Journal of Applied Physics & Nanotechnology

(ISSN 2638-5104) Research Article

The Laws of Heat Radiation from Solids, Gas Volumes and the Fundamental Laws of Physics

This article was published in the following Scient Open Access Journal:
Journal of Applied Physics & Nanotechnology
Received December 1, 2018; **Accepted** January 11, 2019; **Published** January 18, 2019

Anatoliy Nikolaevich Makarov[1]*

*[1]*Tver State Technical University, Faculty of Mechanical Engineering, Department of Electrical Supply and Electrical Engineering, Russia*

Abstract

The analysis of methods for calculating heat transfer in torch furnaces, fire boxes, combustion chambers, based on the law of heat radiation from solids, the Stefan-Boltzmann law was carried out. However, the radiation from gas volumes of torches does not obey the Stefan-Boltzmann law and the error in calculations is 70-90% or more. The paper describes the laws of heat radiation from gas volumes of torches discovered by the author of this article. The basic fundamental laws of physics are listed. The laws of heat radiation from solids and gas volumes of torches refer to the fundamental laws of physics.

The use of the disclosed laws of heat radiation from gas volumes in practices with regard to the design and calculation of rational energy regimes of electric arc and flame metallurgical furnaces, fire boxes, combustion chambers by scientists, engineers allows to save million kilowatts of electric power and million tons of fuel, reduce pollutant exposure, improve the environment and the population's quality of life.

Keywords: Heat transfer, Heat radiation, Torch, Burner, Radiation laws.

Introduction

Flare combustion of gaseous, liquid, pulverized fuel in furnaces, fire boxes, combustion chambers is characterized by volume heat radiation. Radiative heat transfer accounts for 90-98% of the total heat transfer in steam boilers boxes [1,2], torch heating [3] and electric arc steel melting furnaces [4,5]. In the torch emit quadrillions of atoms, the radiation of each atom on the calculated area must be taken into account. To calculate the heat radiation from the torch on the calculated area, it is necessary to solve the triple integral equations of heat transfer by radiation [6].The solutions of triple integral equations for determining the fluxes of heat radiation, the angular coefficients of the torch radiation to the calculated area, the average beam path length from the radiating atoms to the calculated area were not found.

It is believed, that the problem of calculating heat transfer in torch power plants was solved with the advent of computers and the use of a numerical method for calculating integral heat transfer equations. The basis of the numerical method is the law of heat radiation from solids, the Stefan-Boltzmann law. However, long-term theoretical and experimental studies of Heat transfer have shown that the heat radiation from gas volumes of torches does not obey the Stefan-Boltzmann law and the calculation error is 70-90% or more [5-8].

In 1996-2001, the author discovered the laws of heat radiation from gas volumes of torches, the laws of radiation from isothermal isochoric coaxial cylindrical and concentric spherical gas volumes [5-10]. In order to comply with the centuries-old scientific traditions and copyright laws of heat radiation from gas volumes of torches similar to the laws of black body radiation, the laws of Stefan-Boltzmann, Planck, Wine in the diploma for scientific discovery, articles, textbook [5-10] are named after the author, the laws of Makarov. On the basis of scientific discovery, a new concept of calculating heat transfer in torch furnaces, steam boiler boxes, combustion chambers of gas turbine plants was developed [5]. The purpose of working is to inform the scientific community of the scientific discovery of the laws for heat radiation from ionized and nonionized gas volumes and the need for their use by the scientists, engineers in practices with regard to design and operation of arc steel melting and flame furnaces, fire boxes, combustion chambers to save million kilowatts of electric power and million tons of fuel.

***Corresponding Author:** Anatoliy Nikolaevich Makarov, Tver State Technical University, Faculty of Mechanical Engineering, Department of Electrical Supply and Electrical Engineering
22, nab. A. Nikitina, Tver, 170026, Russia, Email: tgtu_kafedra_ese@mail.ru

