IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Calculation of Working Spaces Irradiation in the Steel-Melting Plant of Pjsc «Tagmet» at its Reconstruction by the Method of Construction of Epyures of Irradiation

To cite this article: Y I Bulygin *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **224** 012052

Calculation of Working Spaces Irradiation in the Steel-Melting Plant of Pjsc «Tagmet» at its Reconstruction by the Method of Construction of Epyures of Irradiation

Y I Bulygin[a], N N Azimova[b], I S Kuptsova[c], D S Popov[d], V V Maslensky[e]

Don State Technical University, Rostov on Don, Russia

Email: [a]bulyur_rostov@mail.ru, [b]arkomaazimov@mail.ru, [c]i-kyptsova@mail.ru, [d]popov-denis.93@mail.ru, [e]victor.maslensky@yandex.ru

Abstract. With the growth of thermal capacity of the equipment, the tasks of designing new and modernizing existing thermal workshops, taking into account the safe working conditions of staff, are of great importance. However, there are often no experimental data for measuring irradiation and temperature of equipment and workplaces, and the results of a special assessment of working conditions are available only for existing industries and then the method of constructing radiation exposure diagrams comes to the rescue. The article presents the results of calculations of the exposure levels of open and closed workplaces, which showed that the sanitary and hygienic standard on the working area of the EAF-150 was significantly exceeded. Experimental studies of the temperature of the surfaces of the equipment placed on the working platform of DSP-150 showed that the requirements of sanitary and hygienic standards for temperature are met only on the outer wall of the furnace control panel, which is not acceptable. Thus, at the design stage of the steel-smelting shop, when modernizing the furnaces (switching to super-power furnaces DSP-150), the possible negative effects of radiation sources were not taken into account and the distance protection in the shop was practically not effective.

1. Introduction.

Heat protection in metallurgy is one of the most important problems of ensuring safe working conditions. Thermal radiation is the main occupational hazard of metallurgists, therefore for hot workshops with a thermoradiation microclimate, the reduction of heat radiation is basic in the general system of measures ensuring normal working conditions [1,2].

As a result of the increase in heat loads, the external building structures, as well as the surrounding production equipment, are exposed to high temperatures, which cause their premature wear and impact on work safety. Most thermal units and gears do not have heat shieldings that provide normalized surface temperatures (35…45°C); the temperature of the external walls of steel-smelting and heating furnaces ranges from 100 ° C to 300 ° C.

With the growth of heat capacity (for example, commissioning of DSP-150), the issues of designing or upgrading metallurgical plants are becoming increasingly important, especially in the absence of experimental data on equipment irradiation and heat sources.

Knowledge of the laws of heat transfer in the production environment of metallurgical plants should be used primarily to develop the conditions of thermal protection of personnel at the design stage. Thus, the problem of protection from industrial heat is an important health, socio-economic and industrial value.

The purpose of the work is to provide a scientific justification for the choice of methods for reducing thermal radiation and thermal protection at the workplaces of a steel-smelting plant using the example of the enterprise PJSC TagMet (Taganrog).

2. Research objectives

1. Describe the sources of heat in the shop and features of the technological process;

2. To experimentally evaluate the temperature of the surrounding equipment at the working site of the steel-smelting furnace DSP-150 (previously, open-hearth furnaces were located there);
3. Investigate the thermo-radiation regime of workplaces in the steel-smelting shop using the method of plotting irradiation;
4. Justify the proposed methods and means of protecting workplaces from heat exposure.

3. Epure method

The scientific methodology for the study of the thermoradiation regime of workplaces is based on the method of plotting irradiation [1,3]. Plot is a planar vector diagram of the distribution of irradiations in the space surrounding the source (plot of radiation), or on the surface of the object (plot of exposure). Epures are usually built in the vertical or horizontal plane. For a technically sound solution for the thermal protection of the workplace, it is necessary to know not only the size and type of irradiation, as well as the spectral composition, but also the direction of the prevailing radiant flux in order to correctly determine the installation location and screen or curtain size. A graphic picture of the irradiation field is shown by the irradiation plot, which is the distribution of irradiations that occur on the surface of the object when exposed to various heat sources. Thus, with the help of diagrams, it is possible to express quantitative parameters and distribution of radiant fluxes in the total field of exposure of the workplace. When plotting the open space plot, the worker’s chest is taken as the center. They are built for various operating modes and operations on the basis of theoretical calculation or field measurements of the magnitude of irradiation E_B, kW / m^2.

4. Characteristics of heat sources in the steelmaking shop

Figure 1 presents a general view of the electric steel plant.

