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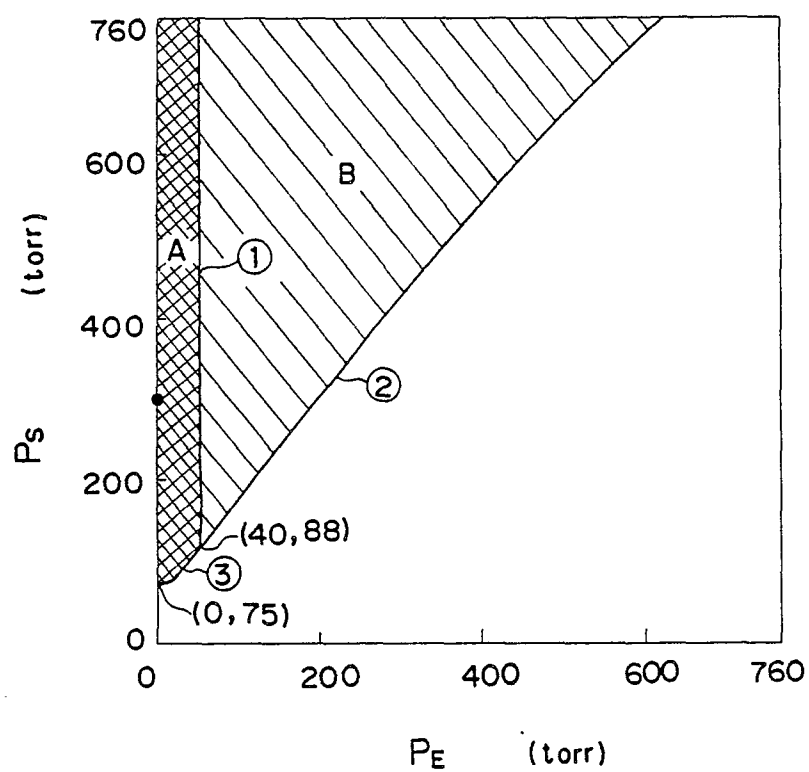
(54) Method for cleaning molten metal.

(57) A method for cleaning molten metal comprises the steps of keeping a pressure inside a vessel having molten metal therein at a pressure of P_S of atmospheric pressure or less, bubbling the molten metal in the vessel by gas soluble in the molten metal, a portion of said gas dissolving in the molten metal and the rest of the gas converting to gas bubbles, and reducing rapidly the pressure in the vessel to pressure P_E , fine gas bubbles being produced in the molten metal in the vessel, nonmetallic inclusions being trapped by said fine gas bubbles and by gas bubbles produced by bubbling and rising to the the surface of the molten metal, and gas dissolved in the molten metal being removed.

Pressure P_S in the step of keeping a pressure and pressure P_E in the step of reducing the pressure are pressures P_S and P_E of atmosphere inside the vessel in a zone enclosed with $P_S = 760$, $P_E = 40$, $(P_S)^{1/2} - (P_E)^{1/2} = 3.06$ in two-dimensional rectangular coordinates, whose ordinate is P_S Torr and whose abscissa is P_E Torr.

EP 0 362 851 A2

FIG. 1



METHOD FOR CLEANING MOLTEN METAL

The present invention relates to a method for cleaning molten metal, and more particularly to a method for obtaining clean molten metal by making nonmetallic inclusions rise to the surface of the molten metal and removing the nonmetallic inclusions from the molten metal.

Since inclusions (for example, alumina inclusions in molten steel) being suspended in molten metal
5 are a cause of producing defects of quality of products, various methods for decreasing or removing the inclusions in molten steel have been proposed.

Out of methods having been very often used as comparatively effective methods, there is pointed out a method for removing inclusions from molten metal, wherein molten metal is bubbled by blowing inert gas from the bottom of a vessel into the molten metal under atmospheric pressure, gas bubbles thus produced
10 trap the inclusions in the molten metal and the inclusions are removed after the inclusions have risen to the surface of the molten metal.

