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High-temperature modeling of hot metal tapping from the converter with argon supply to the tap hole cavity

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Abstract
High-temperature modeling of tapping from the converter with different processing modes of metal flow by argon is carried out. Experiments are conducted on the basis of steel-making laboratory of department of ferrous metallurgy of Dniprovsk State Technical University. The obtained data are indicative of the possibility of gas-metal flow formation with different arrangement levels. The laws of impact of tap hole geometrical dimensions and consumption characteristics of inert gas on flow arrangement are established. The reasonability of two-chamber tap hole for metal flow processing by argon is shown. The authors defined that in case of flow processing by argon with consumption of 1 m^3/t with using the two-chamber tap hole, the gas-metal flow possesses high-level arrangement and moves in line with protective gas. This is conductive to the process of carbon deoxidation not only in gas-feeding zone, but also in the open area of jet. The peculiarities of behavior of liquid metal particles of various sizes in the argon flow out of tap hole are studied with the use of video recording.
Key words: CONVERTER, TAP HOLE, STEEL, ARGON, GAS-METAL FLOW, CARBON DEOXIDATION, HIGH-TEMPERATURE MODELING

Introduction

Obtaining of metal products with high quality indicators largely depends on the technology of production. In steelmaking, the increase in the purity of steel for harmful impurities directly depends on the technology of deoxidation. The most common method is deep deoxidation, when oxygen from the metal is removed using metal deoxidizers (Al, FeSi, FeMn, etc.). At the same time, the deoxidation products are not completely removed into the slag and often are the reason of the workpiece rejection for nonmetallic inclusions (NI). To reduce the amount of nonmetallic inclusions, there are a number of technologies used at various stages of steel production, from smelting in the converter to casting and crystallization.

Carbon deoxidation is the most “clean” (effective) technology of deoxidation. In this case, the deoxidation products are removed to the gas phase in the form of CO and CO_2. According to the literature, the deoxidizing ability of carbon can exceed even aluminum when evacuation.

Numerous studies of carbon properties indicate the possibility of carbon deoxidation during argon blowing without evacuation. Decrease in oxidation is achieved due to post-blowing mixing with argon at combined blowing of a converter bath with a gas flow rate of 0.4-1.2 m^3/t of steel [1]. In the converter, the degree of metal deoxidation is reduced by active mixing with highly oxidized slag, which reduces the efficiency of using argon. The supply of the specified amount of argon to the ladle requires a significant increase in the processing time.

It was proposed in [2] to perform refining of the metal in addition to the slag cutoff. The authors of the work argue that when processing in the tap hole of metal with argon, which is tapped from the converter, it is possible to remove impurities and gases from it. In addition, the refining of the metal during its tapping from the converter in contrast to the most frequently used variant the so-called secondary treatment allows carrying out gas processing with smaller volumes of metal melt, since in the implementation of the proposed method, the gas is injected into a jet of metal bounded by the dimensions of the converter tap hole. Thus, the refining of the metal melt in the tap hole area of the converter allows reducing the pressure and the gas flow, which decreases the energy consumption for the process.

The treatment of the metal with an inert gas in the tap hole will necessarily affect the nature of the organization of the open part of the flow. The effect of the gas consumption characteristics and the geometric parameters of the tap hole on the formation of a gas-liquid flow with a different degree of organization is performed only in [3, 4] on cold models. However, high-temperature studies with the formation of gas-metal flow (hereinafter GMF) in the cavity of the tap hole have not been carried out to date. Obviously, this is due to the prevailing opinion that any violation of the continuity (arrangement) of the metal flow during the tapping of melting will lead to an increase in the contact of surface with air and subsequent saturation of the steel with atmospheric constituents such as oxygen, moisture and nitrogen.

The objective is to study the features of the metal behavior in the flow of argon in the cavity of the tap hole and beyond it when performing high-temperature simulation of the melt tapping from the converter.

Methods of research

High-temperature modeling was performed using a special stand (Fig. 2) in order to study the processes of formation of gas-metal flow during the tapping of melting from the converter (Fig. 1), when gas was fed into the tap hole cavity. The scale factor was taken equal to 0.2. The experiments were performed on the basis of the steel-making laboratory of the Department of the ferrous metallurgy of Dniprovsk State Technical University. Modeling media were as follows: liquid metal - cast iron, inert gas - argon.

