UDC 669.013.5: 502.174

Technology for utilization of the metal contaminated with radioactivity at the enterprises of metallurgy

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Abstract
The technology for utilization of metal contaminated with radioactivity at the enterprises of metallurgy was considered. The presented technology makes use of the influence of the heat (smelting) process on the level of ionizing radiation off the metal surface.
Taking into account the effect of the radioactive self-decontamination and evaporation of radionuclides while metal melting allows return the metal contaminated with radioactivity into economic turn-over. This metal can be used without any restrictions.
Key words: METAL CONTAMINATED WITH RADIOACTIVITY, UTILIZATION, SELF-DECONTAMINATION

Introduction

Ones of the most important problems are these connected with the state of environment where the big quantity of metal contaminated with radioactivity (MCR) is accumulating. As a result of the accidents at the objects of the atomic industry as well as during the nuclear weapon tests, a huge quantity of radionuclides are thrown to the atmosphere. They are accumulated on the surface of different objects including articles of metal. A big quantity of MCR is formed in atomic energetic in the course of exploitation and dismantling of equipment, which worked already out its resource, as well as at enterprises of the gas and oil industry.

MCR is the source of danger for every living thing for a long period of time. For this reason it is unserviceable for the further use for its direct purpose.

Radioactive waste is placed into depots. As to the large-size (habarit) equipment, it is, as a rule, stored on the open grounds. This leads to considerable expenses for maintenance of depots with radioactive waste and to removal of costly materials from the economic turn-over. At the same time, the acute shortage of the scrap metal, which is used as the charge takes place in metallurgy. That is why utilization of a huge volume of MCR accumulated in Ukraine allows solve the problem of ecologic safety and improve technical and economic indices of production process in metallurgy. For repeated use of metal contaminated with radionuclides it is , as a rule, to be subjected to preliminary decontamination. Different methods of decontamination (chemical, mechanical, pyrometallurgical and others) are used. But these methods assure not always the necessary degree of clearing metal surface from radionuclides, and beside that, they create new radioactive waste. A new approach to the problem is considered in the paper [1]. According to it, RCM is charged to the melting furnace with the type (standard) operation process, omitting the stage of preliminary decontamination of the metal contaminated with radioactivity. The maximum quantity of this metal is determined by the value of permissible level of the radioactive radiation off the surface of articles made of smelted metal. In this case the process of melting metal leads to absorption of considerable part of emanation of the redionuclides, brought into the furnace, in the volume of the melting (melted) metal. This decreases considerably the level of the radioactive radiation off the surface of finished articles.

Using the given approach will allow getting the metal production, which can be used later on without any restrictions.

The statement of the basic material of research

The proposed technology is realized at the account of the even distribution of the radionuclides presenting (being) at the surface of the MCR all over its volume in the process of melting in the metallurgical furnace. Each of these radionuclides can be presented as an elementary source of ionizing radiation, and such redistribution of radionuclides exerts the substantial influence upon the level of the summary radioactive radiation of the surface of the melted metal. The phenomenon of absorption of ionizing radiation with metal influences on the intensity of resulting radioactive radiation off the surface of metal. The degree of the weakening the radiation depends on the remoteness of its source from the surface what (where) the level of the radioactivity is to be determined. The further from the surface of metal are the elementary radiators, the greater part of their summary radiation is absorbed in the volume of melted metal without reaching its surface.

Thus, not all the elementary sources of ionizing radiation which are in the volume of the melted metal make their contribution in the forming of activity on their surface. This effect can be called the self-decontamination of the metal contaminated with radioactivity during the melting of latter.

Distribution of radionuclides remains as even in the finished articles being the product of melting MCR as in MCR in the process of its melting in metallurgic furnace. This leads to what that the considerable part of radionuclides brought into the melting furnace do not make their contribution into the dose of external and, all the same, internal irradiation of industrial personnel and do not contaminate the environment.

The approach stated in [2] is used for quantitative evaluation of effect of the self-decontamination which is the basis of proposed technology for utilization of the MCR. It is assumed for definiteness that the article of melted metal has the shape of parallelepiped with area of one of the sides S, length d and volume V = S ⋅ d.

Let us pick out in the thickness of the article an elementary layer dx at the distance x from its front plane (Fig.1). The contribution of this layer in activity on the plane S taking into account the weakening provoked with absorption of radiation in the volume of the article is determined with expression [2]:

$$dA=A_{ед.}*\exp(-\mu x)dx \qquad (1)$$

where: A is activity brought into the furnace, Bk;

$A_{ед}$ = A/d is the activity related to the unit of the article length, Bk/cm;

μ is the coefficient (factor) of radiation weakening in metal, 1/cm.