In the XIX-early XX in furnaces, furnaces on the grates burned solid fuel: coal, peat, shale, wood. The discovery of fundamental laws of heat radiation from blackbody, solids, surfaces of bodies by Stefan (1879), Boltzmann (1884), Wien (1893), Planck (1900) covers this period of time. Laws of heat radiation from blackbody allow to develop a method of calculating the heat transfer in furnaces, fire boxes on solid fuel. The calculation method is highly accurate. According to the Stefan-Boltzmann law, the result of heat transfer by radiation between the radiative surface F_1 and the receiving radiation surface F_2 depends on the temperature of these surfaces, T_1 and T_2, respectively, and is characterized by the density of the resultant radiation flow q_{12}, which is determined by the expression:

$$q_{12} = \frac{\varphi_{12}\varepsilon_1 c_0}{F_2}\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \quad (1)$$

where φ_{12} is the angular coefficient of radiation on F_2; ε1 is the coefficient of radiation from the surface F_1, c_0 is the coefficient of radiation from blackbody Since solids radiate from the surface, there are two-dimensional models that were used to calculate their radiation. The main difficulty in the expression (1) is the calculation of the angular radiation coefficient φ_{12}. However, the solution to double integrals of differential equations of trigonometric functions was found in the XX century and analytical equations for calculating angular radiation coefficients at any attitude of surfaces were obtained.

The discovery of fundamental laws of physics, laws of heat radiation from solids by Wien in 1911 and Planck in 1918 was awarded the Nobel Prize in Physics.

In XX-XXI centuries flaring of gas, liquid, pulverized fuel in furnaces, fire boxes, combustion chambers was widespread. For example, a steam boiler box of 300 MW unit is a rectangular parallelepiped of 14 m width x7m depth x35 m height. When working on fuel oil, the furnace burns 67 tons of fuel every hour. High temperature radiating gas volume is formed in the furnace and fills it. All of 10^{30}-10^{45} atoms radiate in the torch. The radiation of each atom to the calculated area is to be considered.

The calculations of heat transfer by radiation in torch furnaces, fire boxes, combustion chambers were carried out by zonal and numerical methods in the twentieth century. In zonal and numerical methods, the furnace is divided into 1–1,5 million cells, the radiation from gas volume of the torch is modeled by the radiation from the surfaces of these cells. In case of surface and volume zones, we use numerical discrete approximations of radiation heat transfer integral equations for calculating radiation fluxes and zone temperatures on the computer. These methods use the large number of approximate temperatures and optical coefficients of zones and the law of heat radiation from blackbody, the Stefan-Boltzmann law (1). However, the radiation from gas volumes of torches is not subject to the Stefan-Boltzmann radiation law and the calculation of combustion products error accounts for 70-90% or more [5-8].

It is known that the recycling of combustion products into the furnace as well as the injection of water or steam into the torch are used to reduce the yield of nitrogen oxides. The recycling of gases and the injection of water into the torch resulted to decrease in its temperature by 10-12%. However, boiler capacity isn't reduced. Reducing temperature of the torch at its constant power does not lead to decrease in heat flows on the heating surface, does not lead to a decrease in vaporization. Consequently, heat flows from the torch on the heating surface depend not on the temperature, but on the heat of combustion and fuel consumption, that is, on the power of the torch.

In torch furnace, steel products weighing several tons are heated with a single burner before plastic deformation. The power and temperature of the torch are 5 MW and 1300°C, respectively, when air of 20°C is supplied into the burner. When heating the air in the recuperative heater to 600°C, the temperature of the torch increased to 2000°C, that is, 1,5 times, the power increased by 17% to 5,85 MW. When using the Stefan-Boltzmann (1) law in calculations, heat radiation flow from the torch on the product should increase 5 times, that is not observed in the operation of the furnace and contradicts the law of energy conservation. In the real operating conditions of the furnace, the heat flux density of the torch radiation and the heating rate increases by 17%, that is, directly proportional to the increase in the torch power, but not the temperature in the 4th degrees. Consequently, the radiation from gas volumes of torches is not subject to the Stefan-Boltzmann law, the calculation error can reach 500% and the Stefan-Boltzmann law can not be used in the calculation of heat transfer of the torch with heating surfaces.

However, it was not the fault of researchers, scientists that they carried out calculations of heat transfer in torch furnaces, fire boxes, combustion chambers according to the Stefan-Boltzmann law, since in the XIX century Stefan and Boltzmann discovered the fundamental law of heat radiation from solids and throughout the XX century the fundamental law of heat radiation from gas volumes of torches was not discovered. The error in the results of calculations of heat transfer in torch furnaces, fire boxes, combustion chambers was compensated by the researchers with the aid of scientific results of numerous expensive labor-intensive long-term experimental studies of heat transfer in torch furnaces, fire boxes, combustion chambers and the correction of the calculated data with experimental data.

