

Aug. 27, 1968

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3,398,944

METALLURGICAL PROCESSING APPARATUS

Filed Jan. 28, 1966

3 Sheets-Sheet 1

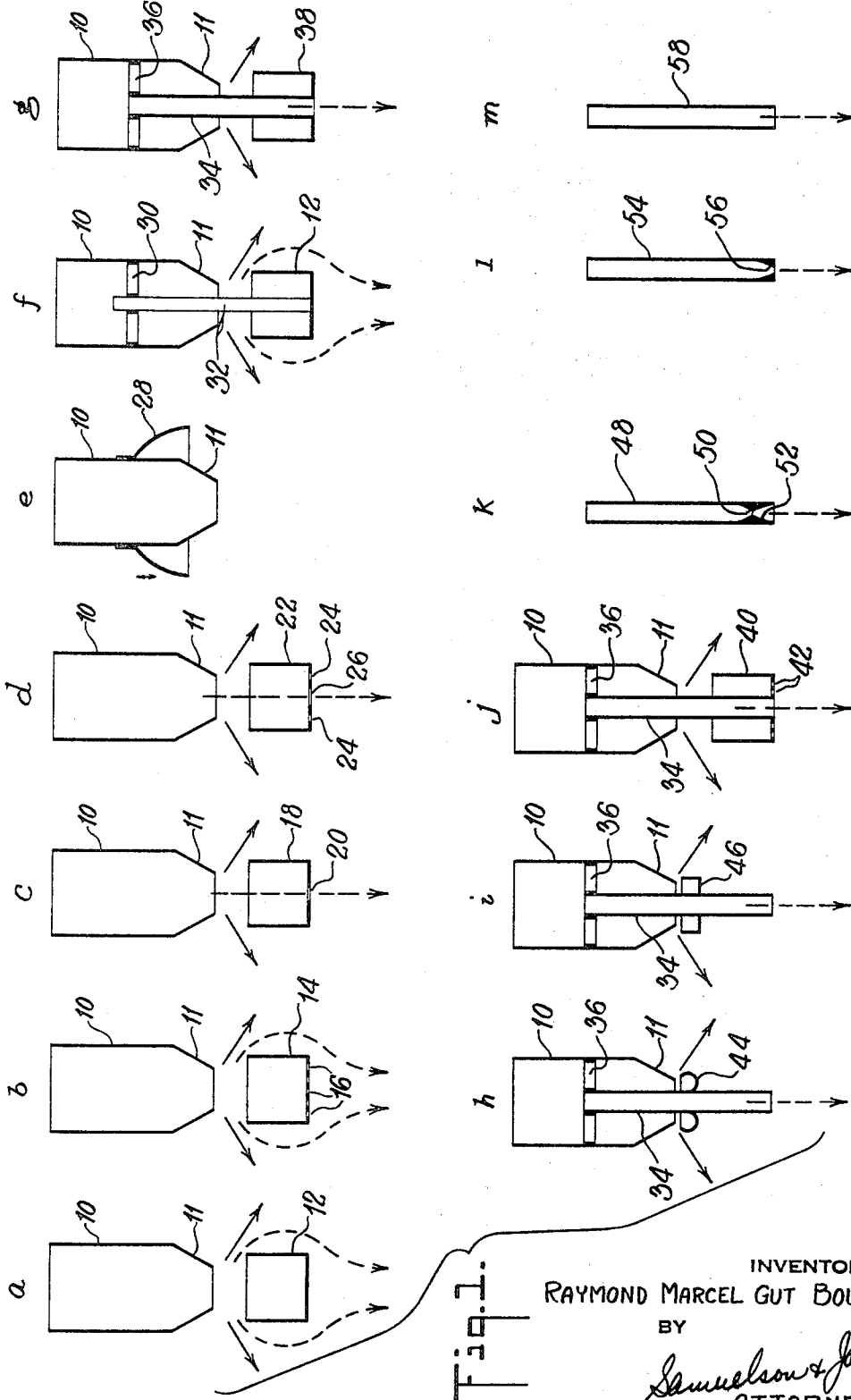


Fig. 1.

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Fig. 2.