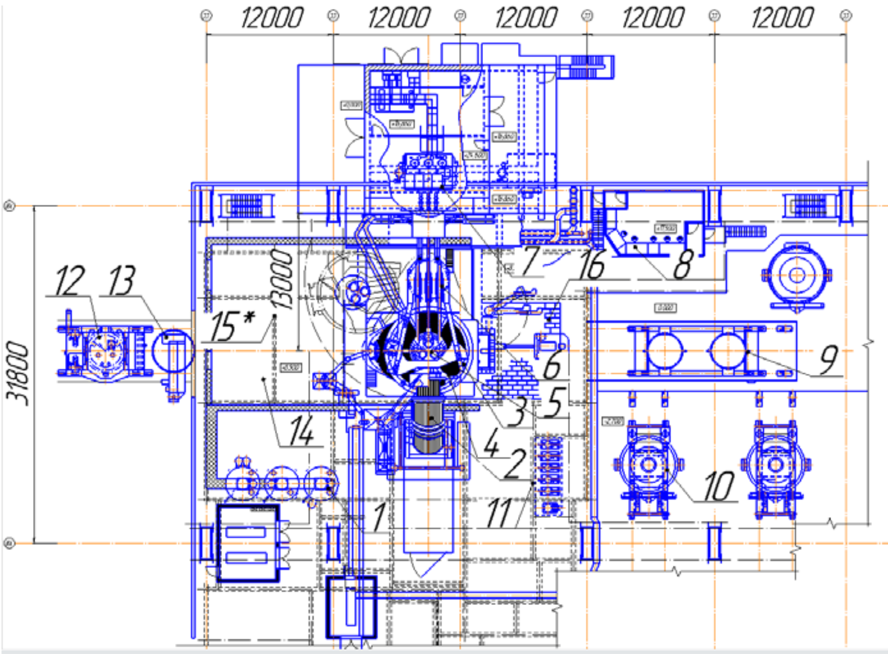

Figure 1. Chipboard area -150 electric steel shop (top view)
1 - Bulk materials; 2 - DSP -150 gas duct; 3 - DSP -150 arch; 4 - Water cooled pipes for roof; 5 - Graphite electrodes; 6 – Electrode holder; 7 - 110 MVA transformer; 8 – Console; 9 – Slag carrier; 10 – Skrapovoz; 11 Backup Electrode Wells; 12 – Steel transporter; 13 - Heating stand; 14 - CO afterburner; 15 - Noise shield; 16 - Work platform.

The main sources of radiation are the elements of the DSP-150 furnace itself, as well as nearby equipment. In accordance with the process with an open working window of the furnace for 20 minutes. (for example, when removing slag) a source of thermal radiation may have a temperature of the order of T_{A1}=1953 K, and in the case when the working window is closed T_{A1}= 573K (by cooling the walls of the furnace with water panels). The gas duct of the DSP-150 furnace with an adjustable break of the gas flow (300...400 mm) is also a source of thermal radiation and has the same temperature inside the gas duct of the DSP-150 furnace of the order T_{A2}=1473 K. Finally, during the technological operation connected with filling scrap into the furnace with the help of an overhead crane, the furnace is open on top (without an exhaust probe) and then the open flame has a temperature of the order of $T_{A2'}$= 1953 K. It should be noted that at such temperatures the infrared radiation spectrum of the infrared is 1.2-1.9 microns.

5. Experimental determination of the temperatures of various surfaces in the working area of the steelmaking shop

According to current sanitary standards [4], the temperature of the outer surface of the walls of the furnaces should not exceed 45 ° C at a temperature inside the heat source higher than 1000 ° C and 35 ° C if the temperature inside the source is less than 100 ° C. To determine the temperature levels of the surfaces of the equipment at the working site of the EAF-150, measurements were made of the actual temperatures of various surfaces by a verified pyrometer TIR-1653. In Figure 2, there is no machine for loading ferroalloys into the furnace, since at the moment (according to the technological process it is not used) and all ferroalloys are fed into the furnace through a conveyor system.

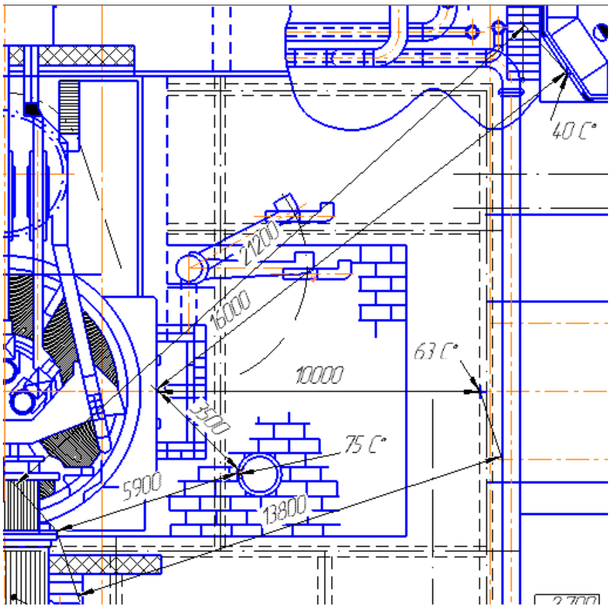

Figure 2. The values of the actual temperatures of the surfaces at the working site of the DSP -150.

