KnE Materials Science
TECHNOGEN-2019
IV Congress "Fundamental research and applied developing of recycling and utilization processes of technogenic formations"
Volume 2020

Conference Paper

Utilization of Acoustic Field Energy for Reduction of Dust Discharge in High-Temperature Furnaces

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Abstract
In order to reduce the total dust discharge from high-temperature furnaces, this study advocates the use of the energy of the acoustic field formed in the furnace body with application of acoustic generators of Hartmann whistle type. The paper provides theoretical justification of dust precipitation inside the furnace and develops principles of its implementation. The efficiency of this method is shown by examples of industrial implementation.

Keywords: dust precipitation inside the furnace, acoustic field energy, Hartmann whistle

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Published: 31 December 2020

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the TECHNOGEN-2019 Conference Committee.

Operation of most metallurgical furnaces using fines or processing liquid melt is accompanied by discharge of a great amount of dust particles of different grain sizes. In order to reduce losses of processed materials and improve the environmental situation in the area of the plant location, a number of dust-separating units (dust precipitation chamber, cyclone system, electric filter) are installed in the way of dust-laden gases. The existing state of metallurgical furnace technology and designs leads to a highly-intensive operation of the gas exhaust duct and equipment installed in this duct, losses of raw materials and high environmental impact.

One of the most efficient methods for reduction of dust discharge in layer-charged furnaces and units is to change conditions of dust formation and precipitation at all stages of the burden heat treatment [1, 2]. Being the biggest source of dust, the working space of the furnace can be used for in-furnace dust precipitation. In this case, the dust particles caught within the working space of the furnace can be added to raw materials and increase their amount involved in technological processes, enhancing thereby productivity of the furnace and decreasing the values of material and heat losses with flue gases. A greater effect of using technological methods will be observed

How to cite this article: V.I. Matyukhin, O.V. Matyukhin, M.A. Putilov, and A.T. Ermekova, (2020), "Utilization of Acoustic Field Energy for Reduction of Dust Discharge in High-Temperature Furnaces" in *IV Congress "Fundamental research and applied developing of recycling and utilization processes of technogenic formations"*, KnE Materials Science, pages 326–331. DOI 10.18502/kms.v6i1.8103

after optimization of design and process parameters providing intensification of heat-and-mass transfer with high technical and economic performance of the end product. In spite of a significant number of dust-precipitating units and methods of their efficiency improvement [1], the use of known equipment is accompanied by reduction in furnace performance, requires additional capital expenditures for processing of caught particles (stocking, recirculation, utilization) and energy costs for heat loss replenishment.

One of the efficient and low-cost methods for improving performance of metallurgical furnaces or their components is to perform dust precipitation inside the furnace using energy of the acoustic field [3] formed directly in the working space.

Under the action of the external acoustic field on solid elements of the dust-laden flow, its separate solid particles (Figure 1) are exposed to forced oscillations, radiation pressure of the plane standing sound wave as well as the action of hydrodynamic attraction and repulsion forces between the elements.

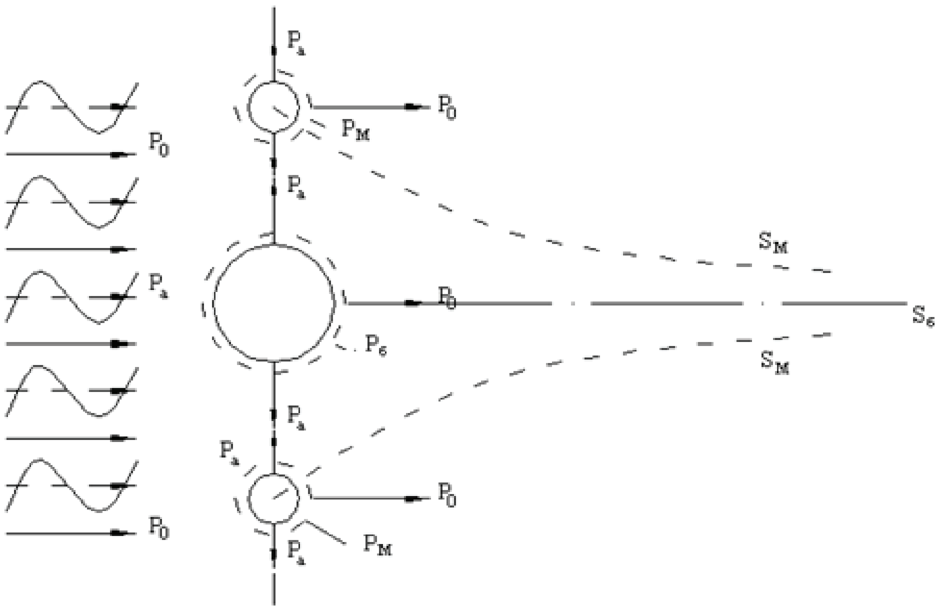

Figure 1: Diagram of acoustic effect on solid elements of the layer: P – static pressure of the gas flow; P – acoustic pressure; P – negative pressure near small elements; P – negative pressure near big elements; S – motion trajectory of small elements; S – motion trajectory of big elements

