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Tanoue et al.

[11] **3,917,240**

[45] **Nov. 4, 1975**

[54] **APPARATUS FOR PROJECTING PIECES OF A DEOXIDIZING AGENT INTO MOLTEN STEEL**

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[22] Filed: **Oct. 17, 1973**

[21] Appl. No.: **407,043**

Related U.S. Application Data

[62] Division of Ser. No. 168,072, Aug. 2, 1971, Pat. No. 3,837,842.

[52] **U.S. Cl.** ..... **266/34 T**; 75/58; 164/57

[51] **Int. Cl.** **C21c 7/00**; B22d 27/00

[58] **Field of Search** ..... 75/58, 12, 61, 46; 164/57; 266/38, 39, 42; 266/34 T

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Primary Examiner—Peter D. Rosenberg

Attorney, Agent, or Firm—Watson, Cole, Grindle & Watson

[57] **ABSTRACT**

An apparatus for projecting pieces of a deoxidizing agent into a molten steel wherein the pieces are thrust into a body of molten steel to a depth such that the pieces will become completely dissolved as they float upwardly through the molten steel. Thus, loss of deoxidizing agent is substantially eliminated and a homogenous steel product is obtained.

4 Claims, 7 Drawing Figures

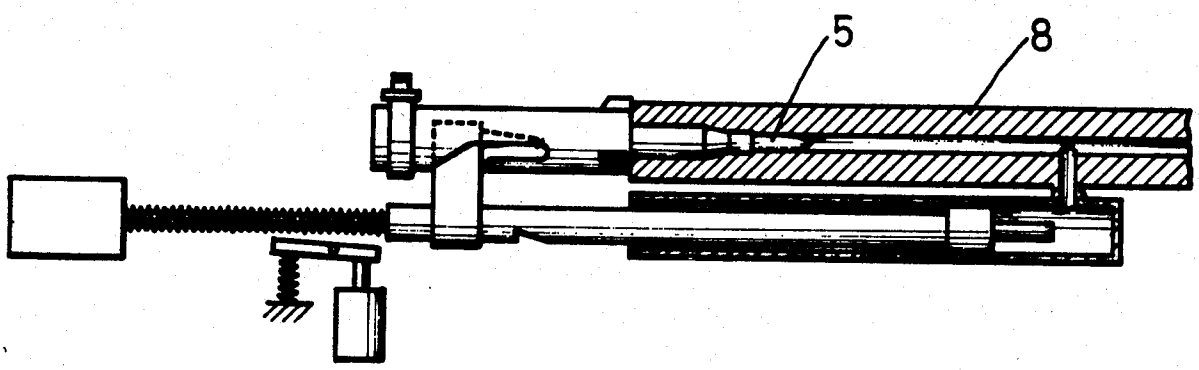


FIG. 1

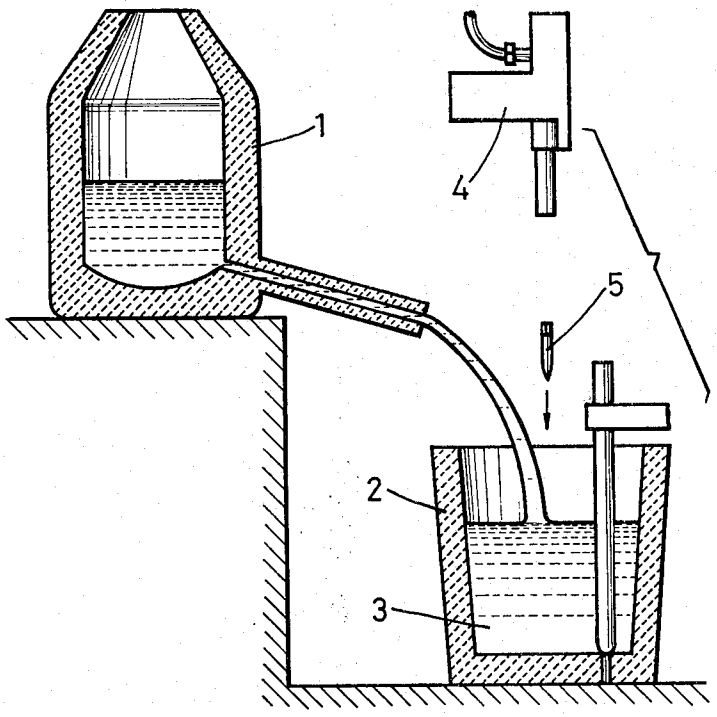


FIG. 2

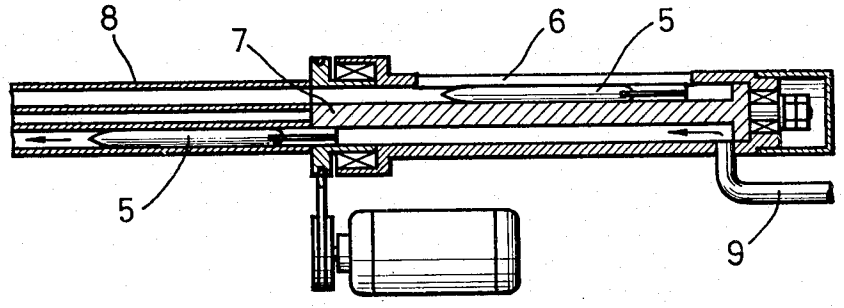


FIG. 3

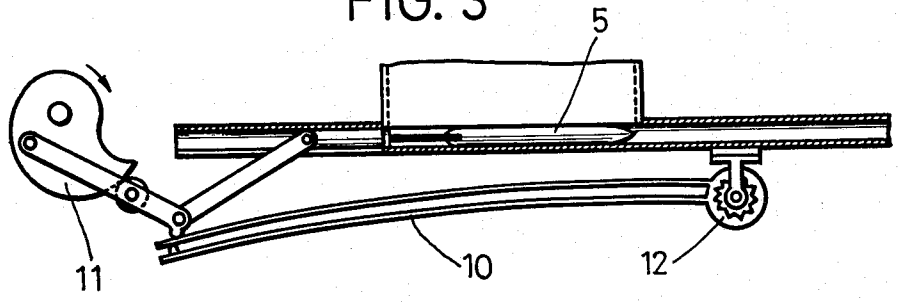


FIG. 4

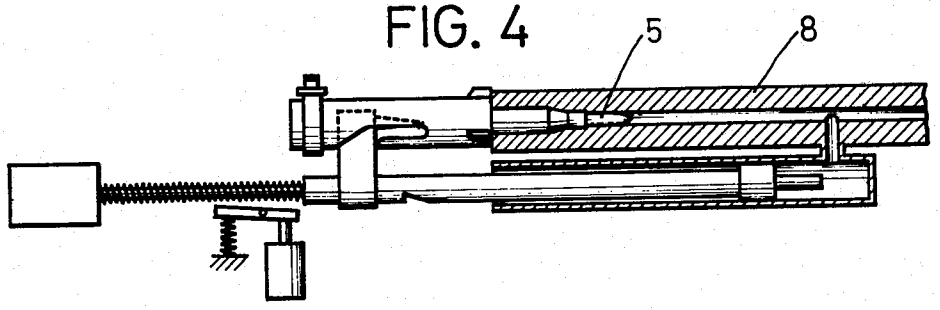


FIG. 5

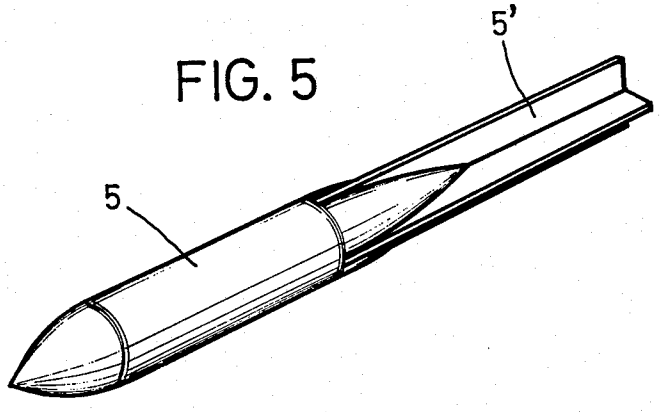


FIG. 6

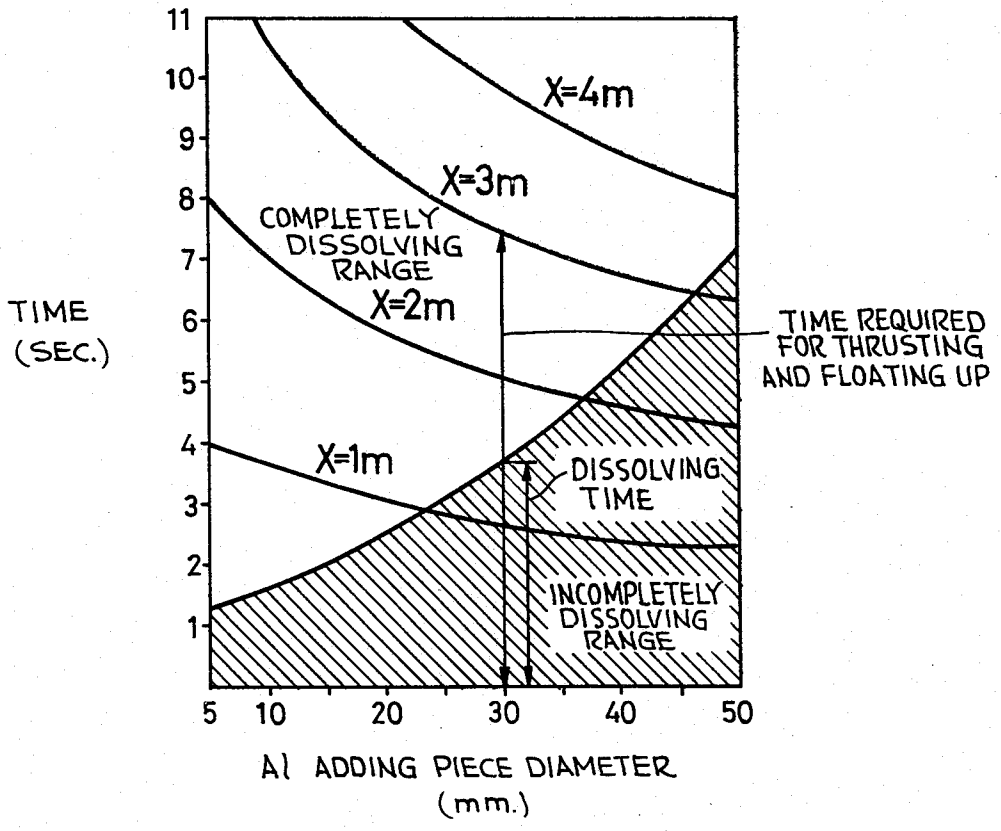

11
10
9
8
7
6
5
4
3
2
1
TIME
(SEC.)
X=4m
X=3m
COMPLETELY
DISSOLVING
RANGE
X=2m
X=1m
TIME REQUIRED
FOR THRUSTING
AND FLOATING UP
DISSOLVING
TIME
INCOMPLETELY
DISSOLVING
RANGE
5
10
20
30
40
50
Al ADDING PIECE DIAMETER
(mm.)

