Science Discovery
2014; 2(2): 34-42
Published online November 10, 2014 (http://www.sciencepublishinggroup.com/j/sd)
doi: 10.11648/j.sd.20140202.12
ISSN: 2331-0642 (Print); ISSN: 2331-0650 (Online)

Theory of radiative heat exchange in furnaces, fire boxes, combustion chambers is replenished by four new laws

Anatoly Nikolaevich Makarov

Department of Electrotechnics and Electric Supply, Tver State Technical University, nab. Afanasiya Nikitina 22, Tver, 170026 Russia

Email address:
tgtu_kafedra_ese@mail.ru

To cite this article:
Anatoly Nikolaevich Makarov. Theory of Radiative Heat Exchange in Furnaces, Fire Boxes, Combustion Chambers is Replenished by Four New Laws. *Science Discovery.* Vol. 2, No. 2, 2014, pp. 34-42. doi: 10.11648/j.sd.20140202.12

Abstract: Review of radiative heat exchange design procedures in electric arc steel melting and flame furnaces, fire boxes, combustion chambers is made. Radiative heat exchange is a uniting factor for electric arc and flame furnaces, fire boxes, combustion chambers. We prove the existence of crisis of heat exchange design procedures in furnaces, fire boxes, combustion chambers. Laws of radiation emitted by gas layers of electric arc, glowing in metallic vapors at atmospheric pressure and a flame of furnaces, fire boxes, combustion chambers are discovered and stated. Laws of radiation form a basis for a new design procedure in electric arc and flame furnaces, fire boxes, combustion chambers, designing new furnaces, fire boxes, chambers.

Keywords: Theory, Heat Exchange, Radiation, Flame, Electric Arc, Furnaces, Fire Boxes, Discovery

1. Introduction

Radiative heat exchange is the main type of heat transfer in furnaces and fire boxes and accounts for 90-98% of the total heat exchange in steam boiler boxes [1], arc steel melting furnaces[2], [3]plasma arc steel melting [3], flame heating and melting furnaces [4], [5]. The quantity of heat, which flame gives burner liners by flame accounts for 0.5-1% and 99-99.5% by radiation [6].

Modern science isn’t a dogma and some of its base may be revised and supplemented with new laws. Since the late 19th

century and throughout the 20th century, heat exchange calculation in flame furnaces, fire boxes, combustion chambers has been carried out on the base of the law, experimentally obtained by Y. Stefan in 1879 in analyzing solid body radiation, and then theoretically proved by Boltzmann in 1884 in studying analytically solid body radiation._ In the late 19th – early 20th century, solid bulk fuel (carbon, shale, turf, fire wood) was burnt in furnaces on fire grates, and the first descriptions of heat transfer processes were essentially descriptions of problems and calculation of radiant heat transfer between two arbitrarily located surfaces (a fuel bed and a heating surface) with the use of Stefan-Boltzmann law.

Heat exchange in flame furnaces, fire boxes, combustion chambers has been investigated since the late 19th century. In the early years two methods (analytical in parallel with empiric) for solving heat exchange problems were outlined . Analytical method is based on the solution of equations, describing heat exchange process and allow to determine effects of separate variable parameters on the process studied and analyze efficiency possibilities of the process. The point of the empiric method adds up to link factual data-based variable parameters, affecting heat exchange schedule. Empiric method is applied for validating the findings of investigations, obtained analytically and also applied in all cases, when it is impossible to solve heat exchange problem theoretically. Theoretical analysis is used until its application appears fruitful in existing learning curve and then experimental material is involved, permitting to solve the problems of analytical solution of equations, describing heat exchange process.

The further development of heat exchange theory in flame furnaces, fire boxes, combustion chambers throughout the 20th century shows, that due to little analytical data on heat exchange and experience miss, heat exchange problems were solved by crude theory in the early 20th century. At a later stage, appeared experimental data denote imperfection of the theory and encourage both derivation of empirical formulas and improvement, development of the theory.

2. Laws of Heat Surface Radiation

Planck's law (the Nobel prize of 1918) characterizes spectral irradiance distribution of black body along the wavelength in the radiation spectrum against the body temperature:

$$E_{ov} = \frac{2\pi h}{c_o^2} v^3 (e^{hv/kT} - 1)^{-1} \quad (1)$$

where h = 6.626×10^-34 J×s – Planck's constant; k = 1.381×10^-23 J/K, Boltzmann constant; $c_o = 2.998\times10^8$ m/s – vacuum velocity; E_{ov} — monochromatic radiation density of black body, $W/(m^2\times s^{-1})$.

Passing from velocity to wavelength, the equation (1.3 b.) can then be written:

$$E_{o\lambda} = c_1 \lambda^{-5} (e^{c_2/\lambda\times T} - 1)^{-1} \quad (2)$$

where $c_1 = 3,742\times10^{-16}$ W×m², $c_2 = 1,439\times10^{-2}$ m×K – the first and the second Planck's radiation constants ; $E_{o\lambda}$, $W/(m^2\times\mu m)$.

Equation (2) is graphically given by Fig.1.