The surface temperatures of 3 objects were measured at different distances from the DSP-150 furnace: 1 – gunning furnace stand (t=75 ºC), located at a distance of 3.5 m from the working window of the furnace; 2 - noise shield (t=63 ºC), located 10m from the working window of the furnace; 3 - outer wall of the main control panel (t=40 ºC), located 16 m from the working window of the furnace (Fig. 2).

All measurements were made at the level of 1500 mm from the pivot point (floor) according to the requirements for temperature control. The temperature in the workshop was in a given period of time (October 2017) 14 ºC . As follows from the measurement results, the requirements of sanitary and hygienic standards for surface temperatures are observed only on the outer wall of the cabin of the oven control panel.

The stand for gunning of the furnace and noise shield will be additional sources of IR radiation in the working area on the working platform of the DSP-150.

6. The method of diagrams for determining the irradiation levels of an assistant steelmaker of DSP-150 furnace

To use this method, we used a CAD system to remove more accurate dimensions from the drawing and build the vector of thermal radiation [5] acting on the worker (Fig. 3).

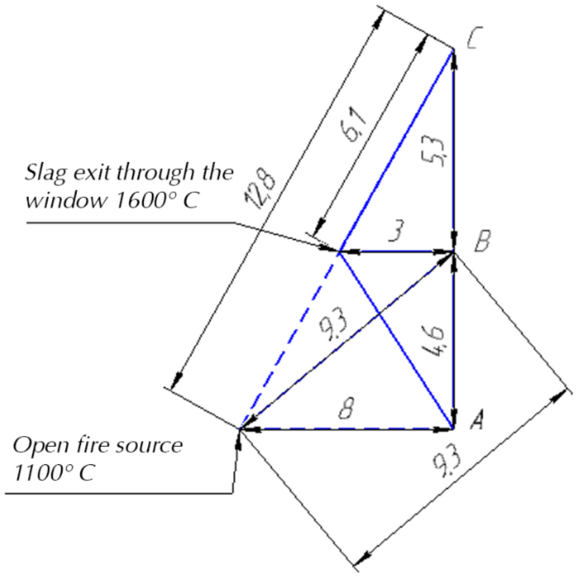

Figure 3. Scheme for calculating the plot of the steelworker's open workplace

Points A, B, and C are the three positions of an improvised steelmaker of an electric furnace servicing the furnace and performing the smelting process during the refining period of smelting when the temperature at the working site reaches a maximum. We also considered two main sources of radiation at high temperatures. Open flame gas duct, whose temperature fluctuates in 300 – 1600 ºC (when calculating we take the average value 1100 ºC). The second source is a working window designed for slag leaping from a furnace, taking metal samples and measuring metal temperatures. The area of the working window 1m^2. The temperature of the slag is downloaded from the furnace within 1500 – 1700 ºC (для calculation will take 1600 ºC). According to the law of Stefan Boltzmann, we find the total radiation power of each source that affects the worker. [6].

$$E_0 = \varepsilon \cdot C_0 \left(\frac{T}{100} \right)^4 , \qquad (1)$$

where ε – degree of blackness; C_0 – black body emissivity, W /(m^2·K) (ºC = 5.67); T – temperature of radiation source, K.

Calculate E_1 for slag downloaded from the working window: $E_1 = 5.67 \cdot 1 \cdot (1873/100)^4 = 697805\ W/m^2$, then E_2 for the flame coming out of the flue: $E_1 = 5.67 \cdot 1 \cdot (1373/100)^4 = 201485\ W/m^2$.

Now we will calculate the thermal radiation acting on the employee in three positions using the formula (2):

$$E_0 = \left(\frac{E_1}{\pi} \cdot \frac{1}{\left(R^2 + b_1^{\,2}\right)^{1.5}} \right) + \left(\frac{E_2}{\pi} \cdot \frac{1}{\left(R^2 + b_2^{\,2}\right)^{1.5}} \right), \qquad (2)$$

where R – distance from source to object, m; b – horizontal distance from the normal to the source to the point in question, m.

Perform a calculation for the position of the employee at 3 points A, B and C:

$$E_A = \left(\frac{201495}{\pi} \cdot \frac{1}{\left(8^2 + 0^2\right)^{1.5}} \right) + \left(\frac{697805}{\pi} \cdot \frac{1}{\left(5.5^2 + 4.6^2\right)^{1.5}} \right) = 1021 \text{ W/m}^2,$$

Similarly E_B = 8280 W/m^2 and E_C = 438 W/m^2.