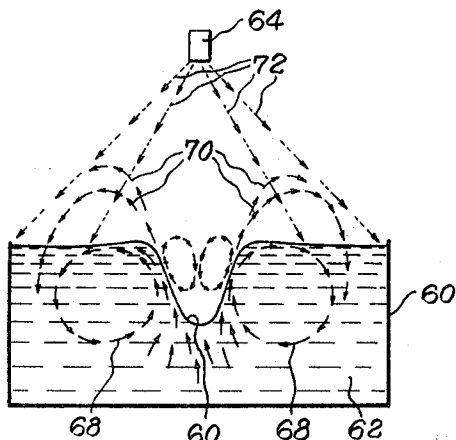
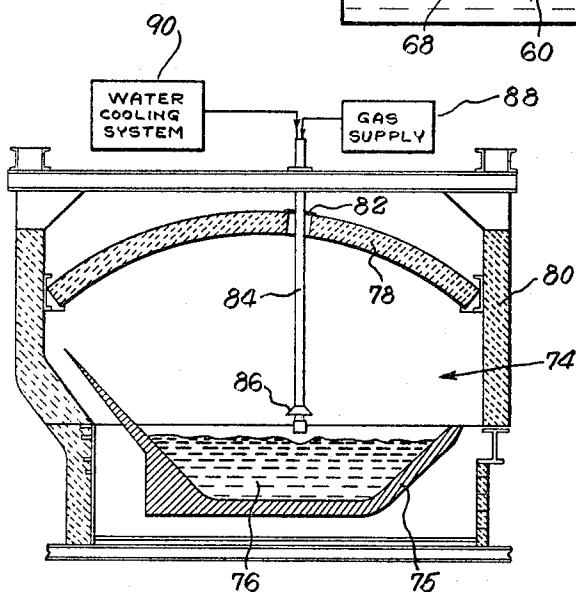


Fig. 3.

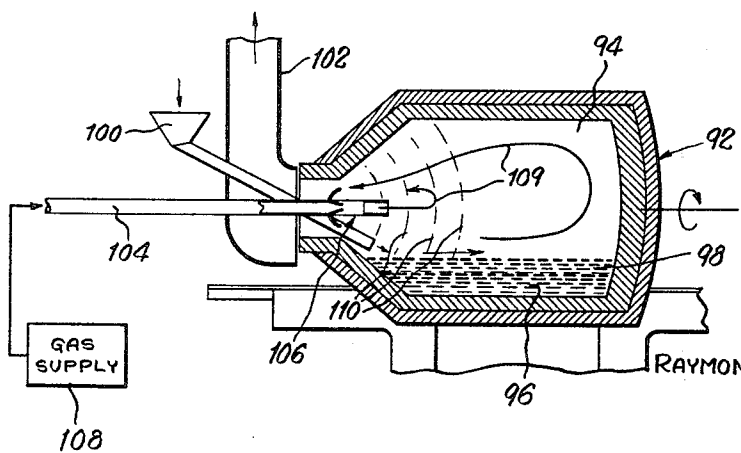


Fig. 4.

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Fig. 5.

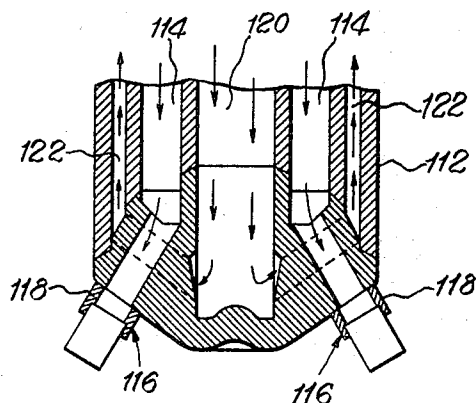


Fig. 7.

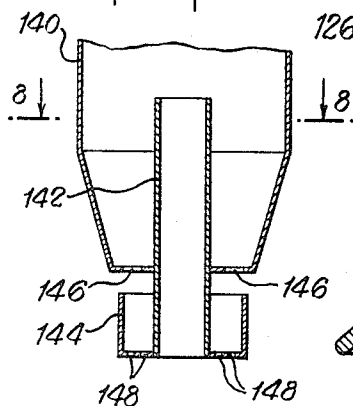
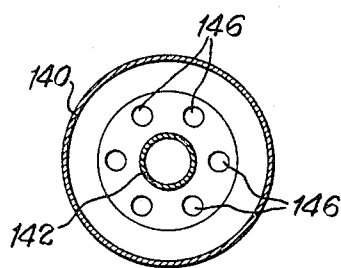


Fig. 6.