FIG. 7

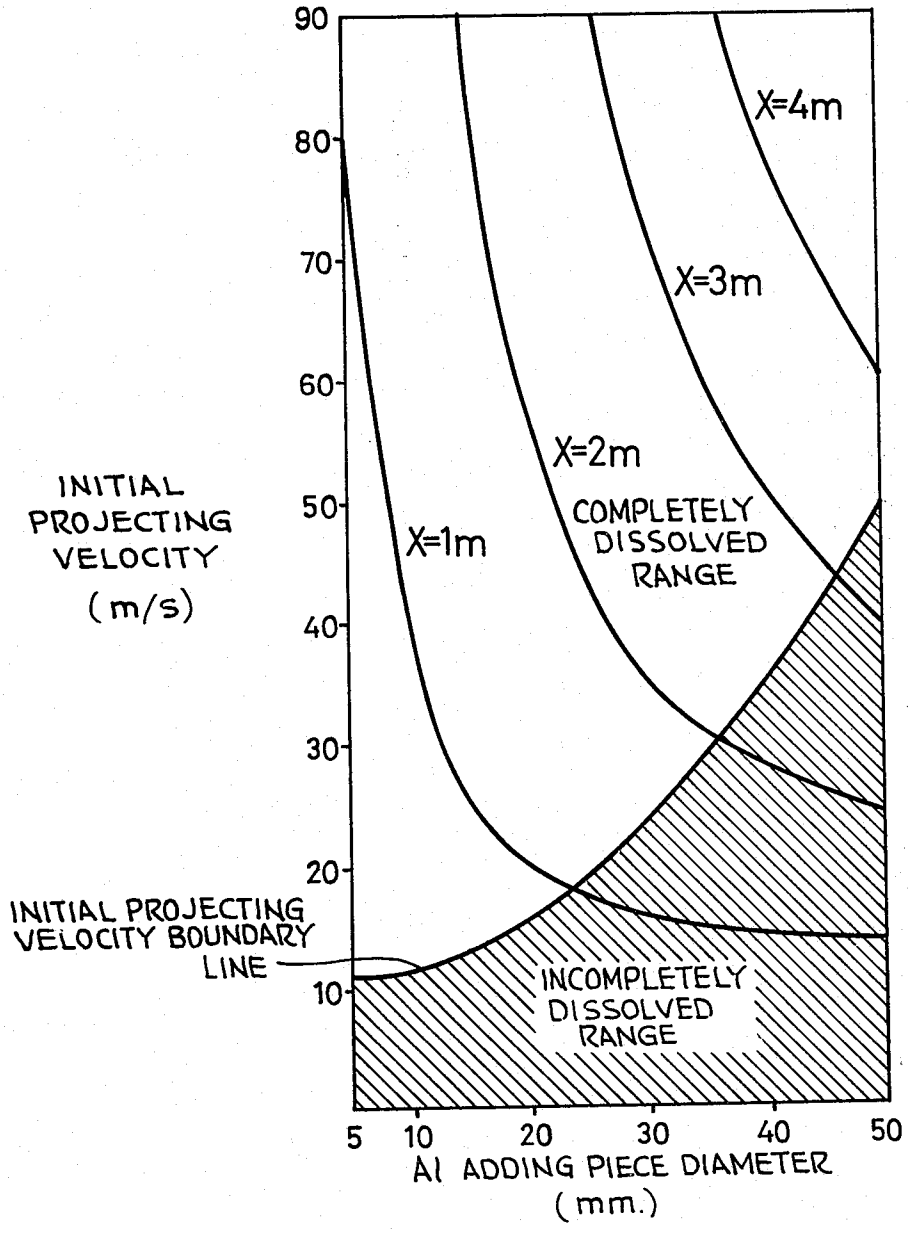

90
80
70
60
50
40
30
20
10
X=4m
X=3m
X=2m
X=1m
COMPLETELY DISSOLVED RANGE
INCOMPLETELY DISSOLVED RANGE
INITIAL PROJECTING VELOCITY (m/s)
INITIAL PROJECTING VELOCITY BOUNDARY LINE
5
10
20
30
40
50
Al ADDING PIECE DIAMETER (mm.)

FIG. 8

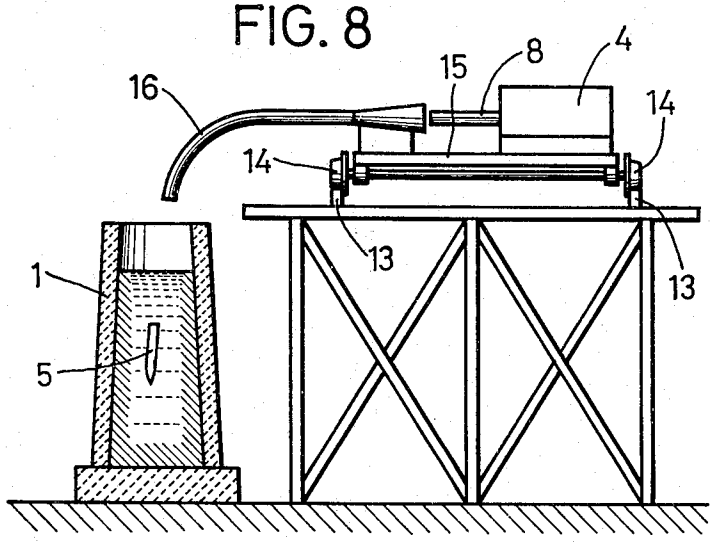
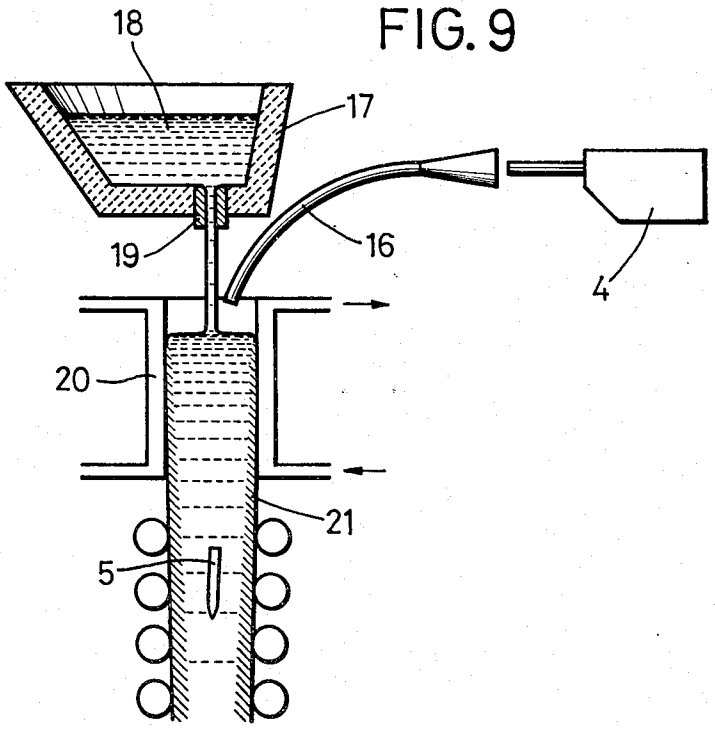


FIG. 9



APPARATUS FOR PROJECTING PIECES OF A DEOXIDIZING AGENT INTO MOLTEN STEEL

This application is a division of Ser. No. 168,072, filed Aug. 2, 1971, now U.S. Pat. No. 3,837,842.

This invention relates to an apparatus for projecting pieces of a deoxidizing agent into molten steel.

Generally, molten steel has been completely smelted in a conventional steel making furnace, such as a converter, an open-hearth furnace or an electric furnace, should be deoxidized prior to being tapped into a ladle for the purpose of producing rimmed, semi-killed or killed ingots in a subsequent ingot making step. Such deoxidation is for the purpose of reducing the amount of oxygen in the molten steel to a predetermined, fixed amount and is carried out by adding an appropriate amount of a deoxidizing agent such as manganese, vanadium, silicon, boron, aluminum, titanium, calcium or magnesium. The foregoing elements may be used alone or in combination. Moreover, these same elements may be added for the purpose of forming an alloy with the steel to thereby alter the physical and mechanical properties of the latter.