In the case of manufacturing a high quality steel, there is a need for limiting the total amount of oxygen in molten steel to 15 ppm or less. There, however, occurs a problem such that molten metal cannot be cleaned to more than ordinary norms of cleanness by the use of the above-mentioned method. Therefore, a
15 new method for cleaning molten metal has been expected to be developed.

That is, there have been difficulties in the prior art bubbling method in that a bubbling zone was limited to a zone which widened from a gas blow opening of the bottom of a vessel upwardly in the form of "V" and it was difficult to bubble molten steel from the entire vessel due to a limit of a gas blowing method. Moreover, there have been problems such that, since sizes of produced bubbles were large, molten metal
20 flows as if it went around the bubbles during rising of the bubbles, fine inclusions move together with a flow of the molten metal, avoiding those bubbles, and, in consequence, the fine inclusions were hard to be trapped by the bubbles.

To overcome the above-mentioned difficulties, the present inventors propose the following method:

In this method, molten metal under elevated pressure is bubbled by a gas soluble in the molten metal,
25 inclusions being suspended in the molten metal are trapped by gas bubbles produced by bubbling and by fine gas bubbles produced by reducing the pressure on pressurized molten metal. After the inclusions have risen to the surface of the molten metal, said inclusions are removed. Ordinary inclusions are trapped by first bubbling. Said trapped inclusions rise to the surface of the molten steel. On the other hand, since pressurized molten metal is bubbled, a large amount of bubbling gas dissolves in the molten metal.
30 Thereafter, gas having dissolved in the molten metal appears as fine gas bubbles from the entire zone of the molten metal by rapidly reducing a pressure inside a vessel. During the bubbling, the fine inclusions are trapped by the bubbles and rise to the surface of the molten metal with the bubbles.

The above-mentioned method is very effective in removal of the inclusions in the molten metal. However, since the molten metal is pressurized at the initial stage of a processing step, some portion of the bubbling gas having once dissolved in the molten metal appears as fine gas bubbles during the reduction of
35 the pressure on the molten metal, but the rest of the gas remains dissolved in the molten metal. Accordingly, one more processing step for degassing the molten metal is required after the above-mentioned processing of the gas has been carried out. Therefore, there have been problems in that degassing capacity and the number of processing steps had to be increased. In addition, a cost for
40 equipment increased because of the use of a pressure vessel.

It is an object of the present invention to provide a method for cleaning molten metal under reduced pressure wherein the above-mentioned bubbling method is improved, any pressure vessel is not used, and degassing of the molten metal is carried out in the same vessel as that of bubbling method.

To accomplish the said object, the present invention provides a method for cleaning molten metal
45 comprising the steps of:

keeping a pressure inside a vessel having molten metal therein at a pressure of P_s of atmospheric pressure or less;

bubbling the molten metal in the vessel by gas soluble in the molten metal, a portion of said gas dissolving in the molten metal and the rest of said gas converting to gas bubbles; and

50 reducing rapidly the pressure in the vessel to pressure P_E , fine gas bubbles being produced in the molten metal in the vessel, nonmetallic inclusions being trapped by said fine gas bubbles and by gas bubbles produced by bubbling and rising to the surface of the molten metal, and gas dissolved in the molten metal being removed.

In the method of the present invention, the molten metal is not processed under elevated pressure as in the prior art method. The molten metal is processed under reduced pressure after the molten metal has

been bubbled by blowing gas soluble in the molten metal at atmospheric pressure or less. Particularly, in this processing under reduced pressure, not only the fine gas bubbles are simply produced, but also said bubbling gas remaining dissolved in the molten metal is removed together with the fine gas bubbles.

The above objects and other objects and advantages of the present invention will become apparent from the detailed description to follow, taken in connection with the appended drawings.