As follows from the results of calculations, the sanitary and hygienic standard for the level of exposure (140 W/m2) of open jobs of the steelmaker at hand is significantly exceeded by 10 ... 60 times. The exposure level reaches 8.28 kW/m^2, which places increased demands on PPE. In PJSC «TagMet», the «MAGNUM» kit is used as the PPE, which includes a jacket, trousers, a raincoat, a helmet with a protective screen, leggings of three-toed / five-fingered or gloves. The jacket, trousers, and raincoat are made of the heat-insulating para-aramid material CK10 / Z (the maximum temperature is up to 1000 ° C with a long-term exposure to a heat source).

7. Construction of the irradiation scheme for the cabin of the furnace control station

To plot the irradiation plot of a closed workplace, for example, a control cabin, the values of measured irradiance values are laid normal to the surface. The ends of the segments connect a smooth curve. The theoretical construction is based on the principle of imposing flows. When exposed to two sources at any point In the irradiated surface (Fig. 4), irradiance from each source occurs separately. In our case, based on the layout and drawings of the shop in the MPS of the DSP-150 section, we will build a design scheme. In it, the source of heat radiation closest to the control room can have a temperature T_{A1} = 1953 K (with the open working window of the furnace for 20 minutes according to the requirements of the process) and in the second case T_{A1}= 573K, when the working window is closed. Accordingly, a farther source of heat radiation to the control station has the same temperature inside the furnace duct DSP-150 T_{A2} =1473 K. For point sources we have:

$$E_1 = \frac{E_{A1}}{\pi \left(r_1\right)^2 Cos\varphi_1}, \quad (3)$$

$$E_2 = \frac{E_{A2}}{\pi \left(r_2\right)^2 Cos\varphi_2}, \quad (4)$$

Because E_B=E_1+E_2, then given that the intensity of the radiation sources $E_{A1} = \varepsilon_{C0}(T_{A1}/100)^4$, $E_{A2} = \varepsilon_{C0}(T_{A2}/100)^4$ W/m^2, where r_1 и r_2 – distance from the source to the object, m;φ_1 and φ_2 – angles between the normal and the direction to the source. After the substitution we get:

$$E_B = \frac{\varepsilon C_0}{\pi} \cdot \left[\left(\frac{T_{A1}}{100} \right)^4 \cdot \frac{1}{\left(r_1\right)^2 Cos\varphi_1} + \left(\frac{T_{A2}}{100} \right)^4 \cdot \frac{1}{\left(r_2\right)^2 Cos\varphi_2} \right], \quad (5)$$

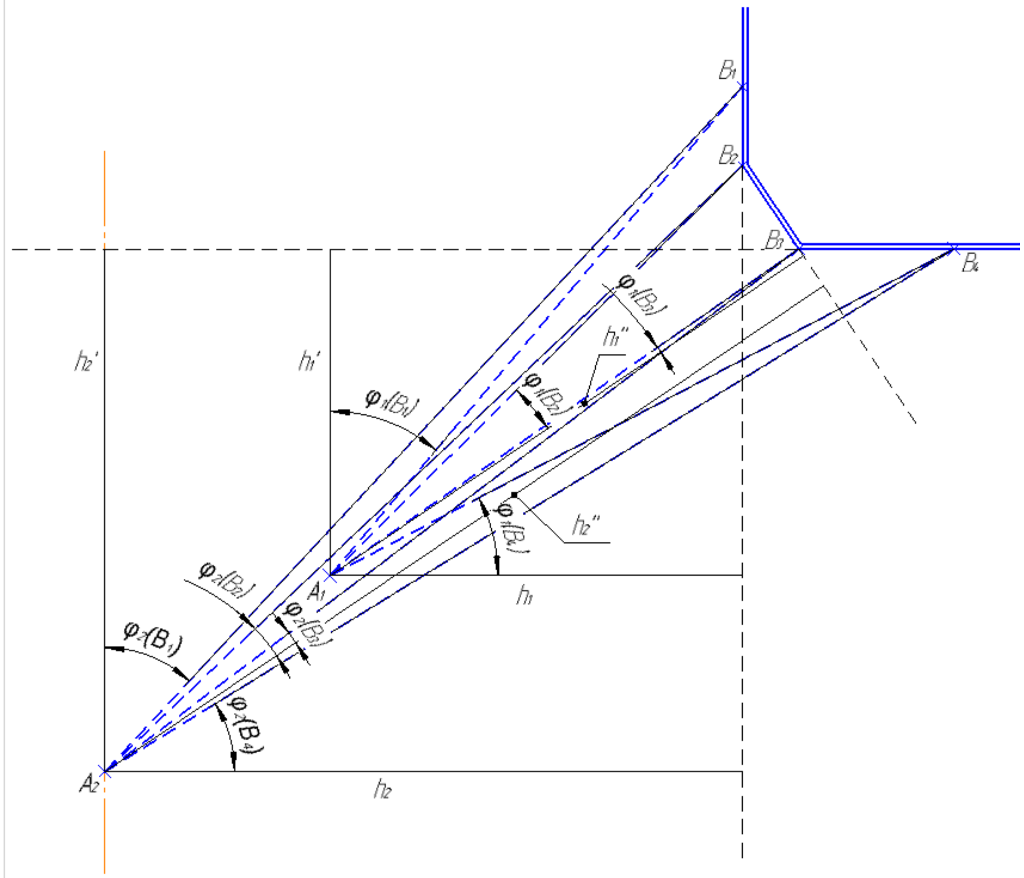

Figure 4. Scheme for calculating the irradiation plot of the control station of the furnace DSP-150

8. Calculation of plots of irradiation of the cabin control oven

The calculation is carried out on the maximum and minimum possible exposure of the cockpit control station.