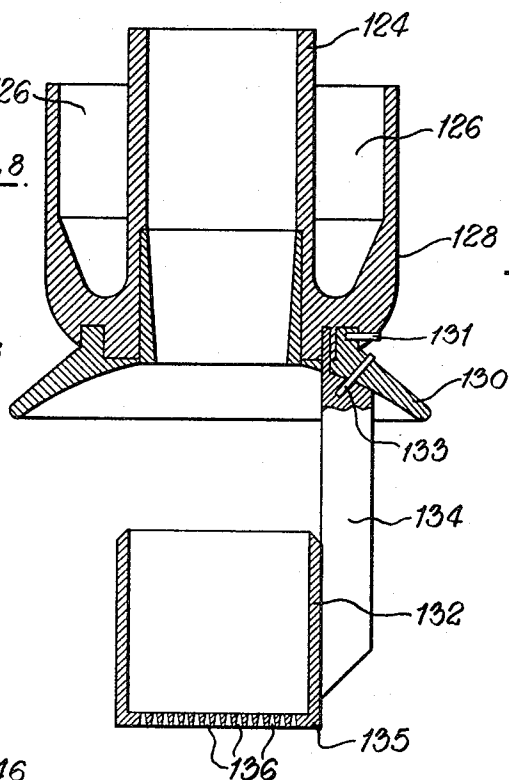


Fig. 8.

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14 Claims. (Cl. 266—34)

ABSTRACT OF THE DISCLOSURE

Metallurgical processing apparatus in which gas is introduced within the heating chamber through a hollow lance so that the gas is emitted at supersonic velocity. Both the gas and the acoustic field are projected onto the molten metal in the heating chamber so that the metallurgical processing is accelerated, the metal quality is improved, and the metal sprays and slag projections are controlled.

The invention relates to apparatus for accelerating oxygen reactions in the production of steel. The teachings of the invention may be used in an open hearth furnace, a Linz-Donawitz (LD) converter, a Stora pig iron rotary furnace, or similar processing chamber. The invention is directed, in particular, toward improving the quality of the finished metal and controlling metal sprays and slag projections by producing a large amount of acoustic energy from a powerful gas flow while also permitting the gas to enter the container. Thus, one obtains more efficient physical and/or chemical combination of the injected gas with the slurry or liquid mass.

It is an important object of the invention to provide means for controlling splashing in various types of metallurgical furnaces or vessels. It is also an object of the invention to use airborne acoustic waves energy for accelerating the reactions between the injected gas or aerosol and the molten ores and metals inside the furnace or converter. It is a further object of the invention to use the acoustic energy in the gas phase for better control and destruction of the foam at the surface of the liquid.

A still further object of the invention is to improve heat and mass transfer at the gas-liquid interface. It is a still further object of the invention to provide means for acoustic agglomeration of large amounts of fumes and particles in the processing furnace or oxygen converter. It is a still further object of the invention to provide large amounts of acoustic energy in a high temperature area while allowing gas jet penetration with a high momentum into the liquid mass.

It is a still further object of the invention to provide apparatus capable of supplying a powerful acoustic field having a sound level of the order of several kilowatts which will control metal sprays and slag projections inside the chambers used in steel manufacture. Such apparatus produces faster oxygen penetration in the molten mass and accelerates all chemical exchanges between the injected gas and/or other material (lime particles, for example) and the metal in fusion. Because of the strong acoustic turbulence above the liquid mass, use of the apparatus of the invention in steel processing results in better foam control, oxide fume and particle coagulation, improved heat utilization and better steel decarburization.

These and other objects, features, advantages and uses will be apparent in the course of the following description when taken in conjunction with the accompanying drawings.

It is to be understood that apparatus of my invention is not limited to applications in the metallurgical field even though it possesses immediate and important utilization in oxygen, lancing, both in open hearth furnaces and LD converters as will appear from the following.

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One of the serious disadvantages in using oxygen in an open hearth furnace to increase the production rate is excessive roof wear and hence high roof costs. There has been evidence to show that excessive roof wear is caused mainly by metal and slag particles rising from the bath and splashing onto the roof. In a series of experiments carried out in an oxygen-blown (OH) furnace it was found that the iron oxide deposit on the roof was several times greater directly above the lance during oxygen blowing than the deposits found in normal practice, even at positions of maximum wear, and that the ratio of the deposits above the lance to those in the center of the roof was about 4.5:1.

