=1}^{n} q_{F_idF}$	The densities of thermal radiation fluxes of a cylindrical gas volume of large diameter and its cylindrical axis of symmetry to the calculation site are equal when the thermal powers released in them are equal.

In the table 2, the conventions used in table. 1, as well as the following conventions: T, V - respectively, temperature, gas volume ° C, m^3; ψ is the generalized angular emissivity; Q - self-radiation flux, kW; α - convection heat transfer coefficient, W / m2 ° C.

Example of calculation of heat transfer in the combustion chamber according to the laws of thermal radiation of gas volumes

According to the procedure developed and described in Table 2, heat transfer was calculated in the gas turbine compressor station with a capacity of 4.25 MW (Figure 7). Open laws of thermal radiation of gas volumes allow accounting for radiation to the design site of each of quadrillions of atoms that make up the gas volume generated during combustion of fuel in combustion chamber [15].

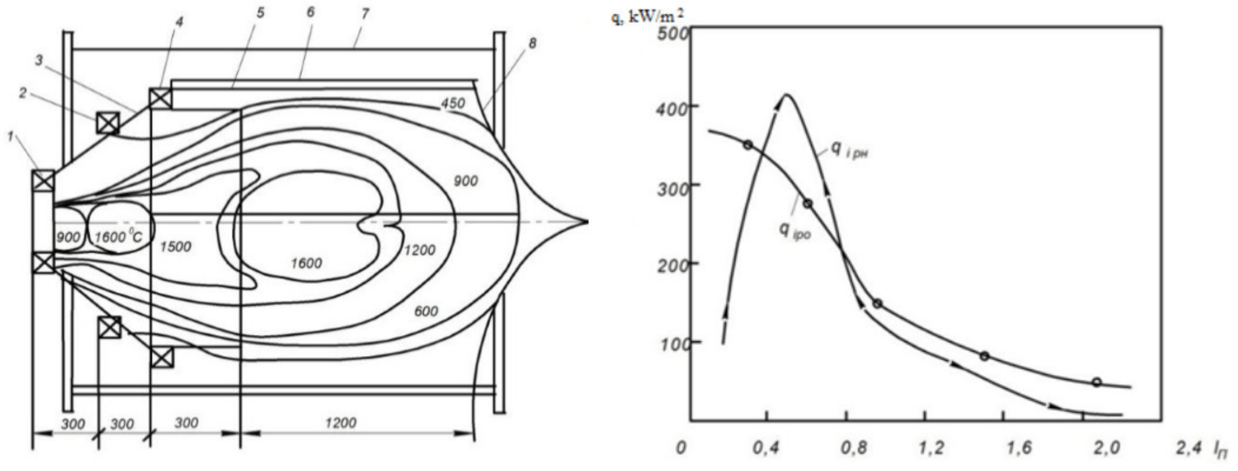
The flare capacity is 16.28 MW. The results of the calculation of the density of the total heating heat flows qipн and cooling flows qipo are shown in the form of graphs in Fig. 7, b. The determining effect on the density of total heat flows of heating is the density of heat flow from the flare; it is 95% of the density of total heat flows falling on the design site.

Analysis of density distribution of the resulting heating flows along the length of the combustion chamber showed their considerable non-uniformity: from 380 kW/ m^2 on the surfaces of the large cone of the bowl to 120 kW/ m^2 in the middle ring of the flame tube and up to 8 kW/ m^2 in the last ring zone of the flame tube near the mixer.

Distribution of densities of resulting convective cooling flows corresponds qualitatively to distribution of densities of resulting heating flows of combustion chamber surfaces: Maximum density of cooling flows 350 kW/m^2 is removed from the surfaces of small and large cones of the bowl, further along the length of the combustion chamber convective heat removal decreases, density of the resulting convective cooling flow in the central belt of the flame tube leaves 85 kW/m^2 and in the last annular zone of the flame tube near the mixer - 45 kW/m^2. As the calculation results showed, in the most difficult conditions, the large cone of the compressor bowl operates, here the density of the resulting flows from the plume causing heating exceeds the density of convective flows of cooling air. In the most favorable conditions, a large cylinder of a flame tube works: the convective heat removal by cooling air exceeds the amount of heat received by the surface of the cylinder from the torch. When the surfaces of the combustion chamber operate in isothermal mode, the amount of heat supplied to its surfaces is equal to the amount of heat removed from them by the convective flow of cooling air.

