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Possibility of Slag Sensible Heat Recovery on Drum-like Installations

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Abstract

A variant of utilizing of slag physical heat in drum-like installations has been considered. A high-temperature melt is delivered to movable metal bodies. Heat is picked up from the working bodies surface and newly generated surfaces of slag due to interaction with working bodies. Surface of slag grains, as they cool down, allows to pick up heat with various energy characteristics.

Keywords: smelter slags, heat content, drum-like installations, picking up and utilization of heat with various energy characteristics.

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Metallurgy is one of the basic energy-consuming industries. In particular, smelting one ton of grey iron takes ~ 450 kg of coke [1]. At the same time, about 14 % of energy is formed as sensible heat of grey iron and slag [2]. Taking into consideration the enthalpy of grey iron and slag [3], one can calculate that heat content of slag for various plants varies within 4.5 - 9%. Whereas chemical and physical heat of grey iron is partially utilized in steelmaking [2], slag heat is not utilized nowadays. Moreover, significant energy and capital resources shall be spent for cooling down of the slag at succeeding processing thereof. For instance, there are 6 trenches with total area of 18,900 sq. m at Novolipetsky Metallurgical United Works designed for cooling down of liquid blast furnace slag.

Heat content (Q) of one ton of slag can be evaluated on the basis of the heat balance equation:

$$Q = C_{\rho ls} \cdot (T_l - T_{cr}) + \lambda_s + {}_{\rho ss} \cdot (T_{cr} - T_t), \quad (1)$$

where: $C_{\rho ls}$ – specific heat capacity of liquid slag, kJ/kg·deg;

$C_{\rho ls}$ = 1.28 kJ/kg·deg for blast furnace slag in the temperature range 1500-1050 °C [3];

$C_{\rho ss}$ – specific heat capacity of solid slag, kJ/kg·deg;

$C_{\rho ss}$ = 1.09 kJ/kg·deg [3] in the temperature range 1050-20 °C;

λ_s – specific heat of slag crystallization; λ_s =240 kJ/kg [3, 4];

T_l – slag temperature at the furnace outlet, °C. T_l = 1500 °C;

T_t – slag final temperature, °C. T_t = 20 °C;

T_{cr} – crystallization temperature, °C. T_{cr} = 1050 °C.

It is of common knowledge that specific heat capacities are a function of temperature. However, it is averaged values for a certain temperature range that are usually taken for engineering calculations.

Substituting the known values in Equation (1) we obtain:

Q = 1.28·(1500-1050)+240+1.09·(1050-20)=1939 kJ/kg=1.939 GJ/t

These estimated parameters conform to the data [5–7].

From the graph of slag output from a blast furnace of volume 3.2 thou. m^3 (Fig. 1) it is follows that its mass from each heat is equal to ∼ 192 t, and Q = 192·1.9=364.8 GJ, or 12.4 t of coal equivalent (1 t of coal equivalent is equal to $29.3 \cdot 10^9$ J) is lost with it. For a year, 21304322 GJ or 72416 tons of coal equivalent will be lost with slag from one blast furnace of volume 3.2 thou. m^3.