Deoxidizing elements of the type identified above generally have a specific gravity which is less than that of molten steel. Accordingly, when such elements are added, by conventional methods, to molten steel being tapped into a ladle, the same will float on the surface of the molten steel during dissolution. Deoxidizing elements naturally have a strong affinity for oxygen and therefore, before the same can be dissolved and diffused into the molten steel, they will be oxidized by atmospheric air introduced into the ladle along with the molten steel to form a slag layer coating on the surface of the molten steel. This, of course, results in a loss of deoxidation efficiency and as a consequence, the homogeneity and the quality of the steel in the ingot produced will be diminished. Prior art methods for dealing with this problem of floatation of the deoxidizing agent include (1) alloying the deoxidizing element with another metal element having a greater specific gravity and (2) placing the deoxidizing element into a container which is subsequently dipped into the ladle. Neither of these methods has completely eliminated the problems involved in the addition of deoxidizing elements to molten steel.

An object of the present invention is to eliminate the problems discussed above by providing an apparatus for projecting pieces of a deoxidizing agent into molten steel wherein contact between the deoxidizing agent and atmospheric air is substantially eliminated as is the resultant production of slag. Accordingly, the amount of deoxidizing agent remaining for use as an alloy agent is stabilized and the efficiency of the process as well as the quality of the steel will also be increased and stabilized.

In accordance with the present invention an apparatus is provided for introducing into molten steel, a deoxidizing agent which has a lower specific gravity than said molten steel. The apparatus is adapted for projecting elongated, generally cylindrical pieces of deoxidizing agent axially toward the upper surface of a quantity of molten steel along a path of travel substantially perpendicular to such upper surface. The projecting step is

conducted such that the projected pieces are provided with an initial velocity defined by the mathematical relationship

$$u_o = K \sqrt{\frac{2(\rho f - \rho s).V.g}{\rho f \,.\, C_D \,.S}} \tan \,.\, \cos^{-1} \exp\left(-1/2 \,.\, \frac{\rho f}{\rho s} \,.\, \frac{S}{V} C_D \,.\, X\right)$$

wherein u_o is the initial projection velocity of the piece in cm/sec, K is an empirically determined velocity loss coefficient representative of the velocity losses occasioned by air resistance and surface impact, pf and ps are respectively the densities in g/cm^3 of the molten steel and the pieces of deoxidizing agent, S and V are respectively the cross-sectional area in cm^2 and the volume in cm^3 of each of said pieces, C_D is the empirically determined thrusting resistance coefficient of the adding piece into the molten steel, g is the acceleration gravity in cm/sec^2 and X is the depth in cm to which the pieces are to be thrust into the molten steel. Thus, pieces thrust into the molten steel will become completely dissolved while the same float upwardly within the molten steel.

In a more specific aspect of the invention, the projecting of the pieces is accomplished by pushing the latter with an expanding initially compressed fluid. In another aspect of the invention the projecting is accomplished by pushing the pieces with an initially compressed spring. In yet another aspect of the invention the projecting is accomplished by pushing the pieces with expanding gases generated by the explosion of an explosive material. In the Drawings:

FIG. 1 is an elevational, cross-sectional schematic view of an apparatus useful for practicing the method of the present invention;

FIG. 2 is an elevational, cross-sectional view of an apparatus for projecting pieces of a deoxidizing agent utilizing the fluid pressure;

FIG. 3 is an elevational, cross-sectional view of a projecting apparatus which utilizes spring pressure to provide the projecting force;

FIG. 4 is an elevational, cross-sectional view of a projecting apparatus wherein ammunition powder is exploded to provide the projecting force;

FIG. 5 is a perspective view of a piece of deoxidizing and alloying agent which may be projected into molten steel in accordance with the present invention;

FIGS. 6 and 7 are charts which relate the dimensions of a piece of an aluminum deoxidizing and alloying agent with the depth to which the same must be projected to provide an adequate dissolution time;

FIG. 8 is an elevational, cross-sectional view of a continuous casting apparatus provided with a projecting apparatus for pieces of deoxidizing agent; and

FIG. 9 is an elevational, cross-sectional view illustrating the projection of a piece of deoxidizing agent into a rimmed molten steel.

FIG. 1 illustrates the method of operation of the apparatus of the present invention wherein a fluid pressure actuated continuous projecting apparatus is utilized. As can be seen in FIG. 1, pieces 5 of a deoxidizing and alloying agent are continuously projected perpendicularly downwardly by a projecting apparatus 4 toward the surface of a body of molten steel 3 contained in a ladle 2. Pieces 5, which are configured in the shape of spinning spindles, are thrust into molten steel 3 in a manner such that they will reach the bottom surface of ladle 2 without colliding with the latter and will then float upwardly during dissolution. In accordance

with the method of the present invention, pieces 5 of deoxidizing and alloying agent will be completely dissolved as they float upwardly within the molten steel. Accordingly, the agent will be diffused into the molten steel and losses occasioned by the reaction of the agent with air or slag will be reduced.

In FIG. 2, pieces 5 of a deoxidizing and alloying agent are charged from a magazine into a rotary cylinder 7 through a charging port 6. As rotary cylinder 7 rotates, pieces 5 will rotate therewith toward a projecting tube 8. Simultaneously with the rotation, compressed gas will be jetted into the rear of cylinder 7 behind the pieces 5 through a compressed gas jetting port 9 so that each piece 5 may be projected from projecting tube 8. Thus, a continuous stream of pieces 5 will be projected from tube 8. The velocity of the projected pieces may be altered by adjusting the pressure of the compressed gas.

FIG. 3 illustrates another apparatus for continuously projecting pieces of deoxidizing agent into molten steel. In this instance, the motive force for projecting pieces 5 is provided by the resiliency of a spring 10. Viewing FIG. 3, it can be seen that as cam 11 rotates in a clockwise direction, pieces 5 will be continuously projected from the apparatus. A device 12 is provided for adjusting the resiliency of spring 10 so that the velocity of the pieces 5 may be varied.

FIG. 4 illustrates yet another apparatus for projecting pieces 5 of deoxidizing agent. In this embodiment, an exploding powder provides the projecting energy. Thus, pieces 5 are continuously projected utilizing a fuse in accordance with the principles of an automatic gun. The velocity of each piece 5 is determined by the amount of powder contained in the respective cartridge.