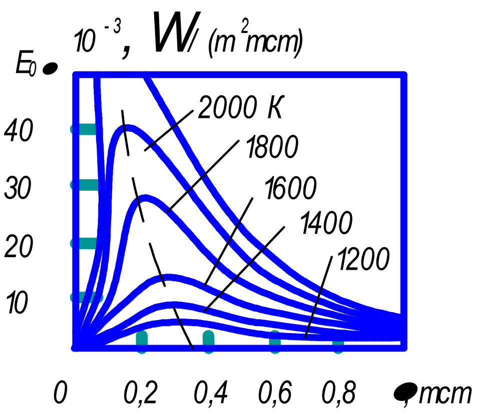

***Fig 1.** Radiation flux density of black body v/s wavelength*

Wavelength, µm×K, at which density of black body radiation attains its maximum value, arises from Wien displacement law (the Nobel prize of 1911):

$$\lambda_M T = 2897,8 . \quad (3)$$

$T \approx 5\,800$ *K* for the sun and electric arc, wave length λ_m = 0,5 µm and peak solar density and electric arc fall at visual spectrum. Solar spectrum is similar to black body spectrum. The fact that black body radiation is a quartic function of its absolute temperature was first determined experimentally by Stefan, then theoretically by Boltzman. This dependence_attracted the title Stefan-Boltzmann law and under radiation flux density it is of the form:

$$E_o = c_s T^4 \quad (4)$$

where c_s = 5,67×10^-8 $W/(m^2\times K)$ – Stefan-Boltzmann constant

For computational convenience Stefan-Boltzman law is written in the form

$$E_o = c_o(T/100)^4 \quad (5)$$

where $c_o = 5,67\ W(m^2\times K^4)$.

Integral flux density of real body is determined by Stefan-Boltzmann law considering total emissivity of ε body:

$$E = \varepsilon\, c_s\, T^4. \quad (6)$$

Kirchhoff's law suggests, that ratio between surface density of real body radiation and absorption body coefficient is equal for all the bodies at the same temperature and equals surface density of black body radiation at the temperature given

$$\frac{E_1}{A_1} = \frac{E_2}{A_2} = . \ . \ . = \frac{E_0}{A_0} = E_0 . \quad (7)$$

From Kirchhoff's law follows, that absorption coefficient equals the radiation coefficient for the black and gray bodies, and the coefficient of radiation for define interval of wavelengths for selectively radiating bodies and gas spaces:

$$A = \varepsilon, \quad A_\lambda = \varepsilon_\lambda . \quad (8)$$

According to Lambert's law, named also cosine law, the intensity of surface radiation in any direction, making an α angle with the normal to a surface is directly proportional to cosine of the angle:

$$I_{O\alpha} = I_{ON} \cos\alpha \quad (9)$$

where I_{ON} – intensity of surface radiation in the direction of N normal to a surface ; $I_{O\alpha}$ – intensity of surface radiation in the direction, making an α angle with the N normal to a surface.

Absorption and radiation flux leakage are designated by Bouguer-Lambert-Beer law that decrease in surface radiation intensity in penetration of elementary layer of absorbent is proportional to substance attenuation factor and beam path length in this layer :

$$I_{ON1} = I_{ON} e^{-kl} \quad (10)$$

where I_{ON1} – intensity of surface radiation at l distance ; k – solid substance attenuation factor; l – beam path length.

As is evident from the foregoing, laws of radiation, discovered in the 19th – early 20 century explain solid radiation. Solid fuel was the main fuel in furnaces, fire-boxes in the 19th – early 20 century. Heat exchange design in furnaces , fire boxes under lump firing on feed grate is carried out by Stefan-Boltzmann law :

$$q = c_S \varepsilon_{rrc} \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] \varphi_{12} \qquad (11)$$

where q – radiant-flux density of fuel to the heating surface; c_S – coefficient of black body radiation; ε_{rrc} – reduced radiation coefficient; T_1, T_2 – temperatures of fuel bed and heating surface accordingly; φ_{12} – angular radiation coefficient of fuel bed to the heating surface.

The calculated results by equation (11) give a good fit with measured results of heating surface temperatures while solid fuel burning.

In the 20th and 21st centuries fluid, gas, powder fuel is used with the flaring formation of gas radiative torch. Throughout the 20th century heat exchange design in flame furnaces, fire boxes, combustion chambers have been accomplished by Stefan-Boltzmann law. Calculating radiative heat exchange in flame furnaces, fire boxes, combustion chambers, we made an assumption, that gas in volume doesn't involve in heat exchange in space but imaginary solid surface, restricted it [7]-[9]. It is assumed, that radiation of this surface is equivalent to gas space radiation. However, flame is not a solid body, but a large radiative gas volume under oil burning, gas – fuel burning, pulverized-fuel burning. In gas burning a torch consists of triatomic products of combustion process and hot smoke particles. In oil burning a luminous torch is formed, consisted of triatomic gases, smoke particles, free carbons. A flame, containing triatomic gases, carbon, ash, ash - subliming products is obtained by solid pulverized-fuel burning. Radiation emitted by triatomic gases, carbon dioxide and water vapours doesn't follow Stefan-Boltzmann law. Radiation emitted by carbon dioxide is proportional to the temperature to the 3.5 power and water vapour radiation to the temperature to the 3 power.