Other experiments conducted under comparable conditions showed that the rate of roof wear in the areas directly above the lance was several times greater than in the center of the roof and that in all cases, wear rate was much greater than in normal practice without oxygen blowing. With ever-increasing demand for higher output rate at lower cost, it was therefore desirable to find ways and means of prolonging furnace refractory life.

The present invention provides a solution to such a problem while also accelerating chemical and physical reactions between the oxygen and the melt.

The apparatus of the present invention comprises a convergent or Laval type nozzle placed at the end of a pipe or lance through which a high speed gas stream flows. The nozzle is facing a resonant cavity which is a hollow chamber whose shape can vary according to the type of acoustic field one wants to create. The nozzle resonator system can be a classical Hartmann (J. Hartmann, Journ. Scient. Instr., vol. XVI, No. 5, May 1939) whistle which consists essentially of a cone shaped jet nozzle and a coaxial cylindrical oscillator facing it. The compressed gas feeding the nozzle expands at the exit of the convergent throat at a supersonic speed. If the head of the oscillator is located in a region known as the "pile up region" (zone of increasing static pressures) oscillations of relaxation are set up. The cavity periodically fills up with gas at a superpressure which is then expelled. This creates powerful periodical pressure variations, i.e., large amplitude sound waves. From a series of experimental tests the following relationship was found between design parameters and the acoustic field characteristics. If one calls A the nozzle diameter, B the resonator mouth, b the resonator depth, and C the resonator nozzle distance, the wave length of the emission is given by:

$$\lambda_0 = 5.8B$$

where B and λ_0 are in mm. Therefore the main frequency of the emission in cycles per second is given by:

$$f = \frac{c}{5.8B}$$

where c is the speed of sound in the gaseous medium (in mm./sec.). The total power radiated by the nozzle resonator system is given by the following empirical formula:

$$W = A^2 988 \sqrt{p - 0.93}$$

Where W is given in watts, A is in cm. and p is the upstream reservoir pressure calculated in atmospheres.

The above formulas are valid when the resonator nozzle diameter ratio ($K=B/A$) is between 1.3 and 1.7. It is to be understood that the above computations are valid only if there is no obstacle placed on the nozzle resonator axis, and when no large hole is present in the resonator bottom. At low reservoir pressures slightly higher acoustic output is observed with a stem on the nozzle resonator axis. An adjustable reflector is fastened to the nozzle in order to focus most of the acoustic energy downstream within a 150° solid cone angle. This configuration enables one to direct the acoustic energy in the melt direction in

such a manner that the iron spray, slag particles and projections are coagulated and pushed back into the melt as is shown later in this specification. The invention thus allows for the creation of a highly directive and powerful sound field to enable the gas stream to impinge on the liquid mass with high kinetic energy.

Theoretical studies and practical experience have shown that the main barrier to oxygen transfer in steel making is in the metal and that optimum efficiencies can only be achieved by either stirring or injecting gas deeply and uniformly through the melt. The apparatus of the invention enables one to achieve such a powerful stirring through deep penetration of the main gas jet which creates a strong convection current inside the melt. Moreover, the high intensity acoustic field not only reduces foam and slag accumulation above the liquid but also produces a strong surface cavitation which promotes internal stirring and accelerates the removal of carbon, phosphorus and nitrogen. With a view to illustrating the magnitude of the gas molecules agitation at the liquid interface, I have found that an acoustic field of 160 db at 1,000 cps. will correspond to the following maximum amplitudes: particle velocity will reach 6.82×10^2 cm./sec., displacement amplitude will reach 0.10 cm. The maximum intensity will be 1.10^7 ergs/sec./cm.² and the energy density will be close to 3.10^2 ergs/cm.³.

In the accompanying drawings, forming a part of this application, and in which like numerals are employed to designate like parts throughout the same,

FIGURES 1a through 1m are schematic views of various embodiments of types of oxygen lances using the teachings of the invention,

FIGURE 2 is a diagrammatic view showing the effect of the gas jet on the molten metal and the iron spray projection and the effect of the acoustic field pattern thereon.