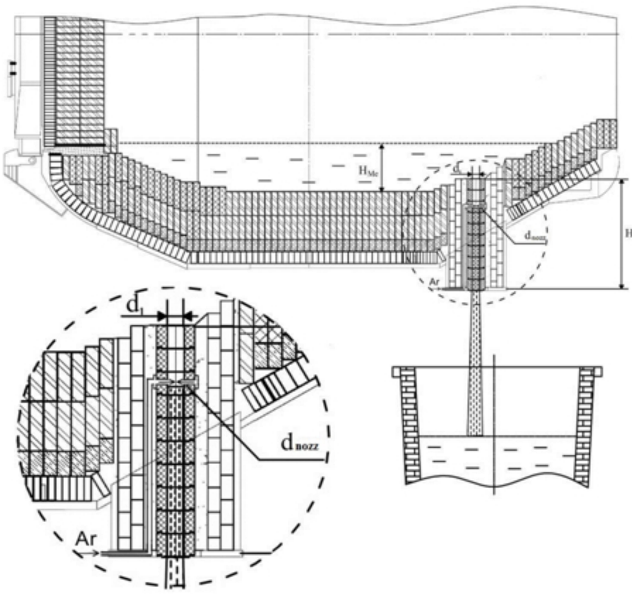
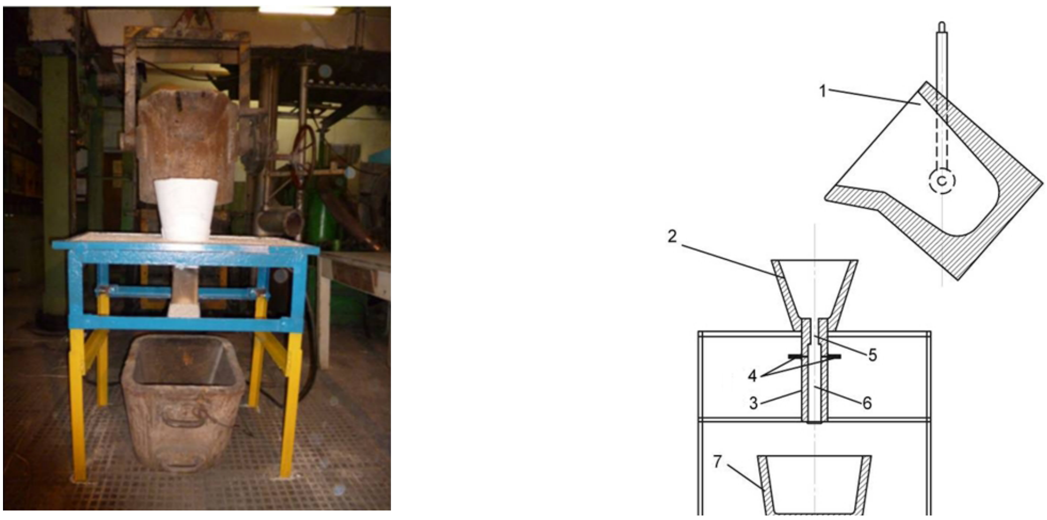


Figure 1. Schematic representation of the process of melt tapping from the converter with the supply of gas into the cavity of the tap hole



a) b)

Figure 2. Laboratory installation for gas supply to the cavity of the tap hole (a) and its scheme (b):
1 – steel-teeming ladle; 2 - intermediate container simulating the level of metal in the converter; 3 - double-chamber tap; 4 - nozzles for gas supply to the cavity of the tap hole; 5 - the first chamber of the tap hole; 6 - the second chamber of the tap hole (expanded); 7 - receiving ladle

In an induction crucible furnace of IST-0.16 type, cast iron with a mass of 100 kg was melted and brought to a temperature of 1400-1600 °C. After reaching the required temperature, the cast iron was poured into the steel- teeming ladle *1* preheated to 600-800 °C. Then, from the steel-teeming ladle *1*, the cast iron was taped into a special intermediate container *2*, which simulated the metal level in the converter in the tapping state. From the intermediate container *2*, the metal entered a double-chamber tap hole *3*, where it was processed with argon followed by the tapping of a gas-metal flow into the receiving ladle *7*.

Video recording of laboratory studies was performed with video cameras in the normal (30 frames per second) and high-speed (300 frames per second) shooting mode.

