# Use of Laws of Quantum Thermal Radiation of Gas Volumes to Reduce Pollutant Emissions at Thermal Power Plants

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Abstract: The laws of thermal radiation from gas volumes of flares of steam boilerfurnaces of power plants, combustion chambers of gas turbine installations of power plants are described.Heat transfer is calculated in the furnace of a steam boiler of a power unit with a capacity of 800 MW.The distribution of temperature, heat fluxes of the flame and deposits in the tubes is significantly non-uniform, which adversely affects the operation of the furnace. A steam boiler furnace has been developed in which the flame temperature and pollutant emissions are reduced and heat fluxes across heating surfaces are equalized.

## 1 INTRODUCTION

In the world 45-50% of produced fuel is burned in steam boiler furnaces and 50-55% of electric power is produced, in Russia 65% of electric power is produced at thermal power plants (TPP). The sizes of furnaces in the form of rectangular parallelepipeds are approximately 7x14x40 m and 10x20x60(80) m. The surface of the furnace of steam boilers (SBF) is lined with pipes in which under the action of the heat of the fuel water turns into steam, the steam enters the steam turbine, the rotor of which rotates the rotor of the generator and in the stator electricity is generated. The SBF burns from 60 t/h fuel oil equivalent in a 300 MW unit to 180 t/h fuel oil equivalent in an 800 MW unit.

The complexity of calculating heat transfer in the TPP SBF is that, according to Bohr's postulates , it is necessary to take into account in calculations of heat fluxes from the flare to the calculated area the quantum radiation of each atom of the gas volume of the flare. Atoms in the SBF of the TPP are quintillions, 1030-1045 atoms. Atoms in the SBF are like grains of sand in the Sahara desert, the calculation is a supercomplex task, so this task has not been solved in Russia, Germany, France, the USA or other countries during the 20th century ((Timofeeva, 2001; Andreeva, Blokh, Zhuravlev, Rozhkov, 1991; Siegel, Howell, 1975; Sparrow, Sess, 1971; Chandrasekar, 1993; Adzerikho, 1975; Klyuchnikov, Ivantsov, 1976)).

## 2 THE PROBLEM OF HEAT TRANSFER CALCULATIONS IN THE FURNACESOF STEAM BOILERS

Throughout the 20th century, the Stefan-Boltzmann-Lawfor radiation from solid bodies, solid fuelwas used for determiningquantum thermal radiation fromthe torch on the heating surfaces in SBFs.In calculations of heat transfer of gas volume, flare correction factorswereintroduced, a number of methods were developed: Chandrasekar, Schwarzschild-Schuster, Eddington, zonal, numerical and others, but obtained the result of calculations with large errors of 200% and more percent, because the radiation of the flare does not obey the Stefan-Boltzmann law.

Throughout the 20th century, the flare in SBF was a "black box", the phenomena occurring in SBF were unclear, incomprehensible: non-uniformity of vaporization in pipes, non-uniformity of deposits in pipes, burnerburnout and other phenomena.

With the discovery by the authorof this article in 1996-2001 of the laws of quantum thermal radiation

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of gas volumes of flares (Makarov, 2022; Makarov, 2014), the problem of calculating heat transfer in SBFs was solved. Until 1996-2001, during 30 years the author developed the theory of heat transfer in electric arc steelmaking furnaces (EASFs), its experimental confirmation, its subsequent adaptation for use in metallurgical companies and for teaching students of metallurgical departments and universities (Makarov, 2022; Makarov, 2014; Makarov, Svenchansky, 1992; Dorofeev, Zinyagin, Makarov, 2021). The electric arc in EASF is modeled by a cylindrical gas volume. Thermal radiation of cylindrical gas volumes was investigated and the following regularities were discovered (Makarov, 2022).

## 2 LAWS OF THERMAL RADIATION OF FLARE GAS VOLUMES

The basic I law of thermal radiation of the gas volume of a flare of any shape and dimensions is derived mathematically and has the following form (Makarov, 2022; Makarov, 2014):

$$q = \frac{\varphi_{fF} P_f}{F e^{kl}}, \qquad (1)$$

where $q$is the quantum heat flux from the flare to the design site; $\varphi_{fF}$is the angular coefficient, i.e., the fraction of flare radiation to the design site; $P_f$is the flare power; $F$is the area of the site; $e$is the number of natural logarithms; $k$is the absorption coefficient of the flare gas medium; $l$is the average length of the path of quanta from all atoms of the gas volume of the flare to the site.

It is a nearly impossible task to find the radiation fraction of the gas volume of a flare consisting of 1030 radiating atoms, filling a furnace of 10x10x40 m, to an area of 0.5x0.5 m.