FIGURE 3 is an elevational sectional view showing the introduction of the oxygen jetting lance of the invention into an open hearth furnace through the roof cooling block,

FIGURE 4 is an elevational, sectional view of a Stora process, rotary furnace showing the position of the oxygen jetting lance therein,

FIGURE 5 is an elevational, sectional view of a multiple jet oxygen lance of the invention, showing a plurality of resonators and a fluid cooling system,

FIGURE 6 is an elevational, sectional view of a further embodiment of lance tip of the invention,

FIGURE 7 is an elevational, sectional view of a still further embodiment of lance tip of the invention, and

FIGURE 8 is a sectional view taken on the lines 8—8 of FIGURE 7, viewed in the direction of the arrows.

In the drawings, wherein, for the purpose of illustration, are shown various embodiments of the apparatus of the invention, the numeral 10 designates a hollow lance tip of the invention. Nozzle 11 is affixed to lance tip 10 or lance tip 10 is tapered to have the effect of a nozzle. Associated with nozzle 11 (FIGURE 1a) is acoustic resonator 12 to form the classical nozzle-resonator configuration. The dotted arrows indicate the flow path of the main jet of gas and the solid arrows show the direction of the main intensity components of the acoustic field.

Nozzle 11 is placed at the end of a pipe or lance through which oxygen or any other suitable gas flows. Resonator 12 is mounted so as to face nozzle 11. The compressed gas flows through the nozzle 11 at an average velocity which is at least half the velocity of sound and can be greater than the velocity of sound in the gaseous medium. The aerodynamic wave structure at the exit of the nozzle determines the position of the resonator 12. It is located at such a distance from nozzle 11 that strong oscillations of relaxation are created when operating the lance at an upstream gas pressure greater than 30 p.s.i.g. The oscillations of relaxation in turn produce large amplitude sonic and ultrasonic waves in the gas phase surrounding the whistle.

Acoustic resonator 14 is associated with nozzle 11 (FIGURE 1b) and is provided with a plurality of openings 16 in its bottom. These holes 16 should preferably be uniformly spaced all over the bottom of the acoustic resonator and the ratio of the sum total of the open areas to the area of the bottom should be between 1/25 and 1/10. If a higher ratio is used, it is not possible to avoid great interference with the sound output and adequate cooling protection from the radiant heat. If a central opening is used in the bottom of acoustic resonator 14, it should be less than 3/10 the internal diameter of the acoustic resonator's chamber. This is necessary for otherwise there will be a sharp drop in the acoustic output of the whistle. Here again, the dotted arrows indicate the flow path of the main jet of gas and the solid arrows designate the direction of the main intensity of the acoustic field.

In FIGURE 1c, the bottom of resonator 18 is provided with a central opening 20 which permits the main jet of gas to be directed through it and to allow direct impingement of the bulk of the kinetic energy of the gas stream on the molten metal. The embodiments illustrated in FIGURES 1b and 1c provide better utilization of the kinetic energy of the main gas flow than does the closed bottom resonator 12 of FIGURE 1a. The central opening 20 allows the main gas jet to penetrate further into the molten metal because the main gas jet will not lose the bulk of its kinetic energy due to its first impinging on a solid resonator bottom. Furthermore, the gas stream flowing through the open bottom provides an efficient protective screen against the heat radiated from the hot molten metal interface.

In FIGURE 1d there is illustrated an embodiment of the invention combining certain structural features of the embodiments of FIGURES 1b and 1c. The bottom of acoustic resonator 22 is provided with a plurality of small openings 24 and a larger axial opening 26. This construction results in a better cooling effect than is possible with the embodiments of FIGURES 1b and 1c.

In FIGURE 1e there is shown a nozzle 11 and an adjustable reflector 28 mounted on the lance tip upstream from the nozzle mouth. The reflector 28 may be fixed in position or adjustable in the direction of the double-headed arrow in the figure. It serves to focus the acoustic emission in a downwardly-directed solid angle of about 150° in such a manner that the bulk of the acoustic energy is directed toward the bottom of the chamber containing the molten metal. Reflector 28 may be used with any of the resonator-nozzle embodiments described heretofore or to be described hereafter.

The resonator dimensions, especially the external diameter, are made of such values that a large proportion of the main gas jet will continue to flow in an axial downward direction without being affected by the high intensity acoustic field.

Resonator 12 of FIGURE 1f is affixed to the lance tip 10 by means of solid stem 32 which is held to the inside of the lance by means of supports 30. Stem 32 may be of metal, ceramic or refractory material which is not affected by the heat and is on the axis of the nozzle-resonator system. The diameter of stem 32 should not exceed 1/2 of the diameter of the aperture of nozzle 11. I have found that good results are obtained when the stem diameter is 1/4 of the diameter of the aperture of the nozzle.