Each solid particle of the gas-laden flow with density ρ, being in the field of external acoustic oscillations with amplitude *A* and angular velocity ω in the gaseous medium with acoustic velocity *c*, is exposed to the action of additional periodic force with the oscillation amplitude:

$$P_a = A \cdot \rho \cdot c \cdot \omega = \frac{\rho \cdot c \cdot \omega}{\omega} \sqrt{\frac{2J}{\rho \cdot c} \cdot 10^7} = \sqrt{2J\rho c}, \text{ atm},$$

the value of which can be changed through design and process parameters. Acoustic oscillations cause destruction of the boundary layer near the particles and emergence of additional convective flows.

In rarefied media, large-scale outlines of circulating groups of particles can appear which lead to emergence of the piston effect. When the dust particles have a poly-dispersed structure, their oscillations cause formation of local zones with the pressure different from the ambient pressure. The bigger the size of the processed particles is, the more significant will be this difference. Therefore, in the dust-laden flow under the action of external acoustic oscillations the small particles move towards the big ones around which the local zone of high negative pressure is formed. It holds dust fractions around the big particles under the action of the acoustic field, which reduces dust discharge.

This effect shows itself most discernibly in conditions of technological processes characterized by low values of gas velocities and high dust content. The bigger the crosswise size of the particles is, the higher will be the level of the negative pressure caused by them. Therefore, when the acoustic field with the design parameters is formed, the small particles will move towards the big ones with subsequent coagulation and fallout from the main flow.

The resultant standing sound waves generate a nonstationary velocity field in the form of nodes and antinodes alternating in time. The occurring consequent external effect on gas flows is concentrated in the points of the nonstationary structure of the substance (interfacial areas, structure defects, internal and external irregularities) and determines their stability and the structure of stationary motion [4].

When implementing dust precipitation inside the furnace, it is necessary to observe the following principles:

1. The fullest and continuous impact of external oscillations on the dust-laden medium. For this, it is necessary to determine the points for installation of acoustic impact sources with a possibility of maximum impact on the dust-laden flow in accordance with design features of the furnace;

2. It is necessary to introduce a time factor of the acoustic impact on the dust-laden flow;

3. Formation of the acoustic field with design parameters established in accordance with design features of the furnace and physical and chemical characteristics of dust particles. For this, it is necessary to determine by calculations and experiments the optimum design and process parameters of acoustic jet-edge generators providing the maximum development of the required technical effect (reduction in dust discharge, intensification of heat-and-mass transfer, destruction of dust buildups and accretions,

etc.). The required acoustic power of the applied field and necessary quantity of the impact sources shall be determined in accordance with the data of laboratory and industrial testing;

4. Industrial testing regarding the use of acoustic field energy with assessment of dust precipitation efficiency and heat-and-mass transfer development.

It is suggested to fulfil formation of the acoustic field in the layer with the help of an acoustic generator (Figure 2) using acoustic ducts of different designs. The acoustic generator represents a variety of the Hartmann whistle and consists of a nozzle, resonant cavity and focusing surface. It is powered by compressed air with the minimum pressure of 3.0 atm. This device is installed outside the working space, which facilitates its assembly, maintenance and operation and also reduces the requirement for materials which are used for its fabrication. The use of the acoustic field directly in the layer makes it safe for operating personnel.

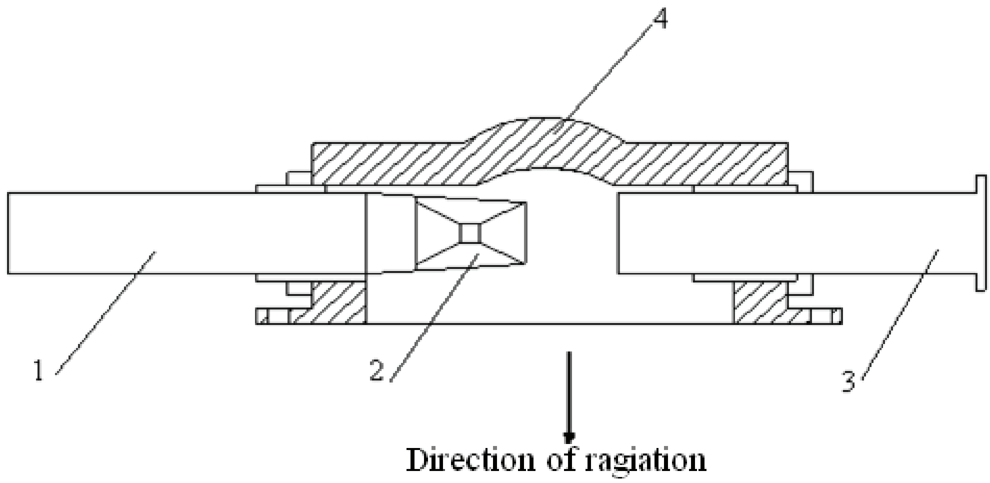

Figure 2: Design of acoustic generator: 1 – nozzle pipe; 2 – air nozzle; 3 – resonant cavity; 4 – focusing surface.