Fundamental Laws and Discoveries of Physics

It is known from school and university courses of physics, that a little more than 30 laws, named after their authors, underpin the whole of physics. Since all literate people are familiar with fundamental laws of physics, that are not many, some 30. Over the last three thousand years the following basic fundamental laws of physics have been discovered. Let us list them in chronological order : Archimedes' principle, Galilei laws, Kepler's laws, Huygens' laws, Hooke's law, Boyle's laws, Pascal's law, Newton's laws, Avogadro's law, Gay-Lussac's laws, Dalton law, Ampere's law, Fourier's law, Ohm's law, Faraday laws, Joule-Lenz's law, Kirchhoffs laws, Maxwell equations, Mendeleyev's law, Stefan-Boltzmann law, Wien's law, Planck's law, Einstein's relativity theory, Bohr postulates.

All the scientists, who discovered the fundamental laws of physics after the time the Nobel Prizes were launched in 1901, were awarded it: Wien (1911), Planck (1918), Bohr (1922). Wien, Planck both received the Nobel prize for their work on the quantum nature of heat radiation from blackbody, Bohr won it for the quantum theory of the atom and radiation from it.

In the twentieth century, between 1923 and 2017 were made, in chronological order, the following major discoveries and inventions, their authors received the Nobel prizes for the discovery of the wave nature of electrons, the creation of quantum mechanics in matrix form, the development of new forms of atomic theory, discovery of neutron, positron, cosmic rays, artificial radioactivity, the invention of the cyclotron, discovery of the ionosphere, the discovery of mesons, the invention of phase contrast microscope, the discovery of transitory effect, Cherenkov effect, the antiproton, the nucleon, the creation of masers and lasers, holography, the development of the theory of superconductivity, the discovery of pulsars, the psi-particles, the discoveries in the field of low temperature physics, relict radiation, laser spectroscopy, electronic spectroscopy, the creation of the theory of formation of chemical elements of the Universe, the discovery of the quantum Hall effect, the creation of electronic microscope, tunnel microscope, the discovery of high temperature superconductivity, neutrino, and pulsars, neutron spectroscopy, diffraction, discovery of tau-lepton, helium super-fluidity, method of neutral atoms recovery, semiconductor heterostructures, integrated circuits, space x-ray sources, development of the theory of superconductivity, super-fluidity, laser spectroscopy, LEDs, development of optical data transmission systems, the discovery of the Universe expansion, neutrino oscillations, topological phases of matter, gravitational waves.

The review of 1923-2017 Nobel prize inventions and discoveries shows that none of them are fundamental laws that bear the name of the author and would be included in physics textbooks for secondary school students and students of engineering specialties of universities. The analysis of the three thousand-year history of the development of natural science, physics, shows that the discovery of the fundamental law of physics occurs on average once in 50-100 years and is an outstanding event in the history of mankind. The fundamental laws of physics are the basis for new knowledge, development of theories and calculation procedures for the creation of new devices, methods, substances in all fields of technology: energy, all branches of engineering, control systems and other industries.

For example, in the electric power industry the development and creation of electric generators, motors, vehicles, power lines, power stations was made possible by the discovery of the laws of physics of Ohm, Kirchhoff, Faraday, Maxwell, Joule-Lenz, these laws bear the names of the authors. The developed theories and calculation procedures for the creation of electric generators, engines, devices, lines and other devices of the electric power industry are based on the above mentioned laws of electrical engineering, without the opening of which it was impossible to build energy. Similarly, the development of heat power industry, the creation of steam boilers, steam, gas turbines, piston engines and other heat power equipment was made possible by the discovery of the laws of Boyle-Mariotte, Gay-Lussac, Fourier, Mendeleev-Clapeyron, thermodynamics, Stefan-Boltzmann, Planck, Bohr postulates.

Laws of Heat Radiation from Gas Torch Volumes

At the end of the twentieth century, in 1996-2001, the author discovered the laws of heat radiation from gas volumes of torches. In the diploma for scientific discovery in order to comply with the centuries-old scientific traditions and copyright, the laws of radiation from gas torches volumes are called Makarov`s laws [5-11]. Consider the radiation of the torch (Figure 1), one of its cylindrical gas volumes. Cylindrical isothermal gas volume F radiates to the calculated area F_2. The size of the area is 0,5x0,5 m.