Maximum exposure is determined by the characteristic points of the cabin B_1, B_2, B_3, B_4:

$$E_{B_1} = \frac{\varepsilon C_0}{\pi} \cdot \left[\left(\frac{T_{A1}}{100} \right)^4 \cdot \frac{1}{\left(r_{A1B1} \right)^2 Cos\varphi_{1B1}} + \left(\frac{T_{A2}}{100} \right)^4 \cdot \frac{1}{\left(r_{A2B1} \right)^2 Cos\varphi_{2B1}} \right] =$$

$$= \frac{0.95 \cdot 5.67}{\pi} \cdot \left[\left(\frac{1953}{100} \right)^4 \cdot \frac{1}{(16.6)^2 Cos50^0} + \left(\frac{1473}{100} \right)^4 \cdot \frac{1}{(24.2)^2 Cos47^0} \right] = 1611 W/m^2$$

$$E_{B_2} = 1275 W/m^2, \; E_{B_3} = 1311 W/m^2, \; E_{B_4} = 1816 W/m^2$$

Similarly, according to the above formulas at the considered characteristic points of the cabin of the observation of the furnace, we determine the minimum values of irradiation. In this case, accept T_{A1}= 573K.

We will summarize the results of calculations of the maximum and minimum irradiation of the control room cab in the table 1.

Table 1. Calculation of the irradiation of the cabin of the control station of the furnace DSP-150 with different operating modes.

Point irradiation	E_{B_1}, W/m²	E_{B_2} W/m²	E_{B_3} W/m²	E_{B_4} W/m²
Open the working window of the furnace	1611	1275	1311	1816
Closed working window	212.5	163	180	240.7

Below, we will construct a plot of the irradiation of the cabin of the control station of the DSP-150 furnace (Figure 5).

As follows from the diagram, even with the most favorable mode of operation, when the working window of the furnace is closed, the irradiation on the outer surface of the cabin of the post exceeds the standard of 140 W/m^2 per 100 W/m^2. In the operation mode with the open working window of the furnace, the irradiation is exceeded by 8-9 times.

Thus, the sanitary and hygienic standard is not complied with.

In the electric arc furnace shop of PJSC TagMet with a thermo-radiation mode, the heat exchange at certain workplaces is periodic, i.e. thermal radiation remains constant during certain periods of the process and is interrupted during other periods [6]. Therefore, the irradiance of workplaces varies depending on the technological process, in connection with which the diagrams are cyclically replaced. Therefore, the levels of maximum and minimum irradiation are shown on them (Fig.5 and Fig.7).

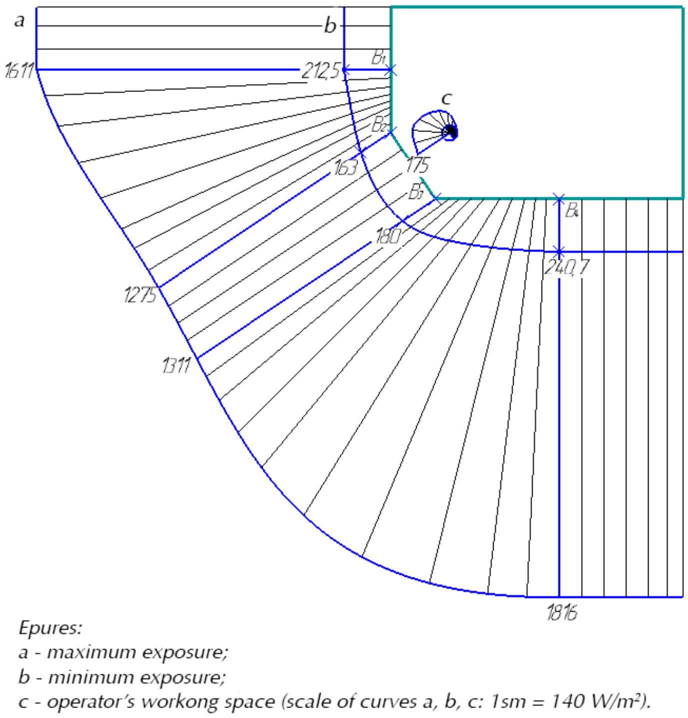

Figure 5. Plot of irradiation post control furnace DSP-150.