Fig.1 is a graphical representation showing the relation between a pressure inside a vessel during bubbling of molten metal by blowing nitrogen gas into the molten metal and a pressure inside the vessel during degassing of the molten metal according to the present invention;

Fig.2 is a vertical sectional view illustrating a refining apparatus for a ladle which carries out VOD processing according to the present invention;

Fig.3 is a vertical sectional view illustrating a refining apparatus for a ladle which carries out VAD processing according to the present invention;

Figs. 4 and 5 are explanatory view of a gas tight vessel having a horizontal rotation axis capable of rotating according to the present invention;

Fig.6 is a graphical representation showing a change of the total amount of oxygen in the molten steel with the lapse of time according to the present invention;

Fig.7 is an explanatory view designating another example of the present invention wherein the same apparatus as in Fig.4 is used.

Fig.8 is a graphical representation showing the total amount of oxygen in the molten steel in another example different from Fig.6; and

Figs. 9 and 10 are explanatory views designating a vessel of rectangular parallelepiped having a gate therein.

25 Preferred Embodiment-1

Fig.1 shows a result of having studied the case when molten steel was used as molten metal and nitrogen as gas soluble in the molten steel. Namely, Fig.1 is a graphical representation designating preferable zones out of coordinates of pressure P_S of atmosphere inside a vessel, under which the molten metal is bubbled by blowing said gas into the molten metal, and of reduced pressure P_E of atmosphere inside the vessel. Units of P_S and P_E are Torr. Zone B shown with oblique lines is a preferable zone. Zone A shown with crossing lines is more preferable zone. The zone B is a zone where the inclusions decrease. However, since the content of nitrogen [N] in the molten steel poses problems depending on steel species, a denitrification step is sometimes required after processing of the molten steel under reduced pressure.

In Fig.1, a boundary ① between the zones A and B, namely, $P_E = 40$ Torr is determined in such a manner as described below. The relation between the pressure P_N inside the gas tight vessel and the content of nitrogen [N] in the molten steel is determined by an equilibrium relation of the following equation (1) in the case of ordinary steel:

$$[N] = 450 (P_N)^{1/2} \quad (1)$$

Units of [N] and P_N are ppm and atm, respectively. The allowable largest value of [N] is estimated at 100 ppm. $[N] \leq 100$ is obtained. $[N] \leq 100$ is substituted for the equation (1) and the pressure unit is converted from atm to Torr, $P_N \leq 38$ Torr is obtained. $P_E = 40$ Torr is obtained by rounding $P_N \leq 38$ Torr.

Line ② passing the lower ends of the zone B is determined for the following reason:

The amount of nitrogen removed from the molten steel which was required for trapping the inclusions and making the inclusions rise to the surface of the molten steel needed to be 50 ppm or more by experience of the present inventors. The amount of removed nitrogen is the difference between [N] S and [N] E. [N] S is the initial content of nitrogen increased by bubbling the molten steel by blowing nitrogen into the molten steel. [N] E is the final content of nitrogen decreased by degassing the molten steel under reduced pressure. That is to say, the line ② is determined by the use of the following equation obtained by putting said equation (1) into $[N] S - [N] E \geq 50$ and representing pressures in Torr:

$$(P_S)^{1/2} - (P_E)^{1/2} = 3.06 \quad (2)$$

The intersection point where the line ① crossed the line ② was (40, 88) in coordinates (P_E , P_S), $P_E = 40$ being substituted for the equation (2). Further, in the case P_E is less than 75 Torr in the equation (1), it takes much time to make an equilibrium state between the pressure P_N and the content [N] and this is ineffective. P_E of less than 75 Torr is considered difficult to apply. As a result, the line ③ passing the lower ends of the zone A was determined by connecting the point (0, 75) with the point (40, 88). More preferable zone A is two-dimensional rectangular coordinates, whose ordinate is P_S Torr and whose abscissa is P_E Torr. The zone A is enclosed with $P_S = 760$, $P_E = 0$ and point (40, 88) and (0, 75) represented

with (P_E , P_S). The preferable zone B is two-dimensional rectangular coordinates, whose ordinate is P_S Torr and whose abscissa is P_E . The zone B. is enclosed with $P_S = 760$, $P_E = 40$ and $(P_S)^{1/2} - (P_E)^{1/2} = 3.06$. Out of the zone B, a zone enclosed with $P_S = 760$, $P_E = 40$, $P_E = 400$ and $(P_S)^{1/2} - (P_E)^{1/2} = 3.06$ is more preferable in the two-dimensional rectangular coordinates, whose ordinate is P_S Torr and whose abscissa is P_E Torr.

