Aeroacoustics of Jet Streams Used in Metallurgy

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Abstract. The supersonic jets of gas which is expiring into the melt from nozzle of BOF lance have a powerful acoustic radiation. The sound intensity of the jets is up to 200 dB and it is the most powerful natural source of sound. The jets invasion into heterogeneous unstable and gas saturated liquid melt-solution is the cause of the cavitation phenomena into the liquid. This explains the spontaneity of the gas formation and the speed of the decarburization process throughout the entire volume of the liquid metal volume. Using sound intensity changes, in the 60-th years of the last century, was developed the acoustic monitoring and control system of slag process into the BOF furnace.

In the 21st century, the metallurgical industry is going through more computerization of control process of the technological process of steelmaking. The new knowledge about the mechanism of decarburization processes can provide solution to the automation problem.

Several hypotheses of the decarburization process of steel in blast oxygen furnace (BOF) are known. The first hypothesis is one-stage, where the decarburization process occurs in the zone of contact of the oxidizing jet with the iron-carbon melt solution. High temperatures in the zone of interaction of the oxidizing agent with the melt facilitate to the diffusion of carbon from the entire volume of the melt into the high-temperature reaction zone. The second hypothesis is two-stage, where iron oxides formed in the reaction zone of an oxygen jet with a melt-solution diffuse into the melt providing intensive boiling of the melt bath with the release of CO bubbles throughout [1]. There is no doubt that the existing hypotheses of both the one-stage and two-stage decarburization process take place and are more characteristic of the open-hearth process, where the decarburization process lasts for hours. But not one of the hypotheses of the mechanism of the decarburization process presented above is unable to explain the high speed of decarburization processes throughout the entire volume of the melt bath, which is typical for the BOF process.

Perhaps there is a hypothesis that allows us to explain the high speed of the decarburization process in the BOF process.

The work [2] shows the intensification of the decarburization of the melt by mechanical vibrations of the oxidizer jet with a frequency of 800 - 900 Hz. It presents a lot of mechanical and gas-dynamic devices that provide an intensification of the decarburization process. The process acceleration mechanism is not explained, but the fact of acceleration of the decarburization process is ascertained.

Regard the aero-acoustic properties of supersonic jets flowing into fulfilled space.

Figure 1 (a) shows supersonic shock wave part of the jet and subsonic blurred part with a small power of turbulence. As a result of the interaction of the jet turbulence with the space surrounding the jet, the supersonic section of the jet dissipates passing into the subsonic part of the stream. Figure 1 (b) shows...
the outflow from the same nozzle in the same mode when the jet was excited by its own acoustic radiation. The own acoustic radiation reflected from the acoustic screen mounted on the surface of the nozzle enter the jet into resonant self-excitation providing the feedback loop. Changing the shape or position of the screen changes the feedback efficiency [7], which leads to a change in self-oscillating processes in the jet with changing the size of the turbulence.

**Figure 1.** Shadow photograph of a supersonic jet flowing from lance nozzles into full filled space (exposure $10^{-6}$ s).

In the nearest acoustic field near the supersonic part of the jet the radiation intensity increases to 200 dB. The directivity of acoustic radiation determined by the scanning method [3] is shown in Figure 2. The acoustic field of the supersonic jet has a specific directivity, along the stream of the jet and against the stream. The radiation directed against the stream is formed by the turbulence radiation of the supersonic part of the jet and has a maximum intensity at the specific frequency. The radiation by direction of the jet's flow is formed by the supersonic and subsonic part of the jet and is a source of broadband white noise. As can be seen in the shadow photograph Figure 3 [4].

**Figure 2.** Acoustic radiation of the supersonic jet.

Figure 3 shows the shadow photograph of acoustic radiation of the supersonic jet. The generation mechanism is the turbulence of the shock-wave structure of a supersonic jet. The intensity of this radiation (120-200dB for supersonic) prevails over the turbulent acoustic radiation of the subsonic part (100-110dB). The supersonic jet is a natural source of acoustic radiation. The intensity and directivity of the radiation depends on the flow regime, size, shape and design of the nozzle block.
An analysis of the operation of factory lances shows that the jets flowing from the nozzles have this radiation and have an effect on the technological process.

From the foregoing, a new hypothesis of the decarburization process can be formulated. The third hypothesis of the decarburization process of the melt-solution is wave model. The melt-solution in its physical nature presents 95% iron in which 4.3% carbon 0.07% of other chemical elements of the periodic table are dissolved. In addition to chemical elements, gases, including oxygen, are dissolved in the melt-solution.

In the process of introducing a supersonic jet of an oxidizing agent into the melt-solution [6–7], the torch of combustion of the oxidizing agent CO gas and metal is formed. With increasing temperature and intensity of acoustic radiation, the magnitude of the supersonic part of the jet increases. The sound wave of high intensity cause to a break in the continuity of the melt-solution medium at concentrators, which are carbon dissolved in the melt. The cavitation and collapse at the place of the bubbles is accompanied by an adiabatic local temperature of more than 10,000 °C [5]. The process is spontaneous in nature throughout the entire volume of the melt-solution bath, causing to the CO gases formation. This explains the high speed of the decarburization process of the melt.

The evidence of the transfer of jet oscillations to the melt with the formation of wave phenomena in the melt is presented in Figure 4 [2].

Figure 3. The shadow photo of the acoustic radiation of the supersonic jet flowing into full filled space.

Figure 4. The reaction zone of the introduction of a supersonic jet into the melt.

Figure 4 [2] shows the surface of the reaction zone, where the vibrations of the supersonic part of jet are transferred into the melt. The cavitation is observed in the form of small bubbles throughout the reaction zone. The supersonic part of jet grows when it expires into the high-temperature space [6]. With an increase of the supersonic part of the jet, the intensity of acoustic radiation and the effect of acoustic feedback are increased [7]. The outflow of the supersonic jet of oxidizing agent into the melt is
accompanied by the formation of a torch. The torch stoichiometry shows that the combustion temperatures are 3000-5000 °C. The acoustic radiation penetrates unhindered into the melt. This is confirming the wave hypothesis of the decarburization process.

Acoustic radiation spreads in the cavity of the steelmaking unit and scans the gas medium, extracting information about the state of the melt. For the first time the acoustic phenomena of jets of blast was used for monitoring and control of the slag phase of the BOF process [8-9]. In the 60s of the last century, acoustic systems for monitoring and controlling the slag-metal phase of the BOF process were introduced (Figure 5).

![Figure 5. 60s acoustic system: 1 - blast oxygen furnace (BOF); 2 - oxygen lance; 3 - supersonic jets flowing from the lance nozzles into the melt - 4; 5 - waveguide; 6 - microphone; 7 - electronics of the acoustic system, which consists of band-pass filters, the receiver of the acoustic signal converted into electric.](image)

The result of processing the acoustic noise signal is transmitted to the recorder, which fixes the received amplitude of the acoustic radiation signal to the chart tape in real time, Figure 6.

![Figure 6. The slag behavior diagram during the smelting process.](image)
The changes of amplitude recorded on the diagram correspond to visual observation of the behavior of slag-metal emulsion in the unit. The slag and blast modes of smelting were optimized using process information. The lack of knowledge about the features of aero-acoustic radiation from jets flowing from nozzles of lances, burners, dispersants causes to the experimental search for the optimal design of the device.

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