Hollow stem 34 is supported in lance tip 10 by means of supports 36 (FIGURE 1g). Circular crown shape cavity 38 is affixed to hollow stem 34 and acts as an acoustic resonator. The main gas jet is directed toward the molten metal through the stem while the balance of the gas stream excites the acoustic resonator 38 to produce the acoustic field.

The embodiment of FIGURE 1j is similar to that of FIGURE 1g except that the bottom of cavity 40 has a plurality of small perforations 42 which improve the

protection of the unit from heat radiated by the molten metal.

Toroidal shaped, resonator cavity 44 is affixed to hollow stem 34 (FIGURE 1h) and functions in the same manner as the resonators described earlier. Cylindrically shaped, resonator cavity 46 (FIGURE 1i) is similar in function and construction to the resonator cavity 44.

Resonators 44 and 46 are preferred shapes of resonant cavities but they may also be ellipsoidal or of any other suitable form. They are acoustically excited by the air flow which escapes from the circular lip around the hollow stem. It is to be noted that the hollow stem extends beyond the resonator cavities in these embodiments and may extend from one to two feet below the bottom of the resonator cavity. This results in better conservation of the kinetic energy of the main gas stream with a consequently more efficient penetration of the molten metal mass. It also enables one to operate the acoustic resonant cavity at a greater distance from the liquid-metal interface with a resulting lower resonant cavity temperature.

It should be noted that the adjustable reflector 28 of FIGURE 1e may be used with any of the nozzle-resonator whistles described herein.

FIGURES 1k, 1l and 1m are illustrative of three distinct types of hollow stem tips which may be used in conjunction with the embodiments of FIGURES 1g, 1h, 1i and 1j. Tip 48 (FIGURE 1k) is of the convergent-divergent type and has convergent conical surface 50 and divergent conical surface 52. The convergent total angle is of the order of between 20° and 35° and the divergent total angle is between 6° and 10°. Hollow stem 54 is provided with a tip having convergent conical surface 56. The divergent total angle is of the order of 6° to 10°. Hollow stem 58 is a straight pipe.

FIGURE 2 is a diagrammatic representation illustrating the action of the metallurgical processing apparatus of the invention. Molten metal 62 is contained in chamber 60 and a gas jet and an acoustic field are directed toward the melt 62 from lance 64. The main gas jet forms a cavity 66 in the melt 62 thereby setting up convection currents 68 and metal sprays 70. The acoustic field 72 is seen forcing the sprays 70 back into the melt 62 in chamber 60.

Open hearth furnace 74 (FIGURE 3) comprises chamber 75 in which molten metal 76 is contained and roof 78 which is supported above the chamber 75 on wall 80. Roof 78 is formed of bonded silica or other refractory material and is provided with block 82 in the shape of a doughnut through which oxygen lance 84 is let down into the chamber. Oxygen lance 84 is provided with a suitable acoustic nozzle-resonator with reflector constructed in any one of the many modes which have been described heretofore.

Oxygen is fed to the lance in a manner well-known in the art from gas supply 88 (details not shown) and the lance tip is water cooled in a manner well-known in the art by water cooling system 90.

Rotary furnace 92 is used in the Stora process for producing high quality pig iron (FIGURE 4). Chamber 94 rotates in the direction indicated by the arrow. Bottom layer 96 is of pig iron and the reaction between the ore and coal, which enter the furnace through hopper 100, and the oxygen, which is injected through lance 104, takes place in reaction layer 98.

Lance 104 is provided with an acoustic nozzle-resonator 106 of the invention and receives its oxygen from gas supply 108 (details not shown). The acoustic waves which act within the furnace are shown diagrammatically at 110 and the combustion gases which leave the furnace through chimney 102 are depicted by arrows 109.

The acoustic lance creates powerful standing waves inside the kiln thereby increasing the CO through improved heat and mass transfer. These Stora furnaces produce pig iron directly from iron ore and can be run continuously or stopped and started with ease.