Features of technology

1. The level of metal in intermediate container *2* was assumed equal to $h_{Me} \approx 0.2$ m in accordance with the procedure given in [5] (with the scale factor taken into account) and kept constant throughout the entire tapping of the melting due to continuously refilling the cast iron from the steel-teeming ladle *1*.

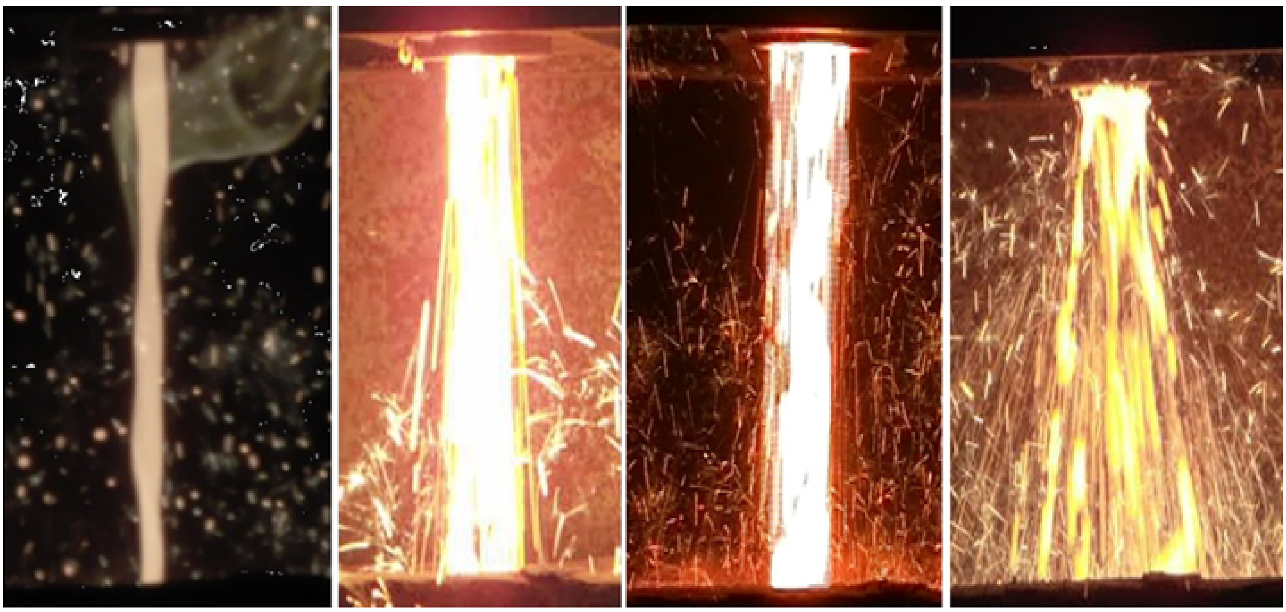
2. The tapping model is adopted as a double-chamber model, as in [4], since at cold modeling, it had the closest to optimal flow and hydrodynamic characteristics. The first chamber *5* with a standard diameter d_1 performs the function of a metal dispenser. The second (expanded) chamber *6* with a diameter $d_2 = (1.2\ldots1.5)d_1$ is equipped with coaxially located nozzles *4* of cylindrical shape with a diameter $d_{nozz} = 2.3$ mm for supplying an inert gas.

Results of the research

Several series of experimental melts have been carried out, during which various regimes of flow outflow through the test tap hole have been implemented.