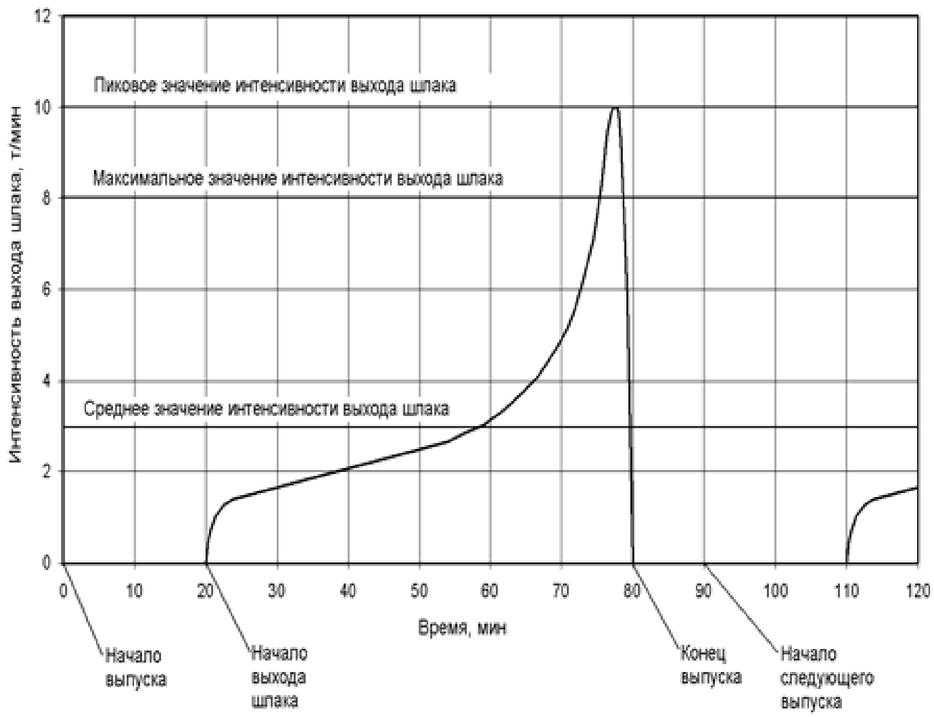

Figure 1: Graph of slag output from a blast furnace of volume 3.2 thou. m^3 Интенсивность выхода шлака = Slag output intensity, tons/min; Пиковое значение = Peak value; Максимальное значение = Maximum value; Среднее значение = Average value; Начало выпуска = Beginning of discharge; Начало выхода шлака = Beginning of slag output; Время, мин = Time, min; Конец выпуска = End of discharge; Начало следующего выпуска = Beginning of next discharge.

As an example of possibility to utilize heat, use of a unit with a ball heat-storing head [8] has been considered, which was developed by Ural Institute of metals and realized on Baostal United Works (PRC) for recycling of steelmaking slags but without heat removal (Fig. 2). The slag melt was cooled down by delivery of water into a drum and a rotary elevator. To maximally cool down balls and structural elements of the unit, the fixed and rotary walls and balls, water delivery is envisaged. Additionally, balls are cooled with water to temperature 20 °C in two chambers and to 50 °C in the drum. The temperature of the rotor and drum fixed wall does not exceed 200 °C. The cooled slag temperature shall be equal to ~ 50 °C.