9. Construction of the irradiation scheme of the cab

To plot the irradiation of a closed workplace, for example, the crane operator's cabin, we also use the CAD system to remove more accurate dimensions from the drawing and construct the vector of thermal radiation acting on the surface of the crane operator's cabin (Fig. 6). In the diagram A_1, A_2 и

A'$_2$ – radiation sources, and B$_1$ – crane operator's cabin. Source A'$_2$ affects the crane operator during the operation of filling scrap into the furnace, when the exhaust probe opens the roof and the upper part of the furnace, the electrodes are also removed, which leads to the formation of an open flame.

10. Calculation of plots irradiation cabin crane

Irradiation is determined by the characteristic point of the cabin B$_1$:

- according to the scheme б:

$$E_{B_1} = \frac{\varepsilon C_0}{\pi}\cdot\left[\left(\frac{T_{A2'}}{100}\right)^4\cdot\frac{1}{\left(r_{A2'B1}\right)^2 Cos\varphi_{2'}} + \left(\frac{T_{A1}}{100}\right)^4\cdot\frac{1}{\left(r_{A1B1}\right)^2 Cos\varphi_1}\right] =$$

$$= \frac{0.95\cdot 5.67}{\pi}\cdot\left[\left(\frac{1953}{100}\right)^4\cdot\frac{1}{(16.6)^2 Cos33^0} + \left(\frac{1473}{100}\right)^4\cdot\frac{1}{(24.2)^2 Cos55^0}\right] = 1684W / m^2$$

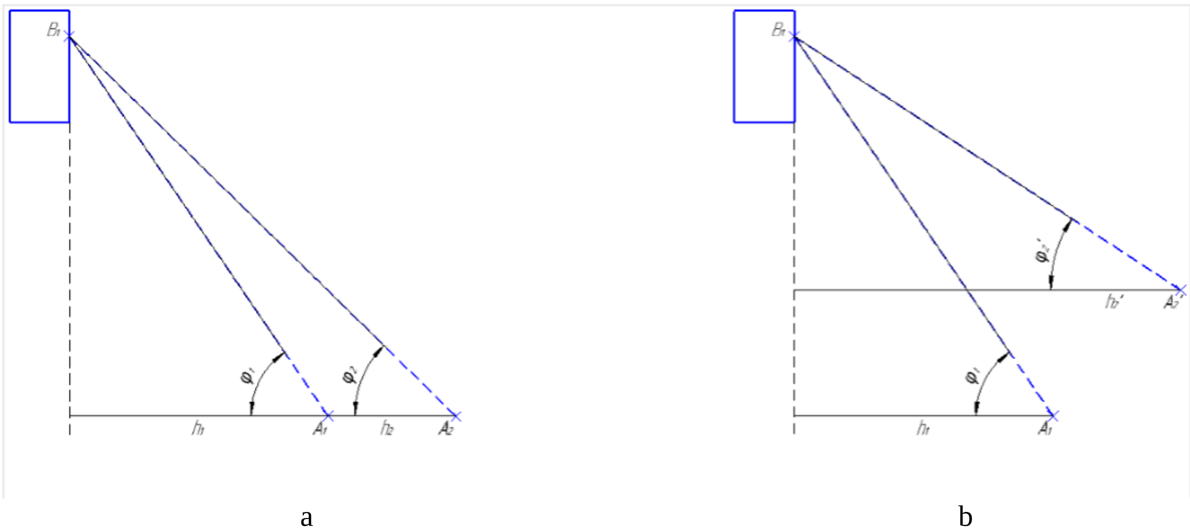

Figure 6. Schemes for calculating the irradiation plot of the crane operator's section of the DSP-150: a – minimum irradiation with DSP-150 closed from above; b – maximum irradiation with DSP-150 open at the top (filling operation in the furnace)

- according to scheme a:

$$E_{B_1} = \frac{\varepsilon C_0}{\pi}\cdot\left[\left(\frac{T_{A2}}{100}\right)^4\cdot\frac{1}{\left(r_{A2B1}\right)^2 Cos\varphi_2} + \left(\frac{T_{A1}}{100}\right)^4\cdot\frac{1}{\left(r_{A1B1}\right)^2 Cos\varphi_1}\right] =$$

$$= \frac{0.95\cdot 5.67}{\pi}\cdot\left[\left(\frac{1473}{100}\right)^4\cdot\frac{1}{(16)^2 Cos55^0} + \left(\frac{573}{100}\right)^4\cdot\frac{1}{(18.9)^2 Cos44^0}\right] = 558W / m^2$$

Similarly, according to the above formulas, we determine the magnitude of the irradiation in the characteristic points of the cab B2 of the cab of the crane operator.

We summarize the results of calculations of the maximum and minimum irradiation of the crane operator in table 2.