Table 2: Equations, formulas for calculating heat transfer in flare furnaces and combustion chambers of gas turbine engines

№ in order	Name of the formula, equation	Equation, formula	Measurement unit
1	Density of the total heat flux incident on the design site	$q_{in} = q_{\text{int}} + q_{inrt} + q_{ins} + q_{inrs} + q_{i\text{con}} + q_{icp},$	kW / m^2
2	The fraction of power released in the gas volume of the torch	$P_1 : P_2 : \ldots : P_n = T_1^3 V_1 : T_2^3 V_2 : \ldots : T_n^3 V_n$	-
3	Density of thermal flux of radiation incident on the design site from the flare (the first law of thermal radiation of cylindrical gas volumes)	$q_{int} = \sum_1^n \frac{\phi_{tji} P_{tj}}{F_i} e^{-kl}$	kW / m^2
4	Density of heat flux of radiation caused by reflection of flame radiation from surfaces to design site	$q_{inrt} = \sum_1^n \frac{P_{tj} (\psi_{tjk} - \phi_{tjk} e^{-kl})}{F_k}$	kW / m^2
5	Density of heat flux of radiation incident on the design site from radiating surfaces	$q_{ins} = \sum_1^n \frac{\phi_{ji} Q_{js}}{F_i} e^{-kl}$	kW / m^2
6	Density of heat flux of radiation caused by reflection of radiation of surfaces and incident on the design site	$q_{inrs} = \sum_1^n \frac{Q_{js} (\psi_{jk} - \phi_{jk} e^{-kl})}{F_k}$	kW / m^2
7	Density of convective flow from flare and combustion products to design site	$q_{i\text{con}} = \alpha_{\text{con}} (t_{\text{gav}} - t_p)$	kW / m^2
8	Density of combustion products radiation flows to design site	$q_{icp} = \sum_1^n \frac{\phi_{cpji} P_{cpj}}{F_i} e^{-kl}$	kW / m^2
9	The flow of radiation flux on the surface	$Q_{jc} = \varepsilon_j c_s (T_j / 100)^4 F_j$	kW / m^2



a

b

Figure 7: Diagram of combustion chamber and distribution of isotherms by volume of flare (a), diagram of distribution of densities of heating and cooling flows along length of flame pipe (b)

The density calculations of the resulting heating and cooling flows of the combustion chamber surfaces are well consistent with the wall temperature measurements:[27] the maximum density of heating heat flows obtained by design method corresponds to the maximum temperature of the bowl metal, the minimum density of heating heat flows obtained by design method corresponds to the minimum temperature of the metal at the end of the flame tube obtained as a result of measurements, which confirms the adequacy of the developed mathematical model to the real heat exchange processes taking place in the combustion chamber of the gas turbine plant.

Similarly, the heat exchange in a combustion chamber with a more complex flare structure is calculated (Figure8).

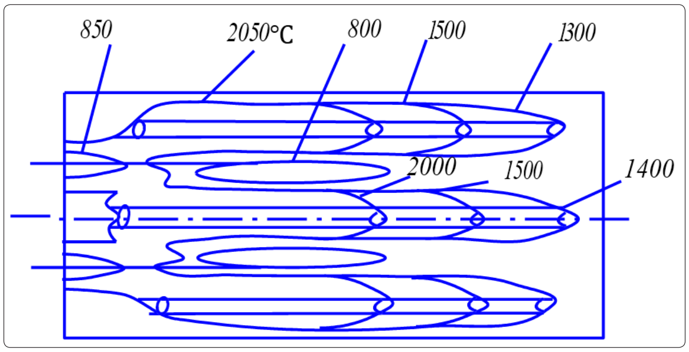


Figure 8: Distribution of isotherms by volumes of flares in combustion chamber with seven burners and cylindrical gas volumes inscribed in flares