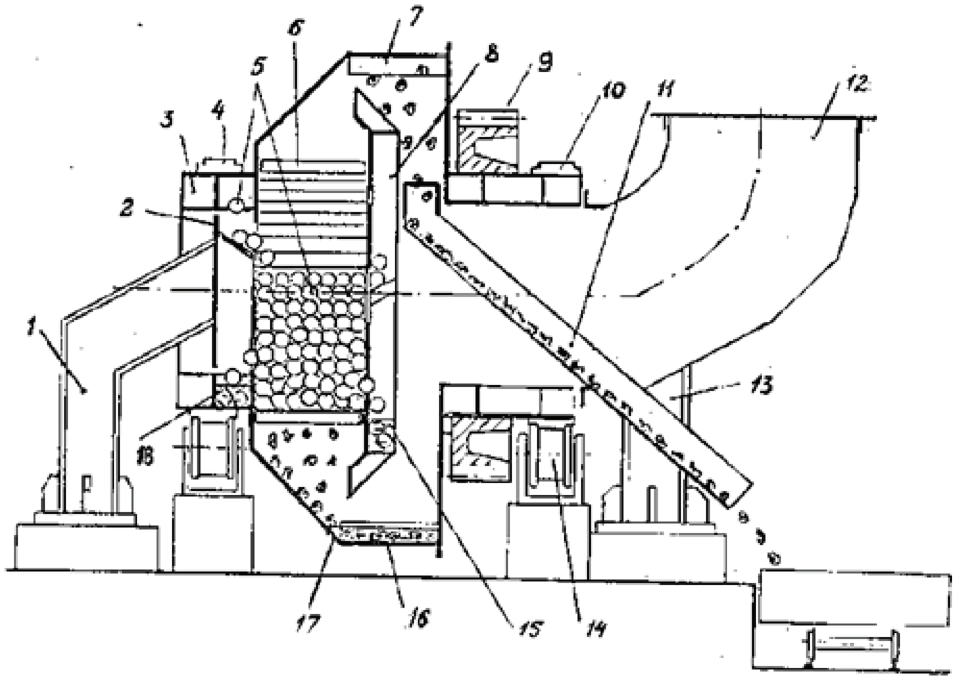

Figure 2: Structural layout of a drum-like installation for recycling smelter slags in molten state. 1-fixed wall support; 2-fixed wall; 3-annular chamber; 4, 10-bandage; 5-working bodies of heat-storing head; 6-fire bars; 7-off-loading drum shelf; 8-movable chamber for cooling of working bodies; 9-toothed wheel; 11-outlet channel; 12-steam removal manifold; 13-manifold support; 14-support roller; 15-water level in movable chamber; 16-cylindric shell ring of off-loading drum; 17-tapered shell ring of off-loading drum; 18-annular chamber cells.

In general, the installation heat balance may be put down as follows:

$$Q = Q_{rad} + Q_d + Q_{wt} + Q_b + Q_{sam} + Q_{pr}, \quad (2)$$

where Q_{rad} – losses of slag heat through radiation will be about 10 % from the slag heat content;

Q_d – amount of heat spent for heating of the drum and fixed jaw;

Q_{wt} – amount of heat spent for heating (Q_h) and evaporation (Q_{evp}) of water;

Q_b – amount of heat spent for heating of the drum's balls;

Q_{sam} – amount of heat withdrawn from the installation by steam-air mixture;

Q_{pr} – amount of heat withdrawn from the drum together with slag products.

The analysis shows that for heat recovery it is possible, in general, to use the heat spent for heating (Q_h) and evaporation (Q_{evp}) of water, the heat withdrawn from the

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installation by steam-air mixture, plus the heat withdrawn from the drum together with slag products. The installation design assumes generating of “cold” slag products upon cooling thereof in a drum-like elevator; thus the heat of heated water and steam-air mixture will be of interest for heat recovery. Such heat can also be used for household and business needs.

Calculation of certain components of Equation (2) was performed by conventional heat balance formulae and would not be given in this paper. To evaluate the amount of heat picked up by the balls it is necessary to determine average temperatures the balls will be heated up being in contact with slag, which are in the drum and delivered upon after-cooling in additional cooling chambers.

Temperatures in the centre and on the surface of the ball, which is placed in a variating temperature environment, were determined within a time span τ with taking into consideration graphic indicators for identifying of dimensionless temperature [9, 10]. With a reasonable accuracy, evaluation of these parameters was performed with assuming the scheme of cylinder cooling at the non-stationary mode [10] with radius r = 0.0625 m. It is assumed for calculation: λ = 37.2 W/m·deg – thermal conductivity coefficient of steel, $a = 6.94 \cdot 10^{-6}$ m^2/sec [11] – thermometric conductivity coefficient, *a*’ = 580 W/m^2·deg [12] – coefficient of heat transfer from slag to steel.

At the moment when slag comes in contact with cold balls the latter will get covered with a crust of crystallized oxides. As heat from the melt to the ball is transferred via the slag layer solidified on the ball surface and depends only on properties of materials and duration of their contact, the melt amount (intensity of the melt delivery into the installation) will not influence the balls heating temperature.

In this case, the task will boil down to determining of the temperature in the centre and of the surface of the ball in τ = 8 s (the time of slag staying inside the drum), of them for 4.3 s, the balls move on the surface (generatic) of the all head on contact with slag, and 3.7 s on the drum generatic in contact with the drum fire bars until the moment of balls cleaning from the slag crust. Temperatures in the centre ($t_{r=o}$) and on the surface ($t_{r=ro}$) were determined by means of graphs $\theta_{r=o} = F_1(B_i.F_o)$ and $\theta_{r=ro} = F_2(B_i.\ F_0)$ [8]. For balls delivered from after-cooling zones, temperature in the centre of the ball will be equal to $t_{r=o}$ =123 ˚C; on the ball surface $t_{r=ro}$=411 ˚C. Consequently, for the balls which are cooled in the drum only: $t_{r=o}$ = 150 ˚C, and $t_{r=ro}$= 430 ˚C. Taking into account the linear temperature change in the ball, one may assume balls cooled down to 20 ˚C will have the average temperature t_{20}=267 ˚C, and those cooled in the drum only – t_{50}=290 ˚C.