During the 20th century this problem indeed had not been solved either in Russia, or in Western European Union (WEU), or other countries. The later discovery of the II law made it possible to solve this problem. Let us inscribe into a furnace a cylindrical gas volume of a flare, 10x10x40 m in size, with a diameter of 10 m and a height of 40 m, in which we will place all 1030 atoms of the gas volume (Fig. 1).

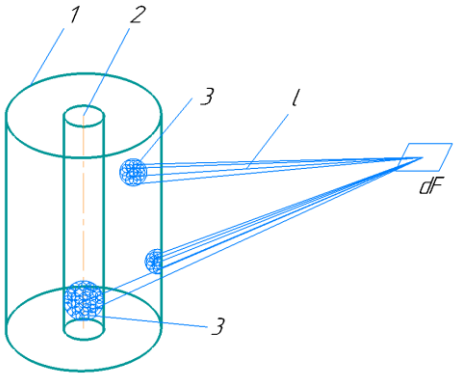



Figure 1: Radiation of a cylindrical gas volume of large diameter 1 and its axis of cylindrical symmetry 2 to the design site *dF*: 3- atoms; *l* – average path length of all quanta from the atoms of the gas volume to *dF*.

The II law of quantum thermal radiation of cylindrical gas volumes of flares is as follows: the angular coefficients, i.e., the radiation fraction, of a cylindrical gas volume of large diameter of 10 m to the design site and its axes of cylindrical symmetry are equal when the number of atoms of the cylindrical volume of a larger diameter and cylindrical axis is the same, i.e. when the same power is emitted in the cylindrical volume of a larger diameter and cylindrical axis:

$$\varphi_{fF} = \varphi_{0F} \qquad (2)$$

where $\varphi_{fF}$, $\varphi_{0F}$ are, respectively, the angular coefficient, i.e., the fraction of quantum radiation, of the cylindrical gas volume 1 of the flare and its cylindrical axis of symmetry 2 to the design area dF.

The unique physical phenomenon described in the II law occurs if all atoms of the large cylindrical gas volume 1 are compressed by radial force on the axis of cylindrical symmetry 2 of the gas volume, in which case the radiation powers and radiation fractions to the site of a large cylindrical gas volume and its axis of cylindrical symmetry are equal. The I and II laws of quantum thermal radiation of gas volumes of flares have been derived mathematically and repeatedly confirmed by experiments (Makarov, 2019; Makarov, 2019; Makarov, 2019; Makarov, 2015; Makarov, 2016; Makarov, Okuneva, Galicheva, 2017). Discrepancies in calculated and experimental data do not exceed 8-10%.

The II law is unique, as it allows us to move from the triple integral at a certain fraction of flare radiation to the calculation site to a single integration along the height of the axis of cylindrical symmetry. The triple integral in calculation of a radiation

fraction of a large gas volume filling the SBF (steam boiler furnace) to a site is solved neither in Russia, nor in WEU, nor in the USA, nor in other countries. Single integrals for calculating the radiation fraction of a flare in the form of a cylindrical gas volume to the site are solved by the author for any position of the flare, i.e., any axis of cylindrical symmetry and heating surface (Makarov, 2022; Makarov, 2014). Thus, the problem of calculating the flare radiation fraction to the heating surface, which had not been solved during the 20th century, has now been solved in Russia in the Tver State Technical University.

The III law is also unique, as it allows us to solve another problem that was previously considered impossible: to determine the average length of the path of quanta l from all quintillion atoms 3 of the gas volume of the flame of a furnace, furnace, combustion chamber to the site (Fig. 1).

The III law of thermal radiation of gas volumes of flares is as follows: the average path length of quanta from all quintillions of radiating atoms of the cylindrical gas volume is equal to the arithmetic mean distance from the axis of symmetry of the cylindrical gas volume to the design site:

$$l = l_{fF} = l_{0F}, \quad (3)$$

where $l_{fF}$, $l_{0F}$ are, respectively, the mean path length of quanta from all atoms of the cylindrical gas volume of the flare and the arithmetic mean distance from its cylindrical axis of symmetry to the design site.