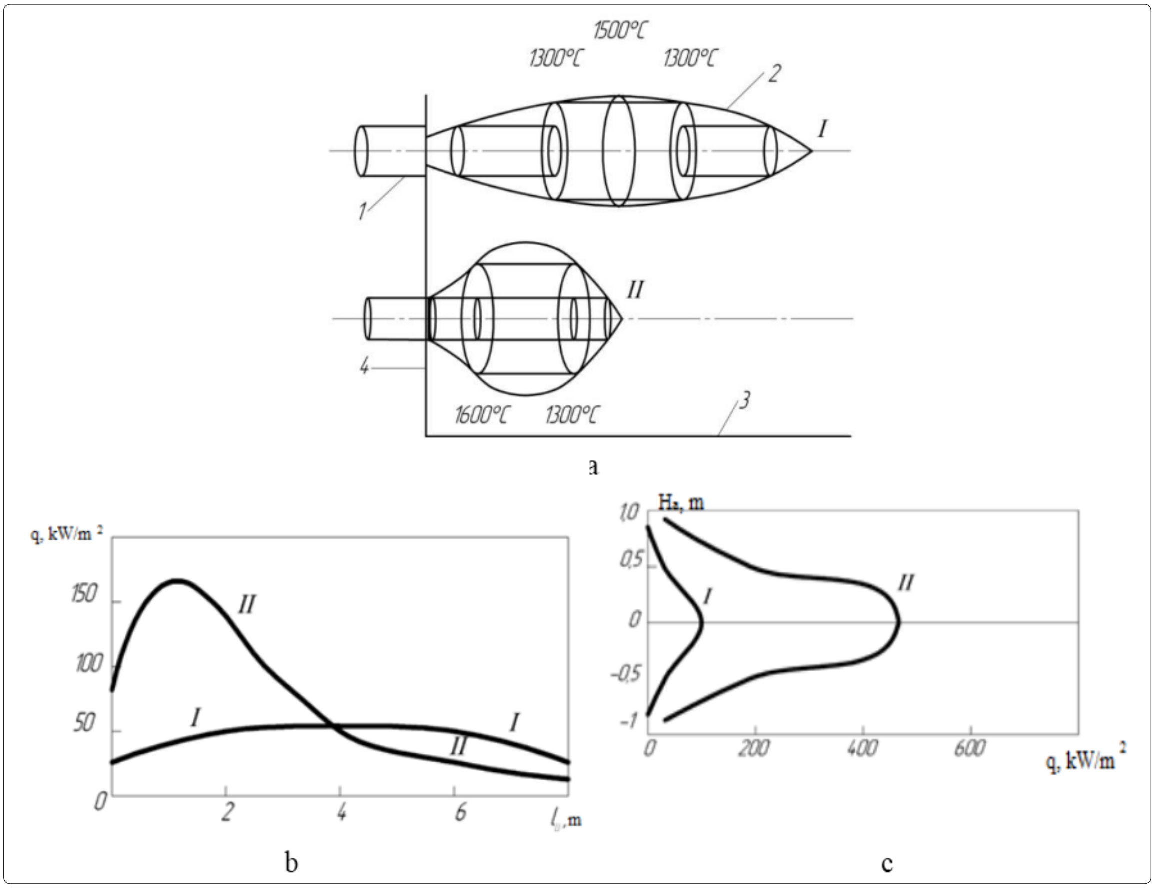


Figure 9: Location and power of the torch I and II: $L_t1 = 8$ m, $l_t2 = 3$ m, Rf = 5 MW (a); distribution of heat flows from the torch on the horizontal heating surface (b) and the surface of the embrasure (c)

Figure 10: A GTD-10RM gas turbine engine with a capacity of 4-10 MW, an efficiency of 32-36% (a) and a GPA-10RM gas pumping unit (b) based onthe GTD-10RM

For example, in a combustion chamber with seven burners that creates seven "tongues" of flame in the form of cones (Fig. 8). In accordance with the above methodology and the distribution of isotherms in the torch, each cone is divided into 3 radiating cylinders. The power in each cylinder and the density of the radiation flux to the calculated point of the heating surface from each of the 21 cylinders and the total density of the heat flux of radiation from the plume are determined. When carrying out the calculations, the Compass - 3D, Microsoft Excel software package was used.