Industrial testing regarding the use of acoustic field energy for intensification of heat-and-mass transfer in a number of technological plants (sintering machines, dense layer in the polymerization furnaces, iron-melting and mineral-wool cupola furnaces, shaft furnaces used in non-ferrous industry) have shown wide possibilities for application of this method.

Thus, industrial testing of this process in conditions of AK-50 Sintering Machine of Serov Steel Plant over a long period of time confirmed its safety in use. Moreover, it became possible to increase productivity of the machine by the value up to 15…20%, intensify the main physicochemical reactions in the layer, reduce harmful emissions from the machine (CO, NO, dust) and decrease the specific consumption of fuel for the process by 10…15%.

The polymerization furnaces for fiber materials were equipped with two to six acoustic generators in the vacuum and drying chambers depending on the furnace design. Testing has shown that it is possible to increase furnace productivity by 30…35% with better quality of using the organic binder.

The results of using acoustic field energy in the working space of iron-melting and mineral-wool cupola furnaces, shaft furnaces in non-ferrous industry (Kirovgrad) have shown that it is possible to increase productivity of melting furnaces by 10…15% with respective reduction in coke consumption and quantity of harmful emissions. In addition, destruction of accretions emerging in the process of gas and material travel was observed, which enhances productivity of the melting furnace and reduces costs for its maintenance.

Formation of the acoustic field with the design parameters in the moving dust-laden flow of finely-dispersed burden in rotating furnaces used for alumina production at Bogoslovsky Aliminium Plant both in the direction of gas flowing and in the opposite direction enabled to fix a stable trend in reduction of dust discharge outside the working space by the value up to 40%. In addition, full completion of all chemical transformations in solid components was observed.

The long period (from September 2009) during which acoustic generators were used in shaft furnaces (Kirovgrad) has demonstrated the possibility of virtually complete destruction of burden accretions emerging in the working space of the furnace. Moreover, the possibility of increasing furnace productivity by 5…10% with reduction in the total quantity of dust emissions by the value up to 25% was shown.

The analysis of industrial testing data regarding the use of acoustic field energy in the working space of the molten bath (SUMZ, Revda) has shown that the use of acoustic field energy with similar parameters of bath operation leads to reduction in dust discharge by 10.94%. In addition, dust precipitation inside the bath results in a higher output of matte approximately by 406 kg/h and slag by 1299 kg/h. With the average content of copper in matte 51.7%, this measure provides a possibility to increase the quantity of copper received by the value up to 210 kg/h.

The results of testing carried out at Converter No.2 of SUMZ with the use of acoustic field energy from two acoustic generators with the pressure of 3 atm installed in the dust chamber and two acoustic generators at the inlet of the cyclones have shown that the total extent of gas dedusting increased by 56-72% during the first period of melt converting. During the second period the extent of dust precipitation with the use of acoustic generators increased by 22% on average.

The use of acoustic generators for dust precipitation in the dust chamber of the Waelz kiln as well as for cleaning of heat-exchange surfaces of the boiler (PJSC Chelyabinsk

Zink Plant) has shown that, with all other conditions being equal, the quantity of recycled dust increased by 8.74% due to intensification of internal coagulation by 25-30%, the quantity of waelz oxide increased by 2.99% due to lower hydraulic resistance in the dust chamber and boiler and higher velocity of gas flowing.

Installation of the acoustic generator in the upper part of convective heat-exchange surfaces for destruction of the dust layer formed on these surfaces has led to reduction in the flue gas temperature at the economizer outlet by 20°C or 6.97%, increase in the total steam pressure in the separator tank by 19.7%, increase in steam productivity of the recovery boiler by 23.19% due to intensification of heat-exchange processes.

The acoustic field in the layer is created by compressed air with the minimum pressure of 3 atm with the maximum flow rate of 50 m^3/h. Compressed air shall be supplied in metal pipes. Compressed air can be replaced with low-grade steam.

The simple design and method of acoustic field energy application, small capital expenditures for implementation, possibility of application at existing plants without interruption of the main technological process allow us to recommend it for industrial testing at existing equipment. The use of acoustic generators makes it possible to increase dust precipitation inside the plant by 20-25% and achieve a number of additional effects for intensification of heat-and-mass transfer during operation of technological equipment.

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