Table 2. Calculation of the irradiation of the cab of the crane operator of the section DSP-150 at different operating modes of the furnace

Point irradiation	E_{B1}, W/m^2	E_{B2}, W/m^2
Open top stove	1684	1750
Closed oven	558	620

Below, we plot the irradiance plot of the crane operator (Fig. 7). As follows from the results of calculations of the irradiation levels acting on the crane operator's cabin, they are exceeded in comparison with the standard values by 5-12 times, which is not permissible. This is where the main criteria are when choosing the method of protection of the radiation source; other signs of systematization of heat-shielding means (nature of the process) are auxiliary. Irradiation is determined using an actinometer or by calculation on the site of the designed protective installation. To determine the length of the protection zone, it is necessary to construct an irradiation plot for this workplace.

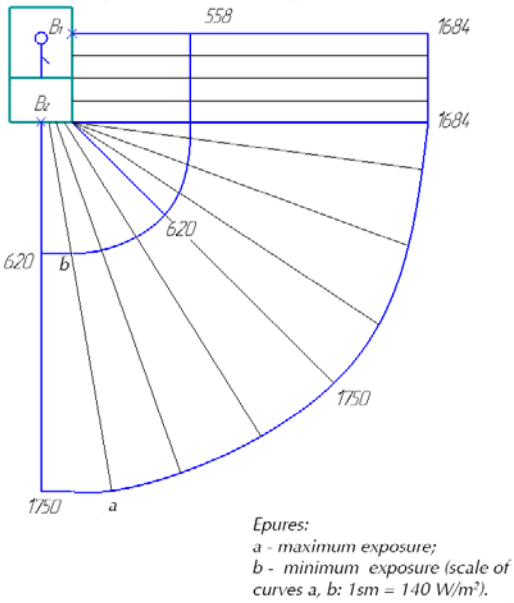

Figure 7. Plot of irradiation cab crane.

11. Proposed methods and means of protecting workplaces from heat exposure at PJSC TagMet

To reduce the impact of thermal radiation on personnel and on the building structures of hot shops, as well as to reduce heat generation in the working space of the shop, devices should be provided that reduce the temperature of the surfaces of the process equipment to 40^{0}C; shielding, damping and finely dispersed water-dispersion of permanent open workplaces; shielding and air conditioning of closed workplaces (control stations and crane cabs); rest cabins for production personnel equipped with cooled walls and ventilation; shielding or protective coating of elements of building structures.

The oven control panels (cabs) must meet the following requirements: the cab volume for the operator must be at least 3 m^3; the walls, floor and ceiling of the cabin must have heat barriers to completely eliminate the receipt of heat radiation inside the cabin; the area of the glazing should be sufficient for easy monitoring of the process and minimal for reducing the heat input. Heat input through the windows is allowed not more than 140 W/m^2 with external thermal radiation up to 350 W/m^2, single glazing is allowed, over 350 W/m^2 - double-glazing with air blowing between the glasses. In the cabs of control stations and cranes in hot spans, the temperature and speed of air movement must correspond to the parameters (Table 3).

Table 3. Parameters of the production microclimate

Air temperature, °C	In the warm period	During the cold period
operator's workplace	18-24	18-21
in the control room	20-27	18-20
by crane		
Air temperature drop at workplace	2-3	2-3
Air velocity, m / s	0.2-0.3	0.2-0.3

The temperature of the inner surface of enclosing structures of cabins should be maintained no more than 24 ° C. In order to avoid colds, according to the data given in [1], the temperature difference between the inside and outside of the cabin should not exceed 7 ° C. What is not observed in the workshop.

Since the normalized value is 140 W/m^2, it can be concluded that the installation of a single-layer heat shield made of tempered glass, painted in mass, with a light transmission of 40% is not sufficient to ensure a satisfactory level of thermal exposure in the control room of the charging cock (Fig.7). Therefore, it is possible to propose to perform the viewing screen of the cabin in the form of a stained-glass window with an air gap, as in the cases of the furnace control cabin. Recommendations can also be directed to the use of laminated triplex glass with anti-reflective coating.

Modern crane operator cabs for metallurgy allow operation at ambient temperatures above 70°C. Features of the control cabin of a metallurgical crane consist in the use of high thermal insulation and sound insulation of walls. The cabin floor is insulated with non-flammable material with low thermal conductivity. The cabin is trimmed with non-combustible decorative materials. Additionally, they use a high-pressure system in the cabin, active filters for protection against harmful gases and vapors, a specialized air conditioner designed for operation at high temperatures and a modern climate control system. In the cabs of cranes and control stations, it is necessary to screen the wall fencing and observation windows, preventing heat generation inside the cab from walls more than 35 W/m^2 and from windows - more than 140 W/m^2. Glass with a reflective metal oxide film should be widely used for transparent screens and enclosures for cockpits, which are blown with air. Air exchange in cabins must be provided depending on the amount of penetrating heat and air mobility. At the temperature of the inner surfaces of the cabins not higher 28°C general exchange ventilation should be used instead of air suppression. Autonomous system air conditioners should be used for the preparation and treatment of air in closed limited volumes (control stations and crane cabins) at a temperature of more than 30 °C.