5 Further, a zone enclosed with $P_S = 760$, $P_E = 40$, $P_E = 200$ and $(P_S)^{1/2} - (P_E)^{1/2} = 3.06$ is most desired.

Example-1

10 An example of the present invention will be described with specific reference to the appended drawings. Fig.2 is a vertical sectional view illustrating a refining apparatus for a ladle having been used for the example of the present invention. In the drawings, referential numeral 30 denotes a gas tight vessel. Ladle 32 of 50 ton capacity, into which molten steel 31 is charged, is put into the vessel. Cover 33 of the gas tight vessel 30 is arranged in a removable state Lance 34 is fixed to the cover to be used for VOD (

15 Vacuum Oxygen Decarbonization). Referential numeral 36 denotes an exhaust opening for making the gas tight vessel vacuum. Referential numeral 36 denotes a porous plug for blowing gas into the molten steel, which is arranged at the bottom of the ladle.

50 t of molten steel charged into the ladle 32 was kept at 1660 °C and at 300 Torr in said gas tight vessel. 6 Nm³ of N₂ was blown into the molten steel from the bottom of the ladle 32 for 10 min. Then, cover

20 33 was changed for another cover 38 having three electrodes as shown in Fig.3 to carry out VAD (vacuum arc degassing). Pressure in the vessel was rapidly reduced to 1 Torr, a heat compensation being made for the molten steel by means of said electrodes 37, and the pressure of 1 Torr was kept for 20 min. At the same time, the molten steel was bubbled by Ar gas blown into the molten steel from the bottom of the ladle at 150 N l/min. A black point shown in Fig.1 corresponds to the Example-1.

25 The content of the molten steel obtained by processing of the molten steel in said Example-1 will be shown in Table 1. Example-2 shown in this Table will be described later. Results obtained in the case of using the prior art pressure elevation and reduction method (Control-1) wherein molten steel was degassed under reduced pressure after the molten steel had been bubbled by N₂ gas under elevated pressure of more than atmospheric pressure and an Ar gas bubbling method (Control-2) are shown as controls in Table 1. In the pressure elevation and reduction method, the pressure in the vessel was

30 increased to 3 atm during blowing of N₂ gas and then reduced to 100 Torr during reduction of the pressure. As for other conditions, the molten steel was processed under the same conditions as those of the example of the present invention. Ar gas, however, was not blown into the molten steel during pressure reduction.

In the Ar gas bubbling method, 50 t of molten steel was kept at 0.5 to 1 Torr in a vacuum ladle and

35 bubbled by Ar gas blown into the molten steel from the bottom of the ladle at a rate of 150 N l/min for 20 min.

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Table 1

		Time,(min) after Pressure Reduction	C %	Si %	Mn %	P %	S %	Sol Al %	T. [O] ppm	T. [N] ppm
5	Example-1	0	0.13	0.32	1.12	0.023	0.006	0.048	42	147
		10	0.13	0.31	1.12	0.023	0.006	0.047	8	38
		20	0.13	0.31	1.12	0.023	0.006	0.047	7	31
10	Example-2	0	0.14	0.33	1.14	0.021	0.005	0.049	42	147
		10	0.14	0.32	1.13	0.021	0.005	0.047	7	60
		20	0.14	0.32	1.13	0.021	0.005	0.047	5	35
15	Control-1 Pressure Elevation and Reduction Method	0	0.13	0.33	1.13	0.020	0.005	0.050	41	632
		10	0.13	0.32	1.13	0.020	0.005	0.048	9	279
		20	0.13	0.32	1.13	0.020	0.005	0.047	9	162
20	Control-2 Ar Gas Bubbling Method	0	0.12	0.33	1.15	0.018	0.005	0.054	42	20
		10	0.12	0.32	1.14	0.018	0.005	0.054	24	19
		20	0.12	0.31	1.15	0.018	0.005	0.052	18	18
25										