FIG. 5 illustrates one example of the shape of a piece of deoxidizing and alloying agent to be utilized in accordance with the present invention. This streamlined spindle shape provides the preferred results in minimizing velocity losses occasioned by surface impact resistance when the pieces thrust into the surface of a body of molten steel and by friction as the pieces thrust with the bottom surface of the ladle. Another feature is that the pieces of deoxidizing and alloying agent have such form and size that the same are completely dissolved and diffused into the molten steel while they thrust and float upwardly within the body of molten steel.

A procedure for determining the form, dimensions and projecting conditions for an adding piece constructed of an aluminum deoxidizing and alloying agent is explained in detail hereinbelow. The motion of a projecting added piece, while the same thrusts downwardly through a body of molten steel until it stops, is described by the following mathematical expression:

$$m_s \frac{du}{dt} = -m_s \frac{\rho f - \rho s}{\rho s} g - \tfrac{1}{2} C_D \rho f S u^2 \qquad (1)$$

wherein

m_s is the mass of the adding piece,
ρs is the density of the adding piece,
ρf is the density of the molten steel,
u is the velocity of the adding piece in the molten steel,
g is the acceleration of gravity,
C_D is the resistance coefficient of the adding piece and
S is the cross-sectional area of the adding piece.

If both sides of the above equation are divided by m_s and if $\rho s \cdot V$ (V is the volume of the adding piece) are substituted for m_s, the equation becomes

$$\frac{du}{dt} = \frac{\rho f - \rho s}{\rho s} g - \frac{1}{2} C_D \frac{\rho f}{\rho s} \frac{S}{V} u^2 \qquad (2)$$

If the velocity loss coefficient for losses caused by air resistance and by impact and friction in the molten steel is represented by K, if the depth to which each adding piece is to be thrust is represented by X and if the above equation is solved, it is determined that the initial velocity u_o of the adding piece is:

$$u_0 = K \sqrt{\frac{2(\rho f - \rho s] \cdot V \cdot g}{\rho f \cdot C_D \cdot S}} \tan. \cos^{-1} \exp\left(-1/2 \frac{\rho f}{\rho s V} S C_D \cdot X\right) \qquad (3)$$

It is also determined that the time for the adding piece to thrust and float upwardly within the body of molten steel is represented by the following formula:

$$T_1 = \sqrt{\frac{2 \rho s^2 \cdot V}{\rho f (\rho f - \rho s) \cdot S \cdot g \cdot C_D}} \cdot \cos^{-1} \exp\left(-1/2 \frac{\rho f}{\rho s} \frac{S}{V} C_D X\right) + X \sqrt{\frac{g \cdot \rho f C'_D \cdot S}{2(\rho f - \rho s) \cdot V \cdot g}} \qquad (4)$$

a ladle in a manner such that the pieces do not collide through the molten steel. The ratio of barrel length to diameter of each piece is preferably in a range of 4:1 to 7:1 but may well take any value. Other shapes, such as, for example, columnar or spherical may be utilized. Further, as can be seen in FIG. 5, direction stabilizing plates 5' may be attached to the tail part of each piece 5. Additionally, a metal piece of a material such as iron which has a greater specific gravity than the remainder of the piece, may be provided at the forward end of each piece 5 so that when the piece is thrust into the molten steel, the same is maintained in a vertical posture. Further, each piece 5 may take the form of a hollow shell of aluminum, paper or an organic material which is charged with a deoxidizing and alloying agent.

An important feature of the present invention is that pieces of deoxidizing and alloying agent are projected continuously from a projecting apparatus at a proper initial velocity and thrust into a body of molten steel in

wherein

T_1 is the time for the adding piece to thrust and float upwardly within the molten steel and
C'_D is the floating resistance coefficient of the adding piece in the molten steel

When the velocity loss coefficient K, the thrusting resistance coefficient C_D and the floating resistance coefficient C'_D were measured empirically using a model, it was determined that K = 1.25, C_D = 0.104 and C'_D = 7.0 for an aluminum adding piece having the form of a spindle. FIG. 6 graphically illustrates the relationship between the upward thrusting and floating time of an aluminum adding piece and the diameter and the depth to which the piece is thrust. FIG. 6 also illustrates the relationship between the amount of time necessary for complete dissolution of an aluminum adding piece dipped into molten steel and the diameter of the adding piece. In accordance with the method of the present invention, it is necessary that an adding piece projected

into the molten steel should become completely dissolved before the same is able to float upwardly and reach the surface of the molten steel and the relationship.

$$T_2 < T_1 \quad (5)$$

must be satisfied. That is to say, the projecting conditions must be such that the intersection between the diameter and the depth to which the aluminum adding piece is thrust (X) is above the aluminum dissolution curve in FIG. 6.

FIG. 7 graphically illustrates the relationship between the initial projecting velocity of the aluminum adding piece and the diameter and the depth to which the piece is thrust in accordance with formula (3) and the measured values of K and C_DFurther, the boundary between the completely dissolved range and the incompletely dissolved range in FIG. 7 is determined from the relationship between the boundary of the zone available for complete dissolution of aluminum and the diameter and depth to which the aluminum adding piece is thrust, as is set forth in FIG. 6. This boundary represents the locus of the minimum initial projecting velocity (u_o) necessary for complete dissolution, and mathematically the same takes the form of

$$u_o = 10 - 0.025\,d + 0.016\,d^2$$

wherein d is the diameter of the aluminum adding piece in millimeters. From FIG. 7, adding piece diameters in the range of 5 to 50 millimeters may be related to require molten steel depths in the ladle in the range of 50 to 400 centimeters after the beginning of tapping, whereby to achieve the objects of the present invention.

To exemplify the present invention, a continuous projecting apparatus was disposed 1000 millimeters, vertically above the surface of the molten steel in a ladle having a capacity of 1 ton. The projecting capacity of the apparatus was 60 pieces per minute. Compressed argon or compressed air was used for the projection of the pieces. At a projecting pressure of 0.5 kg/cm^2 (gauge pressure), the initial projection velocity was 20 m/sec and the depth to which the adding pieces were thrust into the molten steel was 1,000 mm. The aluminum adding pieces were in the form of spinning spindles having the following dimensions: parallel part length, 28.75 mm; parallel part diameter, 20 mm; heat part length, 34.5 mm; tail part length, 51.75 mm; stabilizing plate thickness, 0.7 mm; stabilizing plate length, 40 mm; and total length, 155 mm. The weight of each piece was 67 grams.