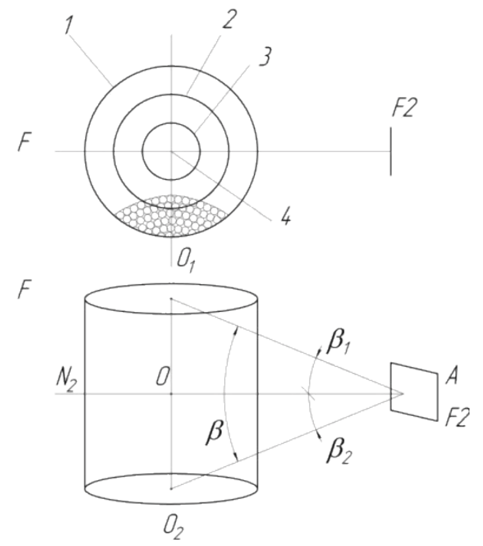

Figure 1: Radiation of cylindrical gas volume on the calculated area F_2.

The diameter of the cylindrical volume D = 3 m, height h = 3 m. Assume, that in the gas volume of the torch $15 \cdot 10^{15}$ atoms emit at the same time, uniformly filling the volume. The atoms filling the volume are modeled by balls (Figure 1). Perpendicular N_2 to the center A of the area F2 passes through the center of the symmetry of the volume point O and divide the axis O_1O_2 in half between the upper and lower bases of the cylindrical volume. Distance AO = r = 3 m. The Power released in the cylindrical gas volume of the P_f torch during combustion of fuel P_F = 42 MW, the absorption coefficient of the gas medium k = 0.162 [5].

Let's divide the isothermal cylindrical gas volume into three equal in volume cylindrical bodies 1, 2, 3 (Figure 1, top view). In each of the coaxial isochoric isothermal cylindrical gas volumes F_1, F_2, F_3 there are $15 \cdot 10^{15}/3 = 5 \cdot 10^{15}$ emitting atoms. The axis of cylindrical gas volumes 1-3 O_1O_2 is a cylindrical gas volume F_4 of infinitesimal diameter. The laws of heat radiation from coaxial cylindrical gas volumes are as follows [5-11].

The first law: the flux density of the heat radiation incident from the cylindrical gas volume to the calculated area qFF2 is directly proportional to the power P_F and the local angular radiation coefficient of the gas volume to the calculated area q_{FF2} and inversely proportional to the coefficient of absorption of gas medium k, the average beam path length from the emitting atoms of the gas volume l and the area of the calculated platform F2:

$$q_{FF2} = \frac{\varphi_{FF2} P_F}{F2 \cdot e^{kl}} \tag{2}$$

In expression (2), the complexity is the calculation of the angular coefficient φ_{FF2} and the mean beam path length l. In zonal and numerical methods, gas volumes of torches are divided into 1 million - 1.5 million cells, rectangular parallelepipeds of infinitesimal sizes. The angular radiation coefficient of the j-th parallelepiped filled with gas to the dF platform is found by three-fold integration over the width a_j, the depth b_j, the height h_j of the j-th parallelepiped:

$$\varphi_{jdF} = \int_{a_j}\int_{b_j}\int_{h_j} \frac{\cos\alpha_i \cos\beta_i}{2\pi r_j^2} \quad (3)$$

where α_i is the angle between the perpendicular to the face of the parallelepiped and the shortest line r_j to the area dF; β_j is the angle between the perpendicular to the area dF and the shortest line r_j.

The solution of the triple integral (3) is a complex mathematical problem, which was not solved in the twentieth century. To calculate the average beam path length from the cells to the calculated area, it is necessary to solve a triple integral equation of a similar nature. The decision in the XX century was not found. The following laws of coaxial cylindrical gas volumes allow to calculate the heat transfer in torch furnaces, fire boxes, combustion chambers.