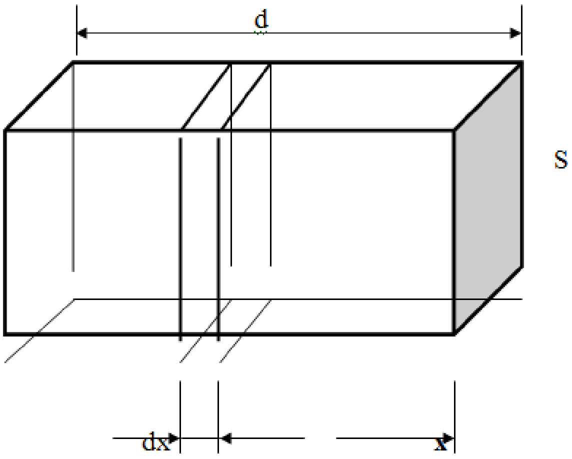

Figure 1. The article under investigation

The total activity on the plane S taking into account radiation weakening in metal is determined with expression

$$A_n=\int_0^d \left(A/d\right)\exp(-\mu x)dx =$$

$$\left(A/d\right)\cdot[(1-\exp(-\mu d))/\mu]. \qquad (2)$$

Taking into account the character of dependence of the level of absorption for the radioactive emanation in the thickness of metal, the coefficient of weakening μ can be written [2] as follows:

$$\mu = \ln 2 / d_{0,5} = 0{,}693 / d_{0,5} \quad (3)$$

where: $d_{0,5}$ is the layer of the half weakening of the radioactive emanation, cm.

With due regard for (3) expression (2) takes the form:

$$A_n = (A \cdot d_{0,5} / 0{,}693d) \cdot [1 - \exp(-0{,}693d / d_{0,5})] \quad (4)$$

The even distribution of sources of ionizing radiations in the mass of melted metal is characterized by the value of the volumetrical activity A_v, Bk/cm^3.

Taking into account that A = $A_v \cdot$ V, expression (4) will take the form:

$$A_n = (A_v \cdot S \cdot d_{0,5} / 0{,}693d) \cdot [1 - \exp(-0{,}693d / d_{0,5})]$$

, Bk (5)

The surface activity on the plane S is determined by the value

$$A_s = A_n / S = (A_v \cdot d_{0,5} / 0{,}693d) \cdot [1 - \exp(-0{,}693d / d_{0,5})]$$

, Bk /cm^2 (6)

The maximum value of expression (6) when d >> $d_{0,5}$ is equal to

$$A_{S\max} = (A_v \cdot d_{0,5} / 0{,}693d) = (A \cdot d_{0,5} / 0{,}693V),$$

Bk/cm^2 (7)

The rated dependence of the surface activity of metal A_S (axis Y) on the length of an article d (axis X) is shown on the Fig.2. The surface activity is fixed to its maximum value $A_{S\max}$, the length of the article d is fixed to the thickness of layer of the metal half weakening $d_{0,5}$.

One can see from the Fig.2 that whatever would be dimensions of an article, activity on its external (outer) surface S can't exceed the value of $A_{S\max}$. It is to be noted that the main contribution to the value of the surface activity is made with radionuclides which are situated in the layer near the surface of the thickness about 4 $d_{0,5}$. Radiation of radionuclides which are situated further, after the mentioned layer is in fact totally absorbed by the metal.

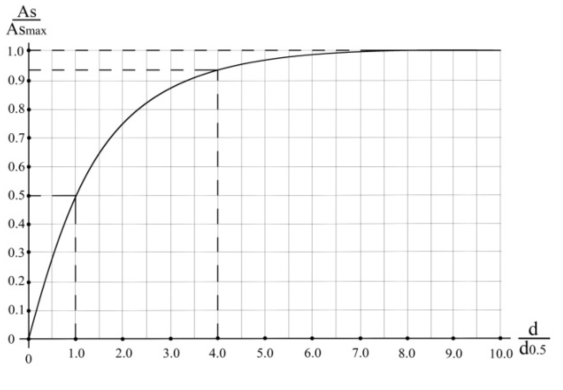

Figure 2. Dependence of the surface activity on the plane S of an article on its length d

For the lack of absorption, when it is supposed that all the sources of ionizing radiation being in the volume of the melting (melted metal) take part in the forming of the surface activity the value of the later is described with expression

$$A_S^o = A / S = (A / V) \cdot d \text{ , Bk/cm}^2 \quad (8)$$

The ratio of expressions (7) and (8) could be named the factor of self-decontamination K_s.

$$K_s = A_S^o / A_{S\max} = 0{,}693 \cdot d / d_{0,5}. \quad (9)$$

This ratio is true (correct) when d >> $d_{0,5}$ what is always kept in practice. It shows what part of activity brought into the melting furnace takes part in the forming of activity on external surface of metal which is the product of the melting (heat) of metal contaminated with radio activity.

All above-stated concerns also in the full measure the finished articles of the smelted metal. As the volumetric activity of these articles is the same as in the melted metal and the volume of each separate article can't exceed the volume of melted metal, then the value of their surface activity can't exceed the value of this parameter for the melted metal.