Throughout the 20th century heat exchange design procedure in torch furnaces, fire boxes, combustion chambers has been perfected ,temperature modifying factors were inserted into formula (11) effective emissivities of gas, radiative gas space were divided into a variety of radiative zones. However, review of centenary operating experience, design of torch furnaces, fire boxes, combustion chambers theoretical and experimental data shows incorrect heat exchange theory for exploitation practice.

3. Crisis of the Existing Heat Exchange Design Procedure in Furnaces, Fire Boxes, Combustion Chambers

At the IV Minsk International Forum on heat-mass exchange (MIF-2000), the existing procedure for calculating radiative heat exchange in furnaces, fire boxes with gaseous ,fuel, pulverized torch with which torch is simulated by equivalent gas hemisphere , isothermal volume or bulk bands with i- parameters were criticized in series of reports [10]. At the I International Symposium on radiant heat exchange in 1995 it was noted, that there isn't sufficiently safe and effective procedure for calculating radiative heat exchange, every existing method has its imperfection and restricted range of application [11].

At present many facts, proving the need of updating the existing procedure for calculating radiative heat exchange in flame furnaces, fire boxes, combustion chambers are accumulated.

Rise of flame temperature without its expansion doesn't reduce to increase in furnace efficiency. Determining influence on radiation torch flux density incident on heating surfaces has its power and not a temperature. At the same torch temperature but different power, generated in it, radiant flux, incident on heating surface and net flux are different. The distribution of incident radiant flux on heating surfaces depends on power distribution along the torch length. In some sources [12] the data for a slight drop in power under the existing reduction of its temperature are cited, that proves weak influence of torch temperature on processes of its heat exchange with heating surfaces.

Torch power and hence, item-heating capacity may be arised by increase in fuel consumption or using fuel with a more high heat value and also by previously heating fuel and air , as evident from equation:

$$P_f = Q_v^h B_{fc} + Q_{sh} V_{ac} + Q_{fsh} B_{fc} \qquad (12)$$

where P_f – torch power; Q_v^h, B_{fc} – heat value and fuel consumption; Q_{sh}, V_{ac} – sensible heat and air consumption; Q_{fsh} – fuel sensible heat .

In [13] characteristics of 7 MW injection burner torch in the antechamber of a calcining machine, operating in technological mode under changes of gas flow from 100 to 500 m^3/h are listed. As investigations show, gas discharge changing doesn't practically affect torch temperature but furnace efficiency arises with fuel rate increasing and torch capacity.

From [14] it is know, that combustion product recycling is made to decrease the yield of nitric oxide. Incorporation of recycling gases in fire chambers provides torch temperature decrease and temperature field correction without decrease in boiler capacity. It only goes to show the determining influence of heat value and fuel rate rather than torch temperature on radiative heat exchange in torch furnaces.

Water injection or steam injection in fuel combustion zone (gas,fuel) is also used for thermal nitric oxide suppression [14].

Decrease in nitric oxide formation is a result of temperature reduction in fuel combustion zone by 10-12 %. Damp injection is directly effected to the center of combustion, torch temperature decreases without decrease in its power and boiler capacity. To reduce torch temperature and repress nitric oxide emission in steam boiler boxes OFA combustion of fuel is applied, when fuel with air deficiency is feeded to furnace through main burners, and the rest of the air is directed further along the torch through specific nozzle or lighted off high-level burners.

In [15] the data are cited, that plant load, fuel rate reduction accompanying air ratio increase result in reduce of luminous part of torch with simultaneous temperature increase .In this case in accord with Stefan-Boltzmann law (11), heat flux on water-cooled surfaces increase and boiler capacity grows, that conflicts with common sense and energy conservation law. Steam supply to torch root was used in Martin furnaces, with this torch temperature decreased by 35-60 ^{0}C, fuel combustion process improved, sooting diminished , heat transfer with a bath increased and furnace capacity rised [16].

It is known, that with the increase in the temperature difference between item and torch ,the net radiation flux on heated body rises. However, as exploitation practice of torch furnaces and fire boxes shows, with the decreasing the torch temperature by 10-20 % without fuel rate reduction, furnace capacity and fire boxes remain at previous level i.e. radiative heat exchange doesn't decline. Calculation by the formula (11) shows, that , with decreasing the torch temperature by − 20 %, the net flux on heated item declines 1.5-2 times.

From equation (12) follows, that torch power may be increased at the expense of air heating. Thus, for instance, when air is heated by 600 ^{0}C , torch power increased by 17 %, and torch temperature increases from 1300 ^{0}C to 2000 ^{0}C, i.e. 1.5 times [17]. By equation (11) net flux density to calculating zone from torch must increase 5 times, heating rate must also increase 5 times that conflicts with energy conservation law. Under actual operating conditions of furnaces, when air is heated and torch power increases by 17 %, heat flux density and heating rate increase by 12-15 % , i.e varies directly as torch power multiplication rather than temperature in the 4th power. [17].