Lance tip 112 (FIGURE 5) is a multi-jet unit. It is seen to comprise two oxygen channels 114 at the end of each of which there is mounted a nozzle-resonator whistle. The resonators are mounted to the body of the lance by means of metal legs 118. Liquid coolant, such as water, enters through channel 120 and leaves through channels 122. It is within the contemplation of the invention to use lances having more than two jets and to use lances of the invention in any position with respect to the molten metal interface (parallel, normal or slanted).

FIGURE 6 is an illustration of still another embodiment of the invention which was used in an LD oxygen converter. Hollow tube 124 of copper is surrounded by water cooling channels 126 which are between tube 124 and outer copper jacket 128. Reflector 130 is preferably formed of copper and is mounted to jacket 128 by means of pins 131. Legs 134, of which there are preferably three, are mounted to reflector 130 by means of pins 133. Resonator 132 is preferably of chrome steel and is affixed to legs 134, preferably by brazing. Openings 136 in bottom 135 of resonator 132 are, in general, of divergent shape since I have found that such geometry minimizes the pressure drop while allowing the best insulation from the heat radiated by the melt.

The lance tip 140 of FIGURES 7 and 8 is provided with hollow stem 142 to which resonator 144 is affixed as shown. The main jet of gas exits from the nozzle through hollow stem 140. Gas, which is ejected through openings 146, impinges on the resonator 144 to thereby aid in establishing the acoustic field. Openings 148 in the bottom of resonator 144 serve the same purpose as holes 16 in acoustic resonator 14 (FIGURE 1b).

While the invention has been disclosed in relation to specific examples and embodiments, I do not wish to be limited thereto, for obvious modifications, changes, alterations and adjustments will occur to those skilled in the art without departing from the spirit and scope of the invention.

Having thus described the invention, I claim:

1. Metallurgical processing apparatus, at least a portion of which is within the heating chamber containing the molten metal comprising:

a hollow lance having an opening in the tip thereof within the heating chamber; and

means for moving gas at supersonic velocity through the tip of the hollow lance within the heating chamber to thereby produce an acoustic field of high energy within the heating chamber and project both the gas and the acoustic field onto the molten metal in the heating chamber so that the metallurgical processing is accelerated, the metal quality is improved, and the metal sprays and slag projections are controlled.

2. The metallurgical processing apparatus of claim 1 including an acoustic resonator mounted at the tip of the hollow lance within the heating chamber.

3. The metallurgical processing apparatus of claim 1 wherein the tip of the hollow lance within the heating chamber has a plurality of openings therein through each of which gas enters the heating chamber.

4. The metallurgical processing apparatus of claim 3 including an acoustic resonator mounted at each of the plurality of openings in the tip of the hollow lance.

5. The metallurgical processing apparatus of claim 4 wherein the end of at least one of the acoustic resonators has a plurality of holes therein.

6. The metallurgical processing apparatus of claim 2 wherein the end of the acoustic resonator has a plurality of holes therein.

7. The metallurgical processing apparatus of claim 1 wherein a hollow stem is mounted at the tip of the lance through which the gas is ejected and including an acoustic resonator mounted on the end of the hollow stem.

8. The metallurgical processing apparatus of claim 7 wherein the acoustic resonator is torodial in shape.

9. The metallurgical processing apparatus of claim 7 wherein the acoustic resonator is cylindrically shaped.

10. The metallurgical processing apparatus of claim 7 wherein the acoustic resonator is cylindrically shaped and is mounted at the end of the hollow stem.

11. The metallurgical processing apparatus of claim 10 wherein the acoustic resonator has a plurality of openings in the bottom thereof.

12. The metallurgical processing apparatus of claim 11 wherein the tip of the lance has a plurality of smaller openings surrounding the hollow stem through which gas is ejected to impinge on the acoustic resonator.

13. The metallurgical processing apparatus of claim 10 wherein the tip of the lance has a plurality of smaller openings surrounding the hollow stem through which gas is ejected to impinge on the acoustic resonator.

14. The metallurgical processing apparatus of claim 1 wherein a solid stem is mounted at the tip of the lance and an acoustic resonator is mounted at the end of the solid stem.

References Cited

UNITED STATES PATENTS

2,657,021	10/1953	Cottell et al.	259—1
3,082,997	3/1963	Kurzinski	266—34.1
3,094,972	6/1963	Leavenworth	116—137 X
3,337,135	8/1967	Blakely et al.	239—4 X

FOREIGN PATENTS

713,446	7/1965	Canada.
190,303	7/1964	Sweden.

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