In this manner, 1139 grams of aluminum (17 aluminum adding pieces) were added, by the method of the present invention, to each ton of a molten steel tapped into the ladle at a temperature of 1,600° to 1,620°C. The composition range of the solid-dissolved aluminum content in the steel after the foregoing addition was 0.02 to 0.05% and the objective composition was 0.03%. Examples of the composition of the steel after the addition of aluminum in accordance with the present invention are shown in the Table I. Examples of the composition of steel wherein aluminum or iron-aluminum pieces are thrown into the ladle during tapping utilizing conventional methods but wherein the objective of solid-dissolved aluminum content was the same, are shown for comparison. As can be seen in Table I, when aluminum is added by the method of the present invention, only about one-half as much aluminum is required for any desired solid-dissolved aluminum content and the desired level of the latter is uniformly obtained.

According to the present invention, as mentioned above, deoxidizing and alloying agent adding pieces are continuously projected from an adding apparatus in a manner such that they reach the bottom part of the body of molten steel and dissolve completely while they float upwardly in the steel. Thus, when adding pieces are added in accordance with the present invention, oxidation efficiency is improved and the content of adding agent in the finished steel is stabilized to a higher degree than has been achieved in the past utilizing conventional adding methods.

Table 1

Adding method	Deoxidizing agent: Kind	Deoxidizing agent: Amount of addition (in g./t.)	Compressed gas used	Sample No.	Time	Steel bath composition (in %): C	Si	Mn	O	Solid dissolved Al
				1	Before Al addition	0.05	Trace	0.34	0.065	—
Adding method of the present invention	Al	1139	Argon		After Al addition	0.06	Trace	0.35	0.005	0.035
				2	Before Al addition	0.05	Trace	0.32	0.070	—
					After Al addition	0.05	Trace	0.32	0.007	0.030
				3	Before Al addition	0.06	Trace	0.37	0.059	—
			Air		After Al addition	0.06	Trace	0.35	0.008	0.032
				4	Before Al addition	0.05	Trace	0.36	0.060	—
					After Al addition	0.05	Trace	0.36	0.005	0.029
Ordinary method of adding during tapping	Al	2000	—	5	Before Al addition	0.05	Trace	0.33	0.068	—
					After Al addition	0.062	Trace	0.31	0.006	0.028
				6	Before Al addition	0.05	Trace	0.38	0.058	—
					After Al addition	0.05	Trace	0.36	0.009	0.051
	Fe-Al (50% Al)	3600 (1800 of Al)	—	7	Before Al addition	0.05	Trace	0.35	0.064	—
					After Al addition	0.06	Trace	0.35	0.007	0.045
				8	Before Al addition	0.05	Trace	0.37	0.069	—
					After Al addition	0.06	Trace	0.36	0.005	0.026

As another example of the process of the invention, molten steel is deoxidized in a casting mold to produce homogenous steel ingots having a rim layer on the surface thereof by projecting the oxidizing agent adding pieces into the molten steel after the same has been subjected to a rimming action.

The surface areas of a body of rimmed steel are covered with a high purity iron phase which is often called a rim layer. Accordingly, rimmed steel has a beautiful surface state and the same is highly workable, platable and weldable.

In one aspect, the present invention provides an apparatus for effectuating a process for obtaining an excellent steel having the surface characteristics of a rimmed steel and which also has the internal uniformity and resistance to ageing of a killed steel. Further, the process facilitates the production of an aluminum deoxidized steel which is resistant to ageing characteristics and which is capable of being deep drawn.

Attempts to deoxidize a rimmed steel in a mold have previously been made. One such process involves pouring molten steel into a casting mold until the latter is

about 90% full and the surface of the molten steel is just below the feed head part. A solid or liquid deoxidizing agent is then added to the mold while the remainder of the molten steel is poured thereinto so that the gravitating flow of the molten steel being poured into the mold may be utilized for distributing the deoxidizing agent uniformly throughout the molten steel.

In another previous process wherein the deoxidation of rimmed steel was attempted, substantially all of the molten steel is poured into the casting mold and a deoxidizing agent is added to the upper surface of the molten steel.

In the former process, uniform distribution of the deoxidizing agent throughout the molten steel is not a substantial problem and the interior of the ingot produced has the characteristics of a killed steel. Therefore, this process may be used for producing killed steel. However, in this process, since the deoxidizing agent is added after most of the steel has been cast, the time available for rimming to occur will be generally insufficient to permit the formation of a sound rim layer at the surface of the steel. Accordingly, even if the addition of the remainder of the molten steel is delayed, it is possible that a surface fault will be produced.

In the latter prior process described above, the deoxidizing agent does not become uniformly distributed throughout the steel whereby deoxidation is excessive and the concentration of non-metallic inclusions increases in the upper portions of the steel to which the deoxidizing agent is added.

In conventional processes wherein the deoxidizing agent is merely thrown into the molten steel, whether the latter is contained in a ladle or in a casting mold, before the deoxidizing agent can be completely dissolved in the molten steel, the same may react with surrounding air to form an oxide which might be forced into the interior of the molten steel and remain there as non-metallic inclusions in the product. Moreover, the degree of such oxidation by air fluctuates greatly with adding conditions, and as a result, the amount of deoxidizing agent which will be available to react with the molten steel or to remain in the latter as an alloying agent is difficult to anticipate. Accordingly, the quality of the steel product will fluctuate.

The following is an example of a process which utilizes an apparatus which embodies the principles and concepts of the present invention wherein the shortcomings of the above-mentioned conventional processes are substantially eliminated. As is shown schematically in FIG. 8, rails 13 are laid along a deck disposed at a proper height above a casting mold 1. A carriage 15 provided with wheels 14 is carried by rails 13 and an apparatus 4 for projecting the deoxidizing agent adding pieces 5 in accordance with the present invention is mounted on carriage 15.

Projecting apparatus 4, which contains a plurality of deoxidizing agent adding pieces 5 made by molding a deoxidizing agent such as, for example, aluminum or an aluminum alloy into the form of bullets, is mounted on carriage 15 in a position such that the deoxidizing agent adding pieces 5 may be projected through a projecting tube 8 utilizing an appropriate power source such as, for example, fluid pressure. The direction of movement of each projected deoxidizing agent adding piece 5 is changed by a curved tube guide 16 whereby each piece 5 is aimed downwardly, straight into the center of mold 1.

The configuration of each deoxidizing agent adding piece 5 is not itself a direct limiting condition for the present invention; however, each piece 5 is shaped, as shown in FIG. 5, in the form of a rocket having a main part 5 and stabilizing fins 5', for example, whereby the same will be able to effectively reach the deepest part of the molten metal in mold 1.