Thus, despite the fact that heat exchange theory in torch furnaces, fire boxes, combustion chambers, based on laws of black body radiation has been improved for the 20th century[18]-[21], it turned out to be approximate and need to be updated. It doesn't fit the requirements of modern exploitation practice of torch furnaces, fire boxes, combustion chambers, doesn't show the real pattern of heat flux distribution on heating surfaces, doesn't meet modern cases of calculation and selection of rational thermal conditions of furnaces, fire boxes, combustion chambers, providing economy of fuel and energy resources.

4. Laws of Radiation Emitted by Gas Layers of Flame and Electric Arc

On 23/05/2011 International Academy of Authors of Scientific Discoveries and Inventions (IAASDI, Russia) registered scientific discovery of laws of radiation of large gas volumes, formed in gas , fluid, pulverized fuel flaring and arc glowing in metallic vapors at atmospheric pressure. Discovery priority: 21.04.1983. – in statement component [22], [23], [24]; 19.03.1987 – in theoretical foundation [25], [26], [27]; 1.05.2001. – in experimental verification [28], [29], [30]. The title of discovery «A Regular correlation between the parameters characterizing radiation from isothermalcoaxial cylindrical gas layers generated during torch combustion of fuel and during the burning of electric arc in metal vapors at atmospheric pressure» (Makarov's regularities).Regularities, laws are synonyms, estimating relationships between some phenomenons.

Discovered formula:« A Regular correlation between the parameters characterizing radiation from isothermal coaxial cylindrical gas layers generated during torch combustion of fuel and during the burning of electric arc in metal vapors at atmospheric pressure, that has previously been unknown is determined. It involves invariance of radiation parameters which characterize electric, geometric and heat indices (angular coefficients of radiation, beam path length, radiation flux density and others) ».

In the 17th– 20th centuries in the scientific world there was a good tradition to name the law after the author, discovered it. It is evident nowadays, that the scientific ethic binds the researchers to mention the author's name when they follow his law in their studies. The point of the discovery is thus the following:

Torch made by single burner in furnaces and combustion chambers represents a large gas volume in the form of spheroid where fuel combustion occurs and combustion products are ejected from spheroid in portions of fuel and oxidizer. Radiative and absorbing cylinder gas spaces are inscribed in spheroid , which torch is simulated by (Fig.2). In steam boilers boxes torch represents a large gas volume in the form of elliptic gas cylinder in which several tens of right circular cylinder gas spaces are inscribed (Fig.3).

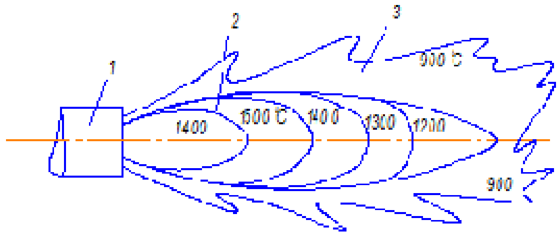

Fig 2. *Fuel torch pattern and its structure with distribution of isotherms by its volume. 1 – burner; 2 – torch; 3 – combustion products*

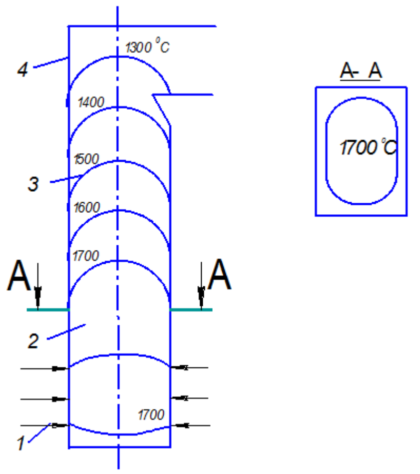

Fig 3. Torch and distribution of isotherms in steam boiler box. 1 – burner; 2 – furnace; 3 – torch; 4 – water-cooled surfaces

Let observe steam boiler box of TGMP-314 plant of 300 MW which presents rectangular parallelepiped 35 m high, 14 m wide and 7 m deep (Fig. 3). Torch and combustion products fill all the space of furnace chamber. Torch is shaped as elliptic cylinder gas space along the height of furnace, in which two or several circle cylinder gas spaces may be inscribed. Isotherms divide circle cylinder gas spaces into several isothermal circle cylinder or several tens of isothermal circle cylinder gas spaces along the height. Let observe the radiation of one isothermal circle cylinder gas space, by a number of which torch is simulated on dF surface element of 0.5×0,5 m. (Fig. 4).

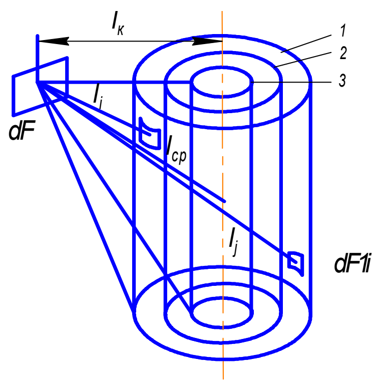

Fig 4. To the calculation of radiant fluxes from coaxial cylinder 1 – 3, l_i, l_j, l_{am} – the distance from surface elements and arithmetic mean distance to dF calculated area.