From the heat balance equation it follows that such components as Q_{rad}, Q_d и Q_b are characteristics of the installation. Recovery of heat of the steam-air mixture, water and slag products is seen as a realizable task. The most essential element with the help of which one can influence the amount of heat suitable for heat recovery is the slag products temperature which depends on the water flowrate and intensity of the melt delivery into the installation. The drum-like installation with elevator wheel envisages cooling of slag products therein to low temperatures (50 degrees) and can be applied for generating low-temperature heat for household needs.

In this connection, a new design of the installation [13] excluding the drum elevator was developed and tested in industrial environment. The new experimental industrial installation was tested in industrial environment at recycling of steelmaking slags from aggregates of extra-furnace steel processing, ferroalloy and copper-smelter slags.

The slag after cooling and crushing in the drum (rotor) will be delivered to the transporter. The slag temperature after the drum may practically reach the temperature of the melt crystallization. Further cooling to necessary parameters will be performed on the conveyor. Thus, apart from low-temperature heat transfer agents (water, steam-air mixture) suitable for household needs, it is possible to obtain high-energy heat transfer agents for generating electric power and process heating of raw stock materials.

The highest energy potential can be obtained at the stage of melt crystallization and from slag coming out of the drum. There are multiple variants of designs of heat exchangers with direct and reverse flow of gas and slag and with suction of gas through the hot slag layer [14]. Heat extraction is realized on the principle of pseudoliquid layer or transfer aggregates. After that, the hot gas will be delivered to power-generating units for electric power generation.

Thereafter, extraction of so-called process heat occurs in the temperature range from 250 to 450 °C. This heat can be utilized for preheating of blast to melting units, heating of furnace charge, etc. At the last stage communal heat with temperature to 100 °C and higher will be extracted which can be used for heating rooms and other purposes.

Evaluation of the heat balance speaks for the fact that about 63 % of slag melt heat can be utilized on installations of such a kind, including 22,5 % of power generating and thermotechnical heat, and 18 % of communal heat. Thus, supplementing of a drum-like installation with units for extraction of slag heat will allow to arrange the process of rational utilization of the heat potential [15]. However, it is worth noting that designing of each heat recovery related unit shall be solved in accordance with construction features of the drum-like installation, and heat parameters of the slag melt, slag products, balls, shipment terms, etc. shall be taken into account. See Fig. 3 where one of variants of the installation layout with heat-exchanging gears is shown.

The new technology of slag melts recycling in drum-like installations with a heat-storing head allows not just to produce commercial slag products from melts directly but also creates conditions for extraction and recovery of power-generating, process and communal heat from recycled slag melts.

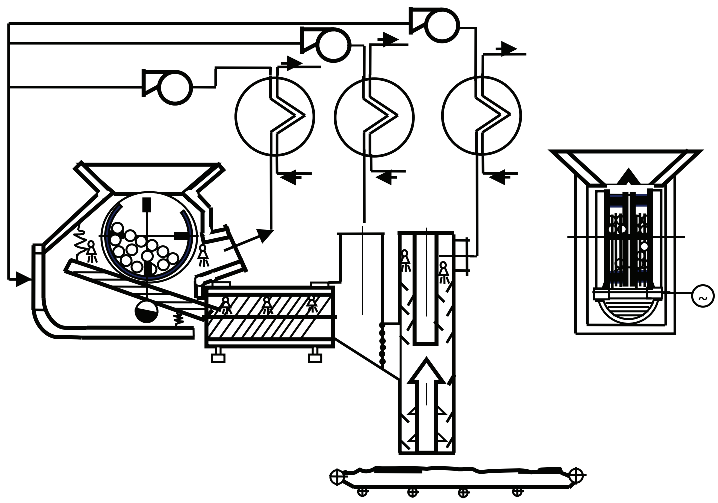

Figure 3: Installation for slag recycling with heat recovery

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