In Table 1, when Example-1 is compared with Control-1 or Control-2 relative to the total amount of oxygen T.[O] and the total amount of nitrogen T.[N] in the molten steel 20 min later after the pressure reduction, T.[O] in Example-1 decreased and T.[N] greatly decreased in comparison with the pressure elevation and reduction method. In comparison with the Ar gas bubbling method, it is recognized that T.[O] decreased. In this case, the amount of nitrogen increased slightly by blowing nitrogen gas, but such T.[N] does not pose any specific problem except for specific cases.

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Preferred Embodiment-2

When the molten steel is stirred by blowing inert gas into the molten steel under reduced pressure as in the Example-1, soluble gas is remarkably removed from the molten steel and the amount of nitrogen decreased to the extent enough to be able to be put to practical use inspite of bubbling of the soluble gas in comparison with Control-1 and Control-2 in Table 1. The soluble gas, however, is removed during the pressure reduction and, at the same time, the occurrence of fine gas bubbles is also decreased. Accordingly, it is thought that the effect of rising and separation of nonmetallic inclusions decreases with the lapse of time. Therefore, it is intended in Example-2 to keep the effect of the rising and separation of the nonmetallic inclusions by blowing the soluble gas together with the inert gas during the pressure reduction.

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Example-2

An example of the present invention will be described specifically. As in Example-1, a refining apparatus for a ladle as shown in Figs.2 and 3 was used. Soluble gas was blown into molten steel before a pressure reduction, 50 t of molten steel being kept at 1660 °C and at 300 Torr. 6 Nm³ of N₂ gas was blown from the bottom of the ladle as shown in Fig.2 into the molten steel by means of a porous plug for 10 min. Then, cover 33 was changed for cover 38. Heat compensation was made for the molten steel by the use of arc heat of electrodes. Pressure in the ladle was rapidly reduced to 1 Torr and the pressure of 1 Torr was kept for 20 min. The molten steel was bubbled by blowing Ar gas as inert gas together with N₂ gas from the bottom of the ladle at a rate of 150 Nl/min. Flow of N₂ gas was decreased to zero in the last five minutes as shown in Table 2 so as to make the amount of soluble gas as small as possible.

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Table 2

		Time after Pressure Reduction		
		0 ~ 10	10 ~ 15	15 ~ 20
Amount of Gas Blown into Molten Steel Nl/min	Ar	100	30	150
	N ₂	50	120	0

The components of molten steel which were obtained as a result of having processed the molten steel in Example-2 will be shown in Table 1. When Example-2 is compared with Example-1 in this Table, it is recognized that T.[O] was decreased by blowing nitrogen into the molten steel under reduced pressure while T.[N] was increased slightly.

The soluble gas is removed by pressure reduction in Preferred Embodiment-1 and Preferred Embodiment-2. However, in case a depth of a molten metal bath is large, a static pressure in a bottom portion of the molten metal bath becomes large. In consequence, it becomes difficult to degass the molten steel by the use of only processing of molten steel under reduced pressure. Specifically, when the depth of the molten steel is 1.5 m or more, the above- mentioned tendency became remarkable. To degass the molten metal in the bottom portion of the molten metal bath of large depth, it is thought to turn a gas tight vessel having the molten metal therein upside down and to greatly stir said molten metal under reduced pressure. This example will be described according to Example-3 and Example-4 shown below with specific reference to Figs.4 to 8.