After the completion of casting and after the molten steel has been subjected to a rimming action for 1 – 10 minutes, the required number of deoxidizing agent adding pieces 5 are projected by apparatus 4 into the molten metal in mold 1 at such velocity that each piece 5 reaches the deepest part of the metal in mold 1.

More specifically, 6.9 tons of a rimmed steel containing 0.07% carbon, 0.37% manganese, 0.008% phosphorous and 0.016% sulfur were poured into an appropriate steel ingot casting mold having a square cross-sectional configuration 677 millimeters on each side and a depth of 2200 millimeters. The steel was subjected to a rimming action for 5 minutes and thirty seconds and then aluminum adding pieces were added to the molten steel in the mold utilizing projecting apparatus 4. The adding piece projecting pressure utilized in apparatus 4 was 8 kg/cm^2, the projecting tube port velocity was 56 m/sec, the curved tube guide outlet velocity was 45 m/sec and the depth to which each piece was projected was 1,500 millimeters.

Thus, each aluminum adding piece 5 had completely dissolved by the time it had floated upwardly 400 mm from the deepest point to which it was thrust. Each aluminum adding piece 5 had a diameter of 11 mm, a length of 132 mm and a weight of 29.1 grams. 234 aluminum adding pieces 5 were added at a rate of 600 pieces per minute. Accordingly, the total amount of aluminum added was about 1 kilogram per ton of steel. The data from this experiment are shown below in Table 2. The cast steel ingot was bloomed to produce a bloom having a diameter of 110 mm and the character of the cross-section of the same was investigated. Thus, it was found that a sound bloom having a rim layer several millimeters deep on its surface and a soluble aluminum content of 0.025% in its central portions, had been obtained.

The effects obtained through the use of the foregoing example of the present invention are: (1) since the time necessary for adding the deoxidizing agent adding pieces is freely determinable, the rimming action can be allowed to continue for a sufficient time to produce a sound rim layer having appropriate characteristics at the upper surface of the steel in the mold; (2) since the deoxidizing agent adding pieces 5 are thrust into the molten steel almost instantaneously, practically 100% of the projected deoxidizing agent is effectively utilized without being wasted and therefore the yield of the deoxidizing agent is improved and the quality of the steel is stabilized; and (3) since the projecting step and the amount are freely determined by selecting the projecting velocity of the deoxidizing agent adding pieces and since the projecting place is free, the quality of the molten steel can be more easily uniformly maintained.

Table 2

	In the molten steel before Al addition	In the central part of the bloom after Al addition
Steel composition (%)		
C	0.06	0.06
Si	Trace	Trace
Mn	0.37	0.38
P	0.008	0.010
S	0.016	0.018

Table 2-continued

	In the molten steel before Al addition	In the central part of the bloom after Al addition
Soluble Al	Trace	0.025
Casting time	1.84 minutes	
Casting temperature	1580°C.	
Cast weight	6.9 tons	
Al adding time	5.50 minutes after the completion of casting	
Al adding amount	6.8 kg.	
Projecting pressure	8 kg./cm².	
Projecting tube port velocity	56 m./sec.	
Curved tube guide outlet velocity	45 m./sec.	
Form of Al adding piece	11 mm. in diameter and 132 mm. long	
Weight of Al adding piece	29.1 g.	
Adding rate	600 pieces/minute	

A process for producing homogenous rimmed steels having a rim layer on the surface by continuously projecting deoxidizing agent adding pieces into uncoagulated molten steel by the methods of the present invention is described below. In this example, the projection velocity is synchronized with the drawing velocity during the continuous casting operation.

Various attempts have previously been made to produce rimmed steel using a continuous casting method; however, no completely satisfactory commercial mass-producing method has yet been discovered. The reasons for this are that: (1) in continuous casting methods, the cross-section of the casting mold is smaller than in the case of ordinary ingot making; (2) the area of contact between the casting mold and the cast ingot, per unit cross-sectional area of the latter, is large; (3) since the uncoagulated portion of the melt extends deep into the mold, bubbles produced at the time of the coagulation are so numerous per unit cross-sectional area of the cast ingot that the melt movement (rimming action) produced along with the production of these bubbles is too strong or stable and in some cases, a dangerous thrust comes from the bottom of the uncoagulated part. Because of the foregoing, there is a trend among those involved in the continuous casting of steel, to make silicon or aluminum killed steels rather than rimmed steels. However, killed steels do not provide the preferred characteristics of rimmed steels, such as, a beautiful surface and high workability. Also, deoxidation by vacuum treatment is practiced by some; however, this procedure is quite costly.

The following example of a continuous casting method which embodies the principles and concepts of the present invention, illustrates how the shortcomings of the above described conventional methods are overcome. Generally, in molds for producing ingots of ordinary rimmed steel, the rimming action takes place 500 to 1,000 millimeters beneath the upper surface of the molten steel. Accordingly, even in the case of continuous casting, from the viewpoint of only the rimming action, the portion of the melt which is deeper than this may be forceably deoxidized so that rimming takes place only in the upper part. On the other hand, since the high purity iron rim layer, which is a feature of rimmed steel, is formed by such rimming action, the range where rimming will occur to create a rim layer will be naturally determined.

As is well known, the coagulating thickness D (in millimeters) is given by the relationship

$$D = K\sqrt{T}$$

wherein T is the coagulating time in minutes and K is a constant which is determined by the cooling conditions and which generally has a value of about 26 during continuous casting. Accordingly, about 2.2 seconds are required to provide a rim layer which is at least 5 millimeters thick.

Thus, at a drawing velocity of 2 m/min, the rimming action may be accomplished over a 74 millimeters length of the mold below the surface of the melt. However, the rimming strength obtained during a rimming action of this length is generally insufficient, and accordingly, it has been found that the rimming action should be continued over a length of about 500 millimeters as described above.

The relationship between the thickness of the rim layer, the velocity V and the deoxidizing position (the distance L below the melt surface) is given by the formula

$$D = k\sqrt{L/V} \qquad (6)$$

A bloom having a fixed quality is required to have a fixed rim layer thickness, and accordingly, the deoxidizing position L must be varied with the drawing velocity. Further, when no adjustment is made in the strength of the rimming action,
by the rim the deoxidizing position L may be varied in a range allowed layer thickness, and the rim layer in such case is determined by the formula (6).