Assume, that during fuel combustion isothermal cylinder gas body of 10 m height, 4.9 m diameter, 180.9 m^3 volume is formed. The power of 700 MWt ·h, which uniformly distributed on all the space of cylinder, is generated. Divide isothermal cylinder emitting and absorbing gas space by three cylinder bodies of equal volume. (Fig. 4). Radius of the third cylinder is 1.39 m, the second is 1.96 m, the first is 2.4 m, volume of each cylinder is 60.3 m^3. Perpendicular to the center of surface element transits of 90^0 to axis of symmetry cylinder gas space through its upper foundation. The shortest distance. l_{sh} from axis of coaxing cylinder gas spaces to surface element amounted to 5.2 m. Assume, that radiation of inner layers of cylinder gas spaces is absorbed by neighbor layers and radiation only of outer surface layers go outside. In this case radiation of isothermal coaxial cylinder gas layers can be exemplified by radiation of three cylinder layers. Element angular radiation coefficients of 1 – 3 coaxial cylinder gas layers on *dF* are determined by the following way [12]:

$$\varphi_{F_1dF} = \frac{\varphi_{dFF_1} F_{dF}}{F_1} = \frac{0.23\times 0.25}{3.14\times 4.8\times 10} = 0.0003815$$

$$\varphi_{F_2dF} = \frac{\varphi_{dFF_2} F_{dF}}{F_2} = \frac{0.188\times 0.25}{3.14\times 3.92\times 10} = 0.0003815 \qquad (13)$$

$$\varphi_{F_3dF} = \frac{\varphi_{dFF_3} F_{dF}}{F_3} = \frac{0.133\times 0.25}{3.14\times 2.78\times 10} = 0.0003815$$

where $\varphi_{dFF_1}, \varphi_{dFF_2}, \varphi_{dFF_3}$ – angular radiation coefficients of surface element on cylinder spaces accordingly 1 − 3; F_{dF} – square of *dF* surface element; F1 − F3 –lateral surface platforms of 1 − 3 cylinders.

From calculated data (13) follows *the first law* of radiation emitted by gas layers of electric arc and torch: « Element geometric configuration factors of coaxial cylinder spaces, layers which electric arc and torch consisted of are equal» .The notation of the first law is given by:

$$j_{F_1dF} = j_{F_2dF} = j_{F_3dF} \qquad (14)$$

The first law of radiation emitted by coaxial cylinder gas spaces was first considered in [28] and confirmed in [29]. Simulating radiation of hundreds and thousands coaxing cylinder gas layers, forming the volume of the first cylinder space, we will obtain the analog result :element angular coefficients of radiation of coaxing cylinder gas layers are equal. Equality of element angular coefficients of radiation of coaxing cylinder gas layers implies the equality of angular mean radiation coefficients since they are the sum of element angular coefficients of radiation of coaxing cylinder gas spaces, layers. Angular mean radiation coefficient demonstrates the irradiation dose of coaxial cylinder space, layer on the surface consisted of a set of surface elements. From the first law follows, that during design of angular coefficients of radiation of coaxing cylinder gas layers, spaces of coaxing cylinder gas spaces, layers, it is enough to determine angular coefficients of radiation of coaxing cylinder space of small diameter, aligned with cylinder gas space. of coaxing cylinder space of small diameter or linear configuration source , aligned with cylinder gas space.

Angular coefficients of radiation are the main design quantities of radiative heat exchange. Angular coefficient of radiation represent complicated geometric character of shape, size and mutual attitude of two bodies in mutual radiative heat exchange. In heat engineering calculations the great difficulties are usually connected with optical and geometric characters of radiative heat exchange between bodies. Using analytic methods of calculation, element and mean angular coefficients of body radiation are determined by direct integrating of corresponding dependences for coefficients. Determinating integration of angular coefficients of radiation of bodies, surfaces, spaces is connected with double and four-times integrals calculation, that complicated the task.

Calculating angular radiation coefficient of great volume, 1 layer on dF platform, it is necessary to perform the integration as by the height, perimeter, so by the depth of cylinder volume, layer i.e.to solve threefold iterated integral, quadrivariate integral.

The first law relieves us of threefold iterated, quadrivariate integrating and solves the problems through single integration by the height of cylinder gas volume of small diameter.

The first law of radiation emitted by isothermal coaxial cylinder gas radiative layers of which electric arc and torch consisted allow to determine slope radiation factors of any cylinder gas space, layer by one time integrating geometric and trigonometric dependences of coaxial cylinder gas space of small diameter or, that it often determined, linear configuration source. The author by integration of geometric dependences between linear configuration sources and heating surfaces at any attitude, solve practically the tasks of determination of angular radiation coefficients of stated bodies and surfaces [30]-[32]. In this way, proceeded from the first property of isothermal gas layers, the author obtain analytical dependences for determinating angular radiation coefficients of coaxing cylinder gas spaces of any size, at different attitude of gas spaces and heating surfaces.