The second law: Average beam path length l_1, l_2, l_3 from a set of radiating atoms each of isochoric isothermal coaxial cylindrical gas volumes to the calculated area equals to the arithmetic mean distance l from the axis of symmetry to the calculated area.

$$l_1 = l_2 = l_{3.} = \left(\frac{\sum_{i=1}^{n} l_i}{n} \right) = l \quad (4)$$

The third law: Local angular coefficients, radiation flux densities from coaxial cylindrical gas volumes F, F1, F2, F3, F4 to the calculated area F2 are equal .

$$\varphi_{F1F2} = \varphi_{F2F2} = \varphi_{F3F2} = \varphi_{F4F2} \quad (5)$$

$$q_{F1F2} = q_{F2F2} = q_{F3F2} = q_{F4F2} \quad (6)$$

The result (6) was obtained by performing calculations using the formula (2) and assuming that $5 \cdot 10^{15}$ atoms are located in a coaxial cylindrical gas volume of small diameter 4.

The fourth law: The flux density of radiation from the central cylindrical gas volume of small diameter on the calculated area qF4F2 equal to the sum of flux densities of radiation from all coaxial cylindrical gas volumes on the calculated area when the radiation power released in the volume of a small diameter is equal to the sum of the radiation power released in all coaxial cylindrical gas volumes radiating to the calculated area.

$$q_{F4F2} = \sum_{i=1}^{3} q_{FiF2} \quad (7)$$

It follows from the laws of heat radiation from coaxial cylindrical gas volumes, that the radiation from any cylindrical gas volume of high power can be equivalently replaced by radiation from coaxial cylindrical gas volume of small diameter of equal power. The laws of warm radiation from cylindrical gas volumes release researchers from three-and four-fold integration in the calculations of heat transfer by radiation and allow to determine the parameters of radiation by a single integration of trigonometric dependencies (3) of coaxial cylindrical volume of small diameter. The results of a single integration over the height of expression (3) at any spatial position of cylindrical volume of small diameter and heating surface F2 are given in [5], the calculation results are placed in the table.

By the formula (2) using the analytical expressions put in table [5] for the calculation of angular radiation coefficients of the torch and the computer, we can calculate the heat radiation fluxes from the gas volume of the torch on the heating surfaces in the furnaces, fire boxes, combustion chambers.

On the basis of the disclosed laws of heat radiation from cylindrical gas volumes, a new concept of calculating heat transfer in electric arc and torch furnaces, fire boxes, combustion chambers is developed. According to the new concept, dozens of calculations of heat transfer in electric arc and torch furnaces, fire boxes, combustion chambers were performed, which results are presented in [5-14]. Experimental studies have confirmed that the error of such calculations does not exceed 10%. This new concept of calculation of heat transfer in electric arc and torch furnaces, fire boxes, combustion chambers is confirmed by experimental studies and approved by the Educational and Methodical Association for education in the field of metallurgy of the Ministry of education of the Russian Federation as a textbook and is used for training students and postgraduates. Laws of heat radiation from gas volumes (2) – (6) combined with the laws of heat radiation from blackbody (1) entered into the textbook [5].

For over 35 years, the theory for heat transfer in arc steel melting furnaces [4],developed by the author of the scientific discovery and presented in monographs, textbooks [5],articles [6-15] has been used for training metallurgical engineers at the technical universities of Russia and Russian-speaking countries, at Russian metallurgical enterprises for calculating rational operating modes of furnaces. Over the past 20 years, Russian metallurgy has reduced power consumption in arc steel-smelting furnaces by 28-30%, by several hundred million kilowatt hours, some of the credit for the positive changes go to the author of the scientific discovery of the laws for heat radiation from ionized and no ionized gas volumes.

The disclosed laws and the theory developed on their basis allow scientists, researchers, engineers to calculate and organize rational heat transfer around the world in tens of thousands of electric arc and flame furnaces, fire boxes, combustion chambers, reduce electric power and fuel consumption, save million kilowatts of electric power and million tons of fuel, reduce pollutant exposure and development pressure on the environment, improve the population's quality of life in many countries worldwide.

Conclusion

The discovery of the laws of heat radiation from gas volumes of torches is a contribution to the foundation of modern physics. The fundamental laws of physics are the basis for obtaining new knowledge, developing theories and calculation procedures for creating new high-performance equipment in all fields of technology. The discovered laws of heat radiation from gas volumes of torches and the calculation technique developed on their basis allow scientists and designers to create new and improve existing energy units.

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