Open workplaces located in the heat-affected zone should be equipped with air showers in accordance with the Guidelines for the Design of Air-Blow-Drying Units with Concentrated Air Supply and SP 2.2.1.1312-03. Shower pipes must be adapted for finely dispersed water. Workplaces near openings of furnaces, near heated metal should be equipped with devices for highly dispersed water spraying using pneumatic nozzles. It is also necessary to widely apply highly dispersed spraying of water for cooling air at workplaces and blowing hot surfaces.

Workplaces located near the molten metal or slag should be shielded with blind reflective or transparent two-layer screens made of safety tempered glass (GOST 5727-57). With an irradiance not exceeding 3.5-4.2 kW/m^2, screens of blue-green plexiglas, dyed in a mass, 5 mm thick, can be used.

12. Conclusions

1. Calculations of exposure levels of open (assistant steelmaker) and closed workplaces (cabin control station and crane operator) showed that the sanitary and hygienic standard on the working site of DSP-150 is exceeded 12-60 times, which corresponds to classes of working conditions from 3.2 to four. Large elevation levels apply to open jobs.

2. Experimental studies of the temperature of the surfaces of the equipment placed on the working platform of the DSP-150 showed that the requirements of sanitary and hygienic standards for temperatures were observed only on the outer wall of the cabin of the control panel of the furnace

(40^0C). The stand for the gunning of the furnace and the noise shield will be additional sources of IR radiation in the working area at the working area of the EAF-150 and have a temperature respectively 75^0C and 63^0C.

3. The study of irradiation levels and equipment temperatures at the working site of DSP-150 site leads us to conclude that at the design stage of the steel-smelting shop, when modernizing the furnaces (switching to heavy-duty DSP-150 furnaces), the possible negative effects of radiation sources and protection in the workshop were not taken into account. practically not effective.

4. It is necessary to justify the proposed methods and means of protection for open and closed workplaces from heat exposure, taking into account the non-stationary (time-varying) thermo-radiation regime.

In the future, it is planned to study the processes of heat and mass transfer from sources of pollution and radiation in the electric arc furnace shop of TagMet PJSC using the developed mathematical models [7-10]. This will provide a more detailed and reliable picture of the formation of dangerous and harmful factors in the production environment.

References

[1] Babalov A.F. Industrial heat protection in metallurgy. M.: Metallurgy, 1971. 360 p.
[2] Erman I.M. Fundamentals of hygiene production microclimate in hot shops. Publishing house «Medicine», 1964.
[3] Babalov A.F. In «Thermal radiation protection». Publishing house «Metallurgy», 1969, p. 13.
[4] SP 2.2.1.1312-03 Hygienic requirements for the design of newly built and reconstructed industrial enterprises.
[5] Bulygin, Y.I. Calculation of workplace exposure in the steel making shop of TagMet PJSC using the irradiation plot method / Y.I. Bulygin, I.V. Chub, L.D. Shulaeva // Innovations and engineering in shaping the region's investment attractiveness: scientific tr. II Open Intern. scientific-practical of the forum. – Rostov-on-Don: Publishing house DSTU-Print, 2017. P. 39–53.
[6] Calculations of material and energy balances in steelmaking in arc steel-smelting furnaces: a teaching guide / A. A. Zhuravlev, V.F. Mysik, A.V. Zhdanov. Yekaterinburg: Publishing house of Ural University, 2016. 128 p.
[7] Logar Vito. Modeling and validation of an electric arc furnace: part 1, heat and mass transfer / Vito Logar, Dejan Dovzan and Igor Skrjanc // ISIJ International. 2012. Vol. 52, No. 3. P. 402–412.
[8] Physical and Theoretical Models of Heat Pollution Applied to Cramped Conditions Welding Taking into Account the Different Types of Heat / Y. I. Buligin, D. A. Koronchik, A. N. Legkonogikh и др. // IOP Confer-ence Series: Earth and Environmental Science [Electronic resource]. 2017. Vol. 66, Is. 1. Article number012015. Access mode: http://iopscience.iop.org/article/10.1088/1755-1315/66/1/012015 (Scopus).
[9] Koronchik D.A. Ensuring the permissible parameters of the production microclimate of areas of increased gas pollution of machine-building enterprises: PhD dis.of tech. sciences, Rostov-on-Don, 2013. 162 p.
[10] Portyannikov A.V. Simulation of air exchange of industrial premises with local exhaust and general exchange ventilation: PhD dis.of tech. sciences, Voronezh, 2010. 147 p.