Calculate radiation flux on dF platform of coaxial cylinder gas spaces, in which radiation power $P_1 = P_2 = P_3 = 700/3 = 233.3$ MW is generated. Take medium parameters character to steam boiler furnace: particle concentration is 0.06 g/m^3,diameter $d_r = 0.3$ mcm, flux 2×10^3 kg/m^3, medium rejection ratio $k = 1{,}5\mu/(d_r\rho) = 0.15$.Calculation results of radiation fluxes of coaxial cylinder gas spaces on dF platform.

$$q_{F_1dF} = q_{F_2dF} = q_{F_3dF} = \frac{\phi_{F_1dF} \times P_1}{F_{dF}} e^{-kl_1} = \frac{\phi_{F_2dF} \times P_2}{F_{dF}} e^{-kl_2} = \frac{\phi_{F_3dF} P_3}{F_{dF}} e^{-kl_3} = \frac{0.0003815 \times 233.3 \times 10^3}{0.25} e^{-0.15 \times 7.8} = 110 \ kW/m^2 \tag{15}$$

where $l_1 = l_2 = l_3$ – average paths length of *1 – 3* cylinders.

Average path length l_{cp} (fig. 4) was determined as arithmetic mean distance from surface elements, which surface of cylinder radiating layer consisted of to dF calculating platform [1]. Average paths length of any isothermal coaxial cylinder layer equals arithmetic mean distance from summitry axis of coaxial cylinder layer to dF calculated platform.

Assume, that 10×10^{30} atoms, electrons are in radiative layer and they are uniformly distributed along space layer. When atom or electron moves to a new or previous energy level, it accompanied by radiation of 10×10^{30} energy photons. Assume, that 10×10^{30} beams are incident on calculated area from a large radiative gas volume, layer. Calculations show, that average path length, radiated by gas layer to dF calculated platform equals arithmetic mean distance from symmetry axis of coaxial cylinder layer to dF calculated platform.

Calculated data by formula (15) give evidence of another two laws of radiation emitted by coaxial radiating and absorbing cylinder gas spaces constituting the electric arc and flame.

The second law: «Average beam path length from coaxial cylinder gas spaces, that torch and arc consist of, to calculated platform equals arithmetic mean distance from summatry axis of cylinder layers to calculated platform».

$$l_{cp} = l_1 = l_2 = l_3 = \left(\frac{\sum_{j=1}^{10\times10^{30}} l_j}{(10\times10^{30})} \right) \tag{16}$$

The third law « Radiation flux density, incident on calculated platform from isochoric coaxial cylinder gas spaces, layers, which arc and torch consisted of are equal»:

$$q_{F_1dF} = q_{F_2dF} = q_{F_3dF} \tag{17}$$

Total radiation flux density incident from three coaxial cylinder gas spaces on dF platform is determined according to the *superposition principle:*

$$q_{FdF} = \sum_{i=1}^{3} q_{F_idF} = 330 \ \text{kW/m}^2 \tag{18}$$

Assume, that radiating power of 700 MW is generated in one of cylinder gas spaces, in the third, for instant. Let find radiation flux density of the third cylinder gas space on *dF platform*:

$$q_{F_3dF} = \frac{\phi_{dFF_3} \times P_3}{F_{dF}} = \frac{0.0003815 \times 700 \times 10^3}{0.25} e^{-0.15 \times 7.8} = 330 \ kW/m^2 . \tag{19}$$

The fourth law of radiation of electric arc and torch is cleared from calculated data by the formulas (18) and (19): «Total radiation flux incident on calculated platform from several radiative and absorbing cylinder gas spaces, layers, which electric arc and flame consist of, equals radiation flux density of coaxial cylinder gas space of small diameter on calculated platform at radiating power, released in cylinder gas space of small diameter that equals total radiated power, released in all coaxial cylinder gas spaces radiating at calculated area»:

$$q_{F_3 dF} = \sum_{i=1}^{3} q_{F_i dF} \qquad (20)$$

This is very important law of radiation emitted by coaxing radiative and absorbing cylinder gas spaces, which electric arc and torch consist of , since it confirms the sufficiency of the passage from threefold iterated, quadrivariate integrating to single integration when calculating the local angular coefficients of radiation of cylinder gas spaces on surface elements and make it possible to determine local angular coefficients of radiation of cylinder gas spaces of small diameter (line radiation source) on surface elements at their any mutual attitude [30]–[32].

From laws of radiation of large gas volumes follows: «When torch and electric arc are simulated by coaxial cylinder gas spaces, layers, the calculated results of heat exchange include volume radiation and absorption of all the layers of torch and electric arc (all atoms and electrons) and their heat exchange with all heating surfaces».