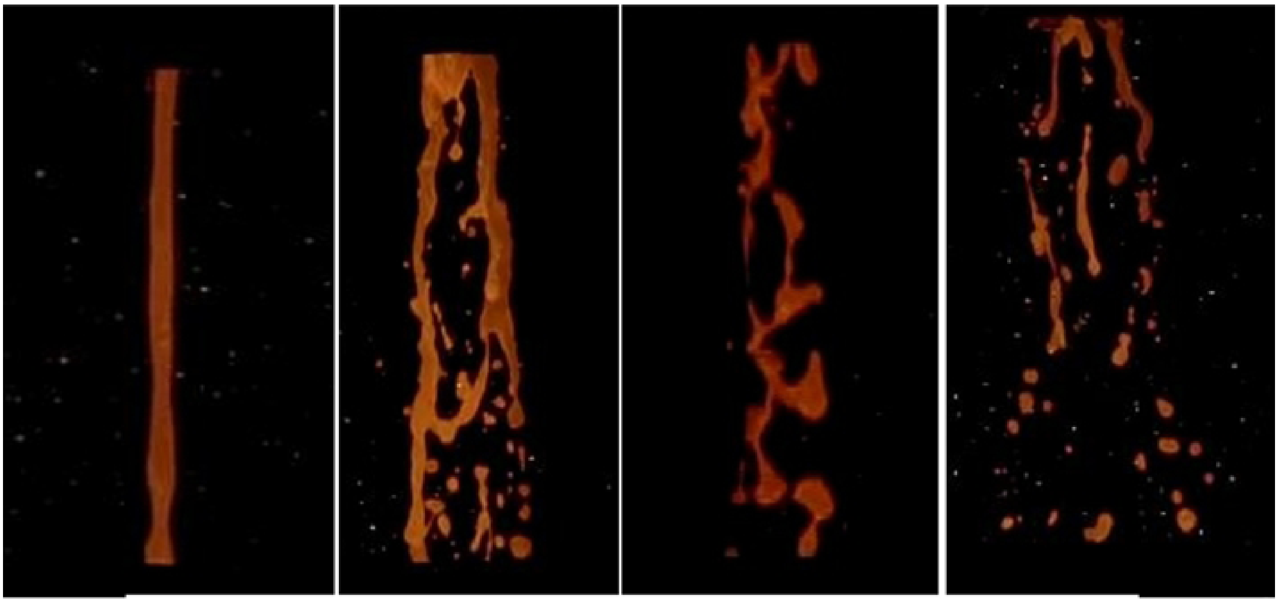
Figures 3a and 4a show the state of the jet during the normal flow of metal without blowing with argon. A pulsation of the flow with a satisfactory organization on the area outside the tap hole was observed. However, with this tapping of the melt, the effect of flame burning takes place around the flow. Most likely, with the usual tapping (without gas supply), a jet of high-carbon metal contacts the surrounding atmosphere and there is interaction of oxygen molecules with carbon atoms adsorbed on the surface of the jet. A similar "flame" effect is observed when carbon steels are tapped from the converter.

In the second series of experiments, the melt tapping was carried out with blowing the metal through two coaxially located nozzles in the second chamber of the tap hole (Figures 3b and 4b) at an argon flow rate 0.2 m^3/min and a pressure of 0.5 MPa, which corresponds to a specific consumption of 1 m^3/t of steel. Figure 3b shows that the GMF has a sufficiently high organization with a small separation of the flow particles. In Fig. 4b, the formation of particles with different degrees of dispersion up to continuous jets is observed. The presence of weakly fragmented jets is explained by the small number of blowing nozzles, but the presence of small particles in the flow indicates a high mixing potential of the gas jets.



a) b) c) d)

Figure 3. Flow condition during normal shooting (30 frames per second):
a - flow without gas supply; b - GMF with blowing through 2 nozzles; c - GMF with a blow through 4 nozzles; d - GMF when tapping through a "hard tap hole"



a) b) c) d)

Figure 4. Flow condition for high-speed shooting (300 frames per second):
a - flow without gas supply; b - GMF with blowing through 2 nozzles; c - GMF with a blow through 4 nozzles; d - GMF when tapping through a "hard tap hole"

In the third series of experiments, the melt tapping was carried out with a metal blowing through four coaxially located nozzles in the second chamber of the tap hole (Figures 3c and 4c) at an argon flow rate 0.2 m^3/min and pressure of 0.3 MPa. It can be seen from Fig. 3c that the organization of GMF increased and the separation of the particles was practically not observed. The data of high-speed shooting (Figure 4c) indicate an increase in the uniformity of the crushing flow, but the particle sizes have increased. The reason for the larger particle size was the reduction in the mixing effect of the gas due to the reduction in blast pressure. The decrease in blast pressure, in turn, was due to an increase in the number of nozzles and the total area of their cross sections.

In the fourth series of experiments, the conditions of the third series were kept, but intense scattering of the GMF was observed (Figures 3d and 4d). This was caused by a reduction in the cross-sectional area of the second chamber as a result of the freezing-out of cast iron on its walls. Freezing-out of cast iron was due to inadequate heating of the second chamber (500 ... 600 ºC) of the tap hole, which was consisted of corundum graphite refractory characterized by high thermal conductivity. It can be argued, with some approximation, that in this case the tapping occurred with blowing through a single-chamber tap hole. Moreover, the character of the spraying of GMFs was very similar to the gas-liquid flow obtained by blowing in a single-chamber tap hole during the cold modeling stage [4].