Example-3

Fig.4 shows an example of a gas tight vessel 1 being able to be turned upside down with horizontal rotation axis in a central portion thereof. Said gas tight vessel 1 is made cylindrical by tightly jointing vessel 1A and vessel 1b, each of which has a form of a ladle of 2 m in diameter and 3 m in height. Gas blow opening 11 is positioned on an end face of the vessel 1b. Exhaust opening for exhausting an atmospheric gas from vessel 1 is arranged in joint portion 13 of the vessels 1a and 1b.

In this example, molten steel was cleaned by the use of the gas tight vessel 1 constituted with the vessels 1a and 1b as described above. 50 t of molten steel 31 was charged into the vessel 1b. Another vessel 1a was tightly jointed to the vessel 1b from above to form the vessel 1. Then, N₂ gas was blown into the vessel 1 through the gas blow opening 11 at a rate of 100 N l/min to bubble the molten steel 31. Gas was exhausted from the vessel 1 through said gas exhaust opening 12 so that the pressure inside the gas tight vessel 1 could not exceed a predetermined pressure. 20 minutes later, bubbling was stopped. In the above-mentioned state, the inside of the gas tight vessel 1 was made vacuum through said exhaust opening 12 with the use of a vacuum pump (not shown) so that the pressure inside the vessel 1 could be reduced to 10⁻² Torr. When this degree of vacuum was kept, N₂ having dissolved in the molten steel 31 appeared as fine gas bubbles which trapped fine inclusions in the molten steel 31 and made the fine inclusions rise to the surface of the molten steel.

5 minutes later after this, the gas tight vessel was turned counterclockwise at 180° as shown in Fig.5 and was made to be in the upsidedown state as shown in Fig.4. Since a portion of the molten steel bath which had been in a deep position and had been under large static pressure was changed for a portion of molten steel bath of small depth, a static pressure decreased rapidly and a large amount of fine gas bubbles were produced from the portion of the molten steel bath of small depth. After the molten steel had been left in this state for 5 minutes, the gas tight vessel was turned clockwise at 180° to be again in the state of Fig.4. In this case, the molten steel 31 was again stirred. Moreover, since the portion of the molten steel bath of large depth was changed for the portion of the molten steel bath of small depth, pressure on the portion of the molten steel bath having been under large static pressure was rapidly reduced, N₂ gas having remained in the molten steel 31 appeared as fine gas bubbles. The molten steel was left in this state for 5 minutes. A vacuum pump was driven to keep the degree of vacuum at 10⁻² Torr during the pressure reduction.

Fig.6 shows a change of the total amount of oxygen in the molten steel 31 with the lapse of time in the

example. According to Fig.6, the total amount of oxygen in the molten steel could be decreased from initial 80 ppm to final 12 ppm.

5 Example-4

An apparatus used for this method was the apparatus having been used in Example-3 as shown in Fig.4. As in Example-3, after molten steel had been kept in the gas tight vessel 1 and bubbled by blowing N₂ gas into the molten steel through gas blow opening 11 positioned in the bottom of the vessel 1, pressure
10 inside the gas tight vessel was reduced to 10⁻² Torr by evacuating the gas tight vessel and the vacuum was kept. After the degree of vacuum had been kept for 5 min, the gas tight vessel 1 was turned at 90° with central horizontal rotation axis 10 in a central portion thereof. The gas tight vessel 1 came to be in the state such that a longitudinal direction of the gas tight vessel of cylindrical shape was kept horizontally. Therefore, an area of bath of the molten steel 31 became large and a depth of the entire molten steel bath
15 became small. As a result, a static pressure on a portion of the molten steel 31 which had been in a deep portion was reduced and fine gas bubbles began to be actively produced.

Fig.8 is a graphical representation designating a change of the total amount of oxygen T.[O] in the molten steel 31 which was processed by the above-mentioned degassing method wherein the depth of the molten steel bath was made small. As shown in Fig.8, it is understood that the degassing method is highly
20 effective in processing of the molten steel since T.[O] in the molten steel was decreased from initial 80 ppm to final 15 ppm. In Example-3 wherein the gas tight vessel 1 was turned to 180°, when rotation of the gas tight vessel 1 was stopped for a while at the position where the vessel was turned to 90°, the effect of turning the gas tight vessel 1 at 180° and 90° can be obtained.