Advantages of flame simulation by cylinder gas spaces:

1 Cylinder gas spaces are geometric figures, inscribing in the torch, made by single burner and representing spheroid, filled up the space more than rectangular parallelepipeds, which flame traditionally is simulated by.
2 Calculating radiative heat exchange by cylinder radiating and absorbing gas spaces, volume radiation of torch is simulated, in case of simulation by rectangular parallelepipeds, torch surface radiation by sides of parallelepiped is simulated
3 In cylinder, used for torch simulation, hundred and thousand coaxial cylinder gas spaces, which simulate radiation and absorption of inner gas torch layers can be inscribed, with equal result of radiative heat exchange calculation is obtained, replaced a number of radiating and absorbing cylinder gas layers with one cylinder gas space. In the following way, from declaration of volume radiation of torch by rectangular simulation, we pass into real volume radiation of flame.

All the four laws are registered as scientific discovery and united by common concept of radiation invariance of isothermal coaxial cylinder gas ionized and non-ionized spaces, layers formed in gas, liquid, pulverized fuel firing and arc glowing in metallic vapors at atmospheric pressure.

The way of transfer heat from power sources to heating surfaces combines torch and electric arc furnaces, steam boiler boxes, combustion chambers: radiative heat exchange and its dependence on power and size of radiation sources. A unified methodology of radiative heat exchange calculation in torch and arc furnaces, fire boxes, combustion chambers is constructed on this fact. A methodology combines two different physical phenomenons: heating energy release at fuel combustion and current flow in gas on the basis of general result of conversion of fuel and electric arc energy to radiation energy.

Volume torch pattern, consisted of a set of coaxial radiating and absorbing cylinder gas volumes, layers is used in radiative heat exchange calculation in torch furnaces, steam boiler boxes, combustion chambers. Calculated data agree closely with measured data of heating flux and temperatures in furnaces, fire boxes, combustion chambers. The discovery enabled us to design new torch furnaces, fire boxes, combustion chambers.On the basis of disclosed laws of radiation of large gas volumes 18 innovative steam boiler boxes, torch heating and electric arc melting furnaces, combustion chambers, ways of heating and melting the metal, providing the improvement in the quality of production, reduction in time of heating and melting the metal, improving the efficiency of plants, decrease in fuel and electric energy consumption, pollutant emissions_ [33-37].

The author is to continue this article, in which heat exchange design procedure, developed on the basis of scientific discovery and its praxis in electric arc steel melting and flame furnaces, fire boxes, combustion chambers will be stated.

5. Conclusion

Modern science isn't a dogma and some of its base may be revised. It is known that no one scientific theory pretends to be an absolute truth, it only describes definite physic phenomenon with more or less degree of accuracy. Subsequently, when images of physic phenomenon extend a concrete theory may be refined or converted into one of the particular cases of new theory. Thus, for instance, Newtonian mechanics became a component of modern mechanics, consisted of classical and quantum mechanics. And analogous processes occur in radiative heat exchange theory: new data arise from exploitation practice of electric arc and torch furnaces, fire boxes, combustion chambers and new refined design procedures, making scientists, researchers reconsider their attitude to existing heat exchange design procedure in furnaces, fire boxes, combustion chambers. In the 19th -20th centuries the laws of black body radiation were disclosed for calculating heat exchange between hard surfaces. In the 21st century the author of this paper disclosed the laws of radiation of large gas volumes for calculating heat exchange between gas volumes of torch and hard surfaces in torch furnaces, fire boxes, combustion chambers.

References

[1] A.G. Blokh, Thermal Radiation in Boilers , Energiya, Moscow, 326 p. 1967.

[2] A.N. Makarov, A.D. Svenchanskii, Optimum Thermal Conditions of Electric Arc Furnaces, Energoatomisdat, Moscow, 96 p., 1992.

[3] A. N. Makarov, Heat Exchange in Arc Steel-melting Furnaces, TSTU, Tver, 184p., 1998.

[4] Heat engineering calculations in metallurgical furnaces: textbook / under the editorship of A.S. Telegin. Metallurgiya, Moscow,368 p., 1993.

[5] V.A. Krivandin, A.V. Egorov, Thermal performance and constructions of iron and steel furnaces: textbook. Metallurgiya, Moscow, 462 p., 1989.

[6] Stationary gas turbine plants // under the editorship of L.V. Arsenyev and V.G. Tyryshkin. Mashinostroeniye, Leningrad, 462 p.,1989.

[7] R.Zigel, J. Howell, Radiative heat exchange. Mir,Moscow, 934 p., 1975.

[8] E.M. Sparrow, R.D. Cess, Radiative heat exchange. Energia, Leningrad, 294 p., 1971.

[9] S. Chandrasekar, Radiation transfer. IL, Moscow, 431 p., 1993.

[10] M.L. Herman, Engineering design method of fire-tube boilers with terminal furnace M.L. Herman, V.A. Borodylia , E.F. Nogotov, G.I. Palchenok // The fourth Minsk International Forum on heat-mass exchange MIF-2000 : Proceedings of Forum. P. 2. Radiative and combined heat exchange. Minsk: ANK Publishing Institute for Heat and Mass Transfer named after A. V. Lykov, pp. 21-31, 2000.