Investigation which was carried out allows formulating requirements as to the quantity of activity to be brought to the furnace. This quantity is determined by norms of the permissible value of the surface activity for the finished articles $A_{S\ per}$. As it follows from expression (7) the total activity brought into the furnace should not exceed the value

$$A_{\max} = (0{,}693 \cdot V \cdot A_{Sper.}) / d_{0,5}. \quad (10)$$

It is to be noted that by any kinds of treatment of the articles made according to technology under consideration the intensity of ionizing radiation off their surface also doesn't exceed permissible norms.

Thus the approach under consideration allows utilize the MCR which is included in the composition of the charge using existing melting furnaces. The quantity of such MCR which can be charged into the furnace under condition of assuring the permissible level of contamination of the finished articles is calculated beforehand.

Let us consider the possibilities of technology proposed for utilization of MCR at the example of using the existing metallurgical furnace working in the regular schedule.

Let us assume that the mass of melted metal M = 150T. If the specific mass of metal $\rho = 7{,}86$ g/cm^3, the volume of metal

$V_m = M/\rho = (1{,}5\cdot10^8)/7{,}86 = 19\cdot10^6$, (cm^3).

Let us assume that the melted metal has the shape of cube. Then its side

$d = (V_m)^{1/3} = (19\cdot10^6) = 2{,}7\cdot10^2$, (cm).

Let us assume that the layer of the half weakening of metal $d_{0,5} = 2{,}6$ cm [3]. Then, as it follows from expression (9), coefficient of the self-decontamination has the value

$K_s = 0{,}693\cdot270/2{,}6 = 72$

According to [4], metals can be used without any restrictions if the power of expositional dose of their ionizing radiation doesn't exceed the normatively permissible value $P_{per} = 30$ mcR per hour. In accordance with [2] this parameter can be evaluated to corresponding value of permissible level of the surface activity

$A_{Sper.} = K_{ev}\cdot P_{per}$, (11)

where $K_{ev} = 3{,}7\ 10^2$ Bk ·hour/mcR· cm^2 is the coefficient of evaluation.

After substitution we shall have

$A_{S\ per} = 1{,}1\cdot 10^4$ Bk/cm^2.

In accordance with (10) in the given example, the total activity which is brought into the melting furnace with MCR should not exceed the value

$A_{max} = (0{,}693\cdot1{,}1\cdot10^4\cdot19\cdot10^6)/2{,}6 = 5{,}6\cdot10^{10}$ (Bk).

The given technology allows utilizing MCR, in the first place, with low activity, the part of this metal in the total mass of accumulated MCR is equal to 80-90%.

Let us use the source of information [5] to calculate the quantity of MCR that can be charged into the given furnace. According to classification adduced in this work, MCR with specific activity in the limits (10^5–10^7) Bk/kg are considered as low-active. The mass of MCR, (5,6 – 560) T can have, depending on its specific activity, (5,6-560)T, permissible in the given example level of the total activity $5{,}6\ 10^{10}$ Bk. Thus, it is possible (one may) to feed the charge containing in its composition up to (5,6 – 150) T MCR into the melting furnace with the mass of melted metal 150 T.

One can see from presented example that it is allowable to feed into the melting furnace MCR with the average level of the power of expositional (exposure) dose

$P_{feed} = P_{per}\cdot K_s = 30$ mcR/hour·72 = 216 mcR/hour.

According to [4], it is permissible to carry out operations with MCR, which has such level of radioactive emanation, to the personnel of category A – persons who work constantly or provisionally directly with the source of ionizing radiation.

While analyzing processes, which take place in the furnace during metal melting it is also necessary to take into account that the boiling temperature of some radioactive substances will be smaller than the temperature in the furnace T_f =1600˚C. So, the boiling temperature of caesium is 685˚C, and the boiling temperature of strontium is 1367˚C. That is why in the process of metal melting the radioactive isotopes of these substances evaporate cleaning additionally production of the melt from a part of sources of ionizing radiation. Such production is safe and can be used in future without any restrictions.

As confirmation of the rightness for results of the carried out analysis serves the presence of such radioactive isotope as cobalt–60 in production got after melting in metallurgical furnace. This radionuclide has the temperature of evaporation 2225˚C. That is why it does not evaporate in the melting furnace and remains in the finished products as the source of ionizing radiation.

Conclusions

The approach consisting in feeding the metal contaminated with radioactive substances into the melting furnace without preliminary decontamination of the MCR serves as basis of considered technology. The maximum quantity of such metal is determined with permissible level of radioactive emanation off the surface of the finished products. Decrease of the level of the radioactive emanation occurs in the process of metal melting when the considerable part of emanated radionuclides is absorbed in the thickness of melting metal, that is on the account of the effect of self–decontamination. In the course of melting radionuclides, which have the boiling temperature lower than the temperature in the furnace, evaporate cleaning additionally the finished products from the part of sources of ionizing radiation.

Application of proposed technology will allow improving substantially technical and economical indices of the process for utilization of the metal contaminated with radioactivity and return to the economic turnover a big quantity of metal, which can be used later on without any restrictions.

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