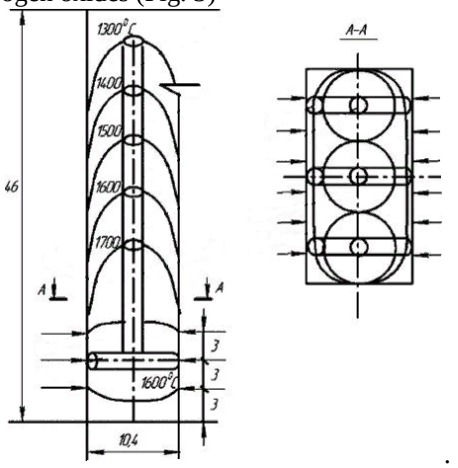
This is a unique physical phenomenon. The problem of determining the average path length of quanta from quintillions of atoms, as numerous in the furnace as grains of sand in the Sahara Desert, that had not been solved during the 20th century has now been solved in Russia, in the Tver State Technical University. With the discovery of the III law of thermal radiation of gas volumes, the solution was proven to be simple, fitting into a few algebraic operations.

The IV law of quantum thermal radiation of cylindrical gas volumes of flares is a direct corollary of the second and third laws and is as follows: Heat fluxes to the design area of a cylindrical gas volume of large diameter and a gas volume of its axis of cylindrical symmetry are equal if the number of radiating atoms and thermal powers of radiations are the same at these volumes. The discovered laws have led to a unique physical phenomenon: cylindrical gas volumes of any size can be inscribed in the gas volumes of radiating flares of any size, and the thermal radiation of the gas volume of the flare can be modelled by the radiation of its axis of cylindrical symmetry.

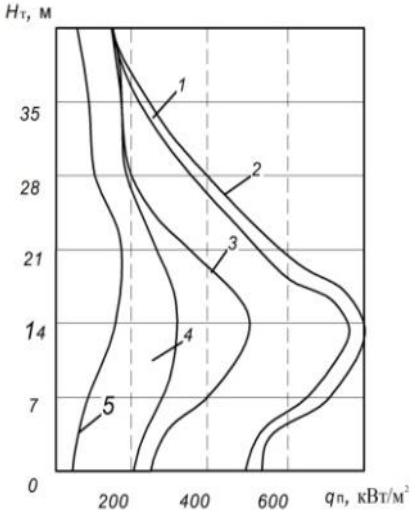
The flares created by single burners are ellipsoids of rotation, so in heat transfer calculations we model them by several radiating cylindrical gas volumes. The flares of the SBF are gas volumes in the form of rectangular parallelepipeds, into which, depending on the location of isotherms, we fit several dozens of cylindrical gas volumes in 2-3 rows and calculate heat transfer in the SBF (Makarov, 2022; Makarov, 2014).

# 3 USE OF LAWS OF THERMAL RADIATION OF GAS VOLUMESTO CLACULATE HEAT TRANSFER IN STEAM BOILER FURNACES

According to the laws of quantum thermal radiation of gas volumes and the calculation method developed on their basis for heat transfer in flare furnaces ,fire boxes and combustion chambers, heat transfer is calculated in the furnaces of steam boilers, of a power unit with a capacity of 800 MW and other power units. For the first time the full picture of the distribution of flare heating fluxes on all surfaces of steam boiler furnace walls has been got. The results of the calculation of heat transfer in the furnace of a steam boiler TGMP-204 are presented in Figure 2. The distribution of temperature, flare quantum radiation fluxes and deposits in the pipes along the perimeter and height of the furnaces are substantially uneven, which negatively affects the operation of the boiler (Figure 2(b)).Changes were made to the location of burners along the height of furnaces, in the design of furnaces in order to reduce temperature, uneven distribution of heat fluxes along the height and perimeter of furnace walls and emissions of nitrogen oxides (Fig. 3)

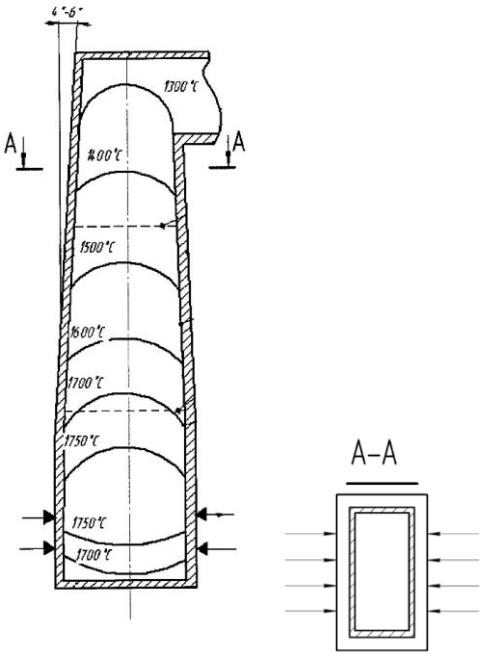



(a)