[11] Radiative Transfer-1. Proceeding of the First International symposium on Radiation Transfer (edited by prof M.Pinar Mengus). Kusadasi, Turkey. ICHMT, p. 800,1995.

[12] A.G. Blokh, Yu. A. Juravlev, L.N. Ryzkov, Radiative heat exchange: Reference. Energoatomizdat, Moscow, 432 p., 1991.

[13] Process fuel combustion and use / A.A. Vintovkin, M.G. Ladygichev, Yu.M. Goldobin, G.P. Yasnikov. Metallurgiya, Moscow, 286 p, 1998.

[14] Roslyakov P.V., Zakorov I.A. Nonstoichiometric natural gas and oil fuel combustion at steam power plant. MIH,Moscow, 144 p, 2001.

[15] A.G. Blokh Heat transfer in steam boiler boxes. Energoatomizdat, Leningrad, 240 p, 1984.

[16] N.V. Lavrov, Physicochemical foundation of fuel combustion. Science, Moscow, 275 p., 1971.

[17] B.S. Mastrukov, Thermotechnical calculations of industrial furnaces: textbook. Metallurgy , Moscow, 368 p., 1972.

[18] Monte Carlo Solution of Thermal Transfer through Radiant Media Betweer Gray Walls / Y.R. Howell, M. Permutter // Yourn. Heat Transfer. pp. 116-122,1964.

[19] On radiative properties of polydispersions / M.P. Mengus, R. Viskanta // Combust Scine and Technicke Vol. 44, pp. 143-159, 1985.

[20] Predictions of radiative properties of pulverized coal and fly-ash polydispersions / R. Viskanta, A. Ungan, M.P. Mengus // ASME Publication 81HT24. pp. 1-11, 1981.

[21] On the cjlculation of spatical temperature and radiative transfer in industrial watertube boiler / S. Zanelly, R. Corsi, Y. Rieri // Heat Transfer in Flames. Washington, Scripta Book Company. pp. 18-24, 1973.

[22] A.N.Makarov, A Regular correlation between the parameters characterizing radiation from isothermal coaxial cylindrical gas layers generated during flame combustion of fuel and during the burning of electric arc in metal vapors at atmospheric pressure (Makarov's regularities, diploma № 417) // Scientific discoveries: collected short descriptions of scientific discoveries, scientific hypotheses, scientific ideas – 211 / Compiler V.V. Potocky. Publsh. RANS, Moscow, pp. 33-37, 2012.

[23] A.N. Makarov, A.D. Svenchanskii, Estimates of reflected irradiance component of lining from arcs in arc steel melting furnaces // Electrotech. industry. Ser. Electrothermics. No 5. pp. 1-2, 1983.

[24] A.N.Makarov, Pecularities of heating flux test on metal bath in arc and plasma-arc furnaces // Electro and thermophysical processes in electroheat installations and control matters : MIH. pp. 108-111, 1985.

[25] A.N.Makarov, Math model of plasma-arc furnace with dominant radiation as electrothermal intensifier // Proceedings of high schools. Ferrous metallurgy. No 7, pp. 139-142, 1989.

[26] A.N.Makarov, Effect of electrode radiation on roof wear of arc steel melting furnaces // Proceedings of high schools. Ferrous metallurgy. No 2, pp. 80-82, 1991.

[27] A.N. Makarov, Radiation flux design on metal bath under inclined position of plasmatrons in plasma arc furnaces. Proceedings of high schools. Ferrous metallurgy. No. 8, pp. 55-57, 1991.

[28] A.N. Makarov, Heat-flux distribution in steam boiler box TGMP – 204 // Electric Power Plants. No. 1, pp. 20-25, 2003.

[29] A.N. Makarov, Flame simulating by radiative cylinders in heat exchange calculation in furnaces and steam boiler boxes // Power engineering. No. 4, pp. 33-39, 2003.

[30] A.N. Makarov, Estimates of angular radiation coefficients of linear source on parallel and normal planes //Heat power engineering. pp. 65-68, 1997.

[31] A.N. Makarov, Estimates of angular radiation coefficients of linear source on arbitrarily-spaced planes. // Heat power engineering. No 12, pp. 58-62, 1998.

[32] A.N. Makarov, Estimates of angular radiation coefficients of linear source and furnace flame of steam boilers // Heat power engineering. No 8, pp. 63-66, 2000.

[33] A.N. Makarov, Heat exchange in electric arc and flame metallurgical furnaces and energy plants :Tutorial, St-Petersburg: Lan,p.384, 2014.

[34] A.N. Makarov, M.N. Shevchenko, Gas –fuel combustion chamber. RF Patent 2400668, 2010.

[35] A.N. Makarov, A.G. Sheglov, Regenerative heating pit. RF Patent 2457262, 2012.

[36] A.N. Makarov, E.V. Kruglov, V.V. Rybakova, DC Arc Steel melting furnace.RF Patent 2516896,2014.

[37] A.N. Makarov, E.V. Kruglov, V.V. Rybakova, Ring-bottomed heating furnace RF Patent 2517079,2014.