Thus, the torch in the combustion chamber of a gas turbine installation in mathematical modeling of heat transfer can be represented by a volumetric body in the form of radiating cylinders, the power and location of which depend on the distribution of isotherms in the combustion chamber. Power distribution over the volume of the torch is characterized by significant unevenness.

The densities of the thermal radiation flux incident from the torch onto the horizontal heating surface and onto the burner at different torch lengths were calculated (Figure 9).

As can be seen from the calculation results, an increase in the length of the torch at a constant power of the torch entails a decrease in heat fluxes to the embrasure and burner. With an increase in the torch length 2.7 times from 3 to 8 m, the density of heat fluxes to the burner decreased 4 times from 480 to 120 kW / m^2. The calculation data are confirmed by experimental studies on the furnaces of steam boilers TGMP-314 of a 300 MW power unit at TPP-21, TPP- 23 Mosenergo and Konakovskaya TPP: with an increase in the length of the flame at constant power from 3 to 5 m, i.e. 1.7 times, the density of the heat fluxes of torch radiation to the burner device decreased by 2 times from 1500 - 1400 kW / m^2 to 700 - 750 kW / m^2, the life of the burners increased by 4 times from 6-12 months to 2-4years.

The calculations according to the laws of thermal radiation of gas volumes and the methodology developed on their basis made it possible for the first time to obtain complete calculated information about the distribution of torch radiation fluxes over the surface of a flame tube, a gas turbine burner device, about the magnitude and location of maximum torch heat fluxes on a flame tube surface for effective cooling and increase the service life of the GTI flame tube.

Practical use of scientific discovery of laws of thermal radiation of gas volumes

Currently, data about the magnitude and distribution of torch radiation fluxes over the surfaces of a flame pipe in a gas turbine compressor station, gas turbine engine and cooling organization are obtained by lengthy expensive experimental studies in which overheating zones are detected, several times bringing the compressor to failure, structural changes are made to the burner device and cooling of the compressor, achieving long-term reliable operation of the compressor. Calculations of heat transfer in a compressor station according to the laws of thermal radiation of gas volumes can reduce at times the number of experimental studies and destruction of experimental copies of a compressor station and reduce the time and cost of creating a compressor station for (GTE) gas turbine engines (Figure 10).

The cost of creating a new, more powerful gas turbine engine is at least 20% of the cost of design work, experimental research, bench testing falls on the gas turbine engine combustion chamber. When creating new, more powerful, with higher efficiency gas turbine engines (GTE), a whole series of complex technical problems are solved: the use of gases in a flame tube of a compressor with a higher temperature compared to gas turbines existing in gas turbine engines, the creation and use of new heat-resistant metals, and the creation of new heat-resistant coatings and other tasks. Currently, the temperature of gases in the compressor station and gas turbine is 1400 - 1600 ° C. The costs of creating a gas turbine engine range from 1.5 to 4 billion dollars. About 20% of this amount, that is, from 300 million to 800 million dollars, is accounted for by the design, experimental and experimental studies of the compressor, testing the new structure of the compressor station before its operational destruction, followed by changes in the design and the use of new alloys to achieve durability, again testing the design of the composite structure before destruction, making changes to the composite structure, creating the design of the composite structure from a new heat-resistant alloy and again testing it to destruction, creating the next prototype composite structure with a heat-resistant coating and such work continues to create a sample compressor station with good functional properties and long service life. The design, research, manufactures and testing of the prototype compressor station continues for several years before the creation of the compressor station sample, which has high heat resistance, reliability and durability.