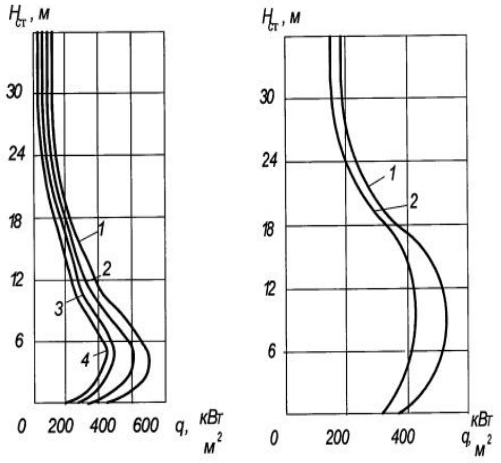



(b)

Figure 2: Distribution of isotherms in the furnace of the steam boiler TGMP-204 (a), distribution of the density of the total quantum radiation flux along the walls of the furnace (b): 1—along the vertical axis of symmetry of the front wall; 2—the same, the measurement result; 3—along the vertical axis of symmetry of the sidewall; 4—along the vertical axis at the periphery of the sidewall; 5—along the vertical axis on the periphery of the front wall.




(a)




(b) (c)

Figure 3: Patent for the invention: the combustion chamber of a steam boiler for burning gas oil with tilting part of the walls inward (a); the calculated distribution of the heat flux of the flare before reconstruction (b); along the symmetry axis of frontal (1), side (2) walls, on the periphery of frontal (3), side (4) walls, after reconstruction (c) along the axis (1) and on the periphery (2) of frontal and side walls.

Calculation according to the laws of quantum thermal radiation of gas volumes allowed for the first time in the world practice to obtain complete information on the flare quantum thermal radiation fluxes falling on the front, rear, side walls along the perimeter and height of furnaces, on the causes of unevenness of deposits along the perimeter and height of furnaces, unevenness of steam formation in pipes, on the causes of burner burnout, and other physical phenomena occurring in the furnaces of steam boilers. The author and his colleagues have developed patent-protected innovative furnaces of steam boilers (Fig. 3), which reduce the above-mentioned negative phenomena occurring in furnaces, their description is set forth in textbooks, monographs (Makarov, 2022; Makarov, 2014; Makarov, Svenchansky, 1992; Dorofeev, Zinyagin, Makarov, 2021).

# 4 CONCLUSION

In the late XX and early XXI centuries, in Russia werediscovered the laws of quantum thermal radiation of gas volumes formed during the burning of an electric arc in electric arc steel melting furnaces,

flaring of fuel in furnaces, fire boxes and combustion chambers.For the first time in world scientific practice, in the chaotic quantum thermal radiation of quintillions of atoms of flares of furnaces, fire boxes, combustion chambers, the laws determining the order in the chaos have been revealed, allowing calculations to take into account quantum thermal radiation on the heating surface of each atom of flares.

The laws of heat radiation of gas volumes, discovered by the author of this article, like all fundamental laws of physics, have multidisciplinary and applicability in a various sectors of economic activities: energy, metallurgy, various industries, education (Makarov, 2014; Makarov, 2019; Makarov, 2021).

With the scientific discovery of the laws of quantum thermal radiation of gas volumes of flares and electric arcs, it became possible to calculate the heat transfer in electric arc and flare furnaces, fire boxes, combustion chambers with high accuracy, to improve the heat transfer and design of electric arc and flare furnaces of industrial enterprises, fire boxes, gas turbine combustion chambers of power plants around the world, save million kWh of electricity and million tons of liquid, gaseous, pulverized fuel, reduce pollutant emissions into the atmospheric air, reduce the technological pressure on the environment in Russia and many cities around the world.

For similar in its significance scientific discovery of the author of the laws of quantum thermal radiation of gas volumes, for the discovery of the laws of quantum thermal radiation of solids, absolutely black solid, by Wien and Planck, Wien in 1911, Planck in 1918 was awarded the Nobel Prize in Physics.

Similarly, for Einstein's discovery of the law of the photoelectric effect of radiation in 1921 and for the development of the theory of the atom and radiation from it by Bohr in 1922 were awarded the Nobel Prize in physics. The laws of quantum thermal radiation of gas volumes, as well as the laws of quantum thermal radiation of solids, blackbody, belong to the fundamental laws of physics, its section "Quantum Physics". Bohr was the last scientist to receive the Nobel Prize in Physics for discovering the fundamental laws of physics.

The discovery of the fundamental laws of physics is an outstanding event in the life of mankind, which occurs once every 50 - 80 years. Confirmation of this fact is physics textbooks for schools and universities (Timofeeva, 2001; Andreeva, 2006), which set out a little more than 30 laws discovered by mankind over 3 thousand years, starting from the III century BC, from the law of Archimedes and ending with the last fundamental laws, postulates discovered by Bohr in 1913, the laws of quantum thermal radiation of gas volumes discovered by the author of this article in 1996-2001.