The common positive moment of the second (two nozzles) and the third (four nozzles) series of experiments is that the motion of different shapes and sizes of metal particles outside the tap hole occurs almost in the argon gas flow along the path to the surface in the ladle, i.e. in the direction specified by the section of the second tap hole chamber. This is an evidence of a good organization of the argon-metal flow and confirmation of the correctness of the chosen parameters-sectionsizes of the second chamber.

On the other hand, the results of the fourth series - the obtaining of a sparse unorganized jet - confirm the decisive importance for the stage of tapping temperature state and the produced liquid metal and refractory material for obtaining a well-organized gas-metal flow, which is decisive for normal tapping practice.

Thus, the third and fourth series of experiments prove a great importance when blowing metal with gases in the cavity of the tap hole of the presence of a second expanded chamber of the optimal section (in our case, it is cylindrical) and of optimum dimensions. Taking into account the modeling data [3, 4], the dimensions of the tap for the 250-ton converter have the following values, mm:

a) first chamber: diameter $d_1 = 150$, length $l_1 = 400$;

b) second chamber: diameter $d_2 = 180...200$, length $l_2 = 1500$.

Intensive mixing of argon with metal takes place inside the cavity of the tap hole channel, especially in the zone of gas nozzles, the actual real picture of the flow of which for this modeling could not be reordered due to the opacity of the tuyere center (it is practically impossible to perform it at the present time). However, as shown by the data of high-speed video shooting in the open area of argon-metal flow, i.e. outside the tap hole channel, the metal particles of different fractions move in the argon flow in one direction, but with different velocities. In turn, particles up to 3 ... 5 mm in size along the way are occasionally coalesced and crushed. Apparently, the processes of coalescence and crushing of metal droplets continue throughout the open part of the argon-metal flow. This process is visualized in the form of a series of high-speed images in Figure 5. The time behavior of two observable particles, close in shape to a spherical one, is indicated on the fragments of argon-metal flow by rectangles. The onset of fusion is observed in 7-8 fragments, ending at 13-14. From the above fragments, the change in shape and position of other larger fragments of the liquid phase can be seen.

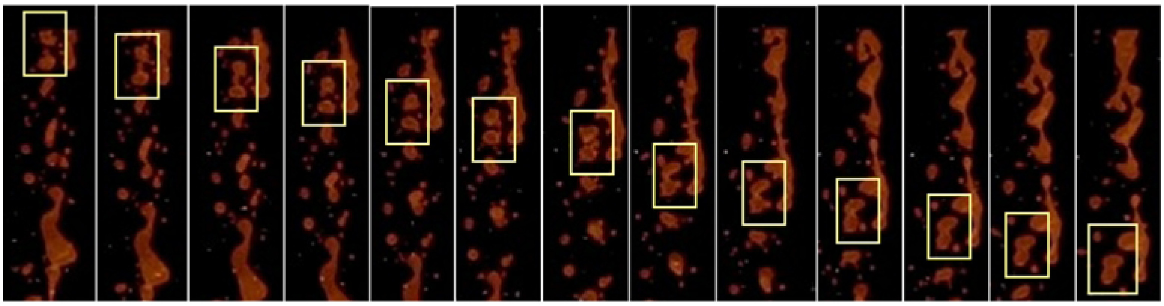


Figure 5. A series of high-speed images characterizing the coalescence and crushing of metal droplets in the open part of the argon-metal flow

It can be seen from Fig. 5 that the surface between the metal and the gas is constantly changing and updating, which facilitates the flow of surface processes. These include the processes of carbon deoxidation, degassing (removal of hydrogen or nitrogen from the metal), desulphurating.

Conclusions

1. When performing high-temperature modeling of the melt tapping from the converter, it is confirmed that a directional, organized gas-metal flow can be obtained by using a double-chamber tap hole channel, the second chamber of which is equipped with nozzles in the upper part for supplying neutral gases at a flow rate up to 1 m^3/t.

2. With the help of high-speed video shooting, the behavior of particles of different fractions and large fragments of liquid metal in the flow of argon outside the tap hole was studied for the first time. The processes of fusion and separation of these particles moving with different velocities were detected, the zone and direction of motion of which were determined by the dimensions of the second chamber and the flow parameters of argon.

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