Using the developed methodology for calculating heat transfer in gas turbine compressor stations, gas turbine engine, based on the open laws of thermal radiation of gas torch volumes, the gas generator time can be reduced by several times, and the cost of creating a gas compressor by 50% from 300-800 million dollars to 150-400 million dollars. The savings in the creation of a new- generation compressor using the open laws of thermal radiation of gas volumes of flares and the methods for calculating heat transfer in the compressor station developed on their basis will amount to $ 150-400 million.

The economic effect is achieved due to the fact that after the first test of the compressor station prototype, the temperature of the gases in the flame tube is measured, the distribution of isotherms over the volume of the flame tube is determined, and the distribution of the flux of thermal radiation from the flame along the surfaces of the flame tube is calculated. According to the calculated density of the torch radiation fluxes along the heating surfaces, it is possible to select a heat-resistant alloy capable of withstanding these heat fluxes. Having data on the distribution of the density of the torch radiation fluxes over the surfaces of the flame pipe, the designers make design changes to direct the maximum amount of cooling air into the zones of the flame pipe with the maximum heat radiation flux falling from the flame. Thus, at the design stage in the zones of maximum heat fluxes of the flame pipe, maximum heat flows of thermal cooling of these zones are created, which allows us to establish the reliability and durability of the flame tube compressor operation at the design stage. Thus, the use of open laws and the developed calculation methodology will reduce the time and costs of creating compressor station, reduce the time and cost of experimental research of compressor station, limit 2-3 prototype compressor station instead of 30-50 prototype compressor station destroyed during the creation of gas turbine engines present. The savings from the use of scientific discovery and the calculation methods developed on its basis in the design of one new gas turbine engine will amount to 150-400 million dollars.

Conclusion

All fundamental laws of physics, laws of Newton, Hooke, Fourier, Ohm, Mendeleev-Clapeyron, laws of thermal radiation of solids Stefan-Boltzmann, Wine, Planck, Einstein's law, Bohr's postulates, laws of thermal radiation of gas volumes Makarov and others, have a relatively simple writing, they have few calculated parameters, but this is their fundamental, universality and inclusiveness, multidisciplinary, accurate description of natural phenomena. Russian metallurgy has reduced over the past 20 years the electric consumption in arc steel furnaces by 28-30%, fuel consumption in flare furnaces, some merit in this belongs to the author of the scientific discovery. The recognition of this fact is the awarding of the author of the scientific discovery and his textbook, which sets out the open laws and the theory of heat transfer developed on their basis in arc steelmaking and flare furnaces, combustion chambers with the Silver medal Of the international exhibition "Metal-Expo 2018" in the nomination "Best publication in the metallurgical industry". For the development of innovative electric arc and flare furnaces, combustion chambers, the author of the scientific discovery was awarded the Silver medal of the International exhibition of inventions "EXPROPRIOTY2013".

With the scientific discovery of the laws of thermal radiation of gas volumes for the first time there was an opportunity to calculate heat exchange in electric arc and flare furnaces, combustion chambers with high accuracy, improve heat exchange and structures of flare furnaces of industrial enterprises, Combustion chambers of gas turbine plants of electric stations, save millions of tons of liquid, Gaseous, pulverized fuel, reduce emissions of pollutants, reduce man-made load on the environment in many cities of the world.

For the scientific discovery of the laws of thermal radiation of gas volumes by the author that is similar in significance, for the discovery by Win and Planck of the laws of thermal radiation of solids, solid fuel, coal, peat, shales, an absolutely black body, W in in 1911, and Planck was awarded the Nobel in 1918 physics award. For Einstein's discovery of the law of the photoelectric effect of radiation in 1921, which was similar in significance and for the development of the theory of the atom and radiation from it, Bohr was awarded the Nobel Prize in physics in 1922. The laws of thermal radiation of gas volumes, as well as the laws of thermal radiation of solids, blackbody, relate to the fundamental laws of physics, its section "Quantum nature and laws of thermal radiation"[17,18,28,29].

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