## REFERENCES


Timofeeva, T.I., 2001. Course of Physics:textbook for university students,Vysshayashkola, Moscow, 369 p.

Andreeva, O.N., 2006. Physics: Reference Book of Necessary Knowledge,Martin,Moscow,408p.

Blokh, A.G., Zhuravlev, A.N., Rozhkov, A.N., 1991. Radiant Heat Transfer: A Handbook. Energoatomizdat, Moscow,432 p.

Siegel, R, Howell, Y, 1975.Thermal Radiation Heat Transfer, Mir, Moscow, 934p.

Sparrow, E.M., Sess, R.D., 1971. Radiation heat transfer, Énergiya,Leningrad,294 p.

Telegin A.S., Shvydkoi V.S., YaroshenkoYu.G. Heat and mass transfer. M.: Metallurgy, 400 p., 1995.

Chandrasekar, S.,1993. RadiationTransfer. M.: IL, 431 p.

Adzerikho, K.S., 1975. Lectures on the Theory of Transfer of Radiant Energy. Ed. M.A. Elyashevich. Minsk: BSU publishing house,192p.

Klyuchnikov, A.D., Ivantsov, G.P., 1970. Heat Transfer by Radiation in Fire Engineering Installations. M.: Energia,400p.

Makarov, A.N., 2022. Heat exchange in electric arc steelmaking and flare heating furnaces, furnaces of steam boilers, combustion chambers of gas turbine installations. Moscow-Vologda: Infra-Engineering, 452 p.

Makarov, A.N.,2014. Heat Transfer in Electric Arc and Torch Metallurgy Furnaces and Energy Plants. Lan, St. Petersburg. [CitationTime(s):4], 384 p.

Makarov, A.N., Svenchansky, A.D., 1992. Optimal thermal modes of arc steelmaking furnaces. M.: Energoatomizdat, 96p.

Dorofeev, G. A., Zinyagin, G. A., Makarov, A. N., 2021. Steel Production Based upon Direct Production Iron: Scientific Issue [in Russian], TNT, Starii Oskol,324p.

Makarov, A.N., 2019. Calculation of heat radiation from gas volume of the torch, Part II. Calculations of radiation from the on burner, JP Journal of Heat and Mass Transfer. 16(1): 43-52.

Makarov, A.N., 2019. Calculation of heat transfer in torch furnaces, JP Journal of Heat and Mass Transfer. 2019: 18(1): 1-20.

Makarov, A.N., 2019. Calculation of heat transfer infurnaces of steam boilers under laws of radiation ofgas volume, JP Journal of Heat and Mass Transfer. 18(2): 423-436.

Makarov, A.N., 2015. Radiation from Large Gas Volumes and Heat Exchange in Steam Boiler Furnaces.Power Technology and Engineering. 3(49):196-201.

Makarov, A.N., 2016. Flare Temperature and Nitrogen Oxide Emission Reduction and Heat Transfer in the

TGMP-314I Steam Boiler Firebox.Power Technology and Engineering. 2(50):200-203.
Makarov, A.N., Okuneva, V.V., Galicheva, M.K., 2017. Influence of the Length of a Torch Tongue on Heat Flow in a Burner Device.Power Technology and Engineering. 4(51):445-450.
Makarov, A.N., 2019. Calculation and analysis of the relationship between the efficiency and position of electric arcs and power consumption in clectrie arc furnaces (EAF) of smaller and larger capacity. Part.I. Calculation and analysis of the relationship between arc efficiently and power consumption. Metallurgist. №63 (3-4). P. 341-349.
Makarov, A.N., 2019. Calculation and analysis of the relationship between the efficiency and position of electric arcs and power consumption in clectrie arc farnaces (EAF) of smaller and larger capacity. Part 2. Calculation and analysis of the relationship between position arcs, walls and power consumption. Metallurgist. №63 (5-6). P. 441-450.
Makarov, A.N., 2021. Effect of the sloganeer thickness, gas composition, and furnace capacity on the arc efficiency and heat transfer in arc furnaces. Part I. Effect of the slag thickness and furnace capacity on arc efficiency. Metallurgist. №64(9-10). P. 987-996.
Makarov, A.N., 2021. Effect of the sloganeer thickness, gas composition, and furnace capacity on the arc efficiency and heat transfer in arc furnaces. Part II. Effect of the slag thickness on the magnitude of are heat radiation incident to the walls. Metallurgist. №64(11-12). P. 1121-1129.