That is to say, the deoxidation may be carried out at a deoxidizing position (depth) selected to conform to the state of the molten steel, drawing velocity and cooling conditions, and thus, the rimming action may be caused to take place at a shallower depth than said deoxidizing position and deoxidation itself may be carried out at a greater depth than said deoxidizing position whereby to obtain a homogenous bloom.

The present invention makes such deoxidation possible through the use of an apparatus which utilizes the principle of feeding an amount of deoxidizing agent practically instantaneously into a batch of molten metal at a projecting velocity sufficient to project the pieces of deoxidizing agent into the molten metal to a depth beneath the uncoagulated part of the bloom. An apparatus for projecting bullet shaped pieces of deoxidizing agent is provided above the casting mold so that the bloom may be deoxidized while the pieces of deoxidizing agent float upwardly.

The operation of the method of the invention is illustrated in FIG. 9 in connection with a conventional continuous casting apparatus wherein cast blooms are continuously cast by pouring a molten steel 18 in a tundish 17 into a water-cooled casting mold 20 through a nozzle 19. Pieces 5 of deoxidizing agent are continuously projected deep into the uncoagulated portion of a cast bloom at a velocity syncronized with the bloom drawing velocity. Such projection of pieces 5 is accomplished with a projecting apparatus 4. The deoxidizing agent adding pieces 5 are constructed in the form of bullets of aluminum or an aluminum alloy.

Projecting apparatus 4 contains a pluralilty of deoxidizing agent adding pieces 5 and consists of a projector utilizing a motive force provided, for example, by fluid pressure. A curved tube guide 16 is disposed adjacent apparatus 4 as can be seen and the adding pieces 5 may be of the form illustrated in FIG. 5.

In an illustrative operational example, the steel 18 in tundish 17 was a very low carbon steel containing 0.05% carbon, 0.01% silicon and 0.050% manganese, and aluminum was used as the deoxidizing agent. Streamline pieces 5 of aluminum having a diameter of 10 millimeters, a length of 135 millimeters and weigh-

ing 21.4 grams were provided. The respective values in formula (3) for a thrusting depth of 800 mm are K = 1.25, $\rho f = 6.9$, $\rho s = 2.7$, $C_D = 0.146$, S = 0.785 cm^2 and V = 7.92 cm^3, and the initial projecting velocity u_o is 15.5 m/sec.

The aluminum adding pieces described above were projected into the melt to the depth of 800 millimeters and then they began to float upwardly due to buoyancy. By the time the pieces have risen 400 millimeters, the same had become completely dissolved in the molten steel.

The bloom produced in accordance with the foregoing had a rectangular shape of 156 mm × 1040 mm, the drawing velocity was 1 m/min and the amount of aluminum added was 750 g/ton. The aluminum adding pieces were projected into the steel at the rate of 298 pieces per minute under a projecting pressure of 1.1 kg/cm^2 from a projecting apparatus including a projecting tube having a length of 300 mm to obtain a slab stabilized with 0.03% soluble aluminum and having a very beautiful surface skin.

The oxygen analysis value before the addition of aluminum was about 0.04% and therefore it can be seen that the aluminum addition loss was about 50 g/ton, a value obtained by subtracting the deoxidation yield from 750 g/ton. Thus, it is manifest that the efficiency of the addition is much better than in conventional processes.

The important data from the above example is tabulated in Table 3 below.

Table 3

Steel composition (%)	In the case molten steel	In the interior of the bloom
C	0.05	0.05
Si	0.01	0.01
Mn	0.50	0.49
P	0.012	0.012
S	0.021	0.022
Soluble Al	Trace	0.030
Casting temperature		1540°C.
Form of bloom		156 × 1040 mm.
Casting velocity		1 m./min.
Projecting pressure		1.1 kg./cm^2.
projecting tube port velocity		15.5 m./sec.
Form of Al adding piece		10 mm. in diameter and 135 mm. long
Weight of Al adding piece		21.4 g.
Adding rate		298 pieces/minute

What is claimed is:

1. An apparatus for continuously projecting pieces of a deoxidizing agent into molten steel, comprising:

projection means for projecting said pieces into the molten steel in a direction substantially perpendicular to the upper surface of the molten steel at an initial velocity selected such that said pieces descend to a predetermined depth within the molten steel.

means for feeding said pieces to said projection means; and

means for adjusting said projection means so that the initial velocity at which said pieces are projected is defined by the following relationship

$$u_o = K \sqrt{\frac{2(\rho f - \rho s)\, V \cdot g}{\rho s \cdot C_D \cdot S}} \tan.\cos^{-1} \exp \left(-1/2 \frac{\rho f}{\rho s} \cdot \frac{S}{V} C_D \cdot X\right)$$

wherein u_o is the initial projection velocity of the piece in cm./sec., k is an empirically determined velocity loss coefficient representative of the velocity losses occasioned by air resistance and surface impact, ρf and ρs are respectively the densities in g./cm^3. of the molten steel and pieces of deoxidizing agent, S and V are respectively the cross-sectional area in cm^2 and the volume in cm^3 of each of said pieces, C_D is the empirically determined thrusting resistance coefficient of the adding piece into the molten steel, g is the acceleration of gravity in cm/sec.^{2} and X is the depth in cm. to which the pieces are to be thrust into the molten steel, in response to their dimensions and the molten steel depth;

whereby said pieces will subsequently float towards the top surface of the molten steel and will dissolve within the molten steel prior to reaching the top surface of the molten steel.

2. An apparatus for continuously projecting pieces of a deoxidizing agent as set forth in claim 1 wherein a compressed fluid is used as a projecting energy, said apparatus comprising a cylinder having an introducing tube for introducing the compressed fluid, a projecting tube fitted to said cylinder to project the pieces of deoxidizing agent with the compressed fluid and said means for feeding feeds the pieces of deoxidizing agent one by one to said projecting tube.

3. An apparatus for continuously projecting pieces of a deoxidizing agent as set forth in claim 1 wherein the pressure of a spring is used as a projecting energy, said apparatus comprising a cylinder interengaging with said spring, a projecting tube to project the pieces of deoxidizing agent with the pressure of said spring and said means for feeding feeds the pieces of deoxidizing agent one by one to said projecting tube.

4. An apparatus for continuously projecting pieces of a deoxidizing agent as set forth in claim 1 wherein an exploding powder is used as a projecting energy, said apparatus comprising a bolt for locking, a hammer to fire a fuse of a cartridge having each piece of deoxidizing agent as a bullet and charged with the exploding powder, a projecting tube to project the bullets and said means for feeding feeds said bullets one by one to said projecting tube.

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