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Example-5

Fig.9 is a schematic illustration showing another example of a method for promoting degassing of molten steel by making a depth of molten steel bath small. In this example, gas tight vessel 2 of parallelepiped of 3 m in width, 3 m in height and 8 m in length was used. Removable gate 3 of 3 m in
30 length, 2.3 m in width and 0.5 m in thickness was arranged inside the gas tight vessel 2. The inside of the gas tight vessel 2 was divided into two chambers 2a and 2b. In the drawing, referential numeral 22 denotes an exhaust opening for exhausting inside atmosphere which is arranged in a ceiling of the gas tight vessel 2, 21 a gas injection opening arranged in the bottom of the chamber 2a, 23 an exit port for outflow of the
35 molten steel which is arranged in the bottom of the chamber 2b and 24 an inlet for inflow of the molten steel which is arranged in a ceiling of the chamber 2a. Said gas injection opening 21 and said inlet for inflow of the molten steel are arranged so that they can be opened or closed if necessary.

A method for cleaning molten steel by the use of the gas tight vessel 2 constituted in such a manner as described above will be described. In Fig.9, gate 3 is positioned 2 m away from the left face of the gas tight
40 vessel 2. Approximately 90 t of molten steel 31 is charged through the inlet 23 for inflow of the molten steel into one chamber 2a separated from the other chamber 2b by the gate 3. During charging of the molten steel, the exit port 23 for outflow of the molten steel is closed. The volume of the molten steel 31 comes to be 12 m³ of 3 m in length, 2 m in width and 2 m in depth. N₂ gas is blown through the gas blow opening 21 at a rate of 100 N l/min and the molten steel 31 is bubbled by N₂ gas. During bubbling, the inside
45 atmosphere is simultaneously exhausted through said gas exhaust opening 22 so that there cannot be any excessive pressure inside the gas tight vessel. The bubbling of the molten steel is stopped 20 minutes later and the inside of the gas tight vessel 2 is evacuated through said gas exhaust opening 22 by the use of a vacuum pump (not shown). An opening is made between the bottom face and the lower ends of the gate 3 by lifting the gate 3 upwardly as shown in Fig.10 when the pressure inside the gas tight vessel 2 is reduced
50 to 10⁻² Torr. Then, the molten steel having been stemmed by said gate 3 spreads in the whole vessel 2. As a result, the depth of the molten steel 31 having been 2 m initially comes to be 0.5 m.

Since the depth of the molten steel becomes rapidly small and the area of the surface of the molten steel bath widens, fine gas bubbles are actively produced. When the molten steel 31 is discharged by opening the exit port 23 for outflow of the molten steel, approximately the total amount of the molten steel
55 flowed out of the vessel 2 a quarter of an hour later.

It is clearly understood that the above-mentioned method is highly effective in cleaning of molten steel since the total amount of oxygen was decreased from initial 80 ppm to final 12 ppm as a result of having cleaned the molten steel in such a manner as described above.

Claims

1. A method for cleaning molten metal characterized by comprising the steps of:
 keeping a pressure inside a vessel having molten metal therein at a pressure of P_S of atmospheric pressure
 5 or less;
 bubbling the molten metal in the vessel by gas soluble in the molten metal, a portion of said gas dissolving
 in the molten metal and the rest of said gas converting to gas bubbles; and
 reducing rapidly the pressure in the vessel to pressure P_E , fine gas bubbles being produced in the molten
 metal in the vessel, nonmetallic inclusions being trapped by said fine gas bubbles and by gas bubbles
 10 produced by bubbling and rising to the surface of the molten metal, and gas dissolved in the molten metal
 being removed.
2. The method of claim 1, characterized in that said pressure P_S in the step of keeping a pressure and
 said pressure P_E in the step of reducing the pressure are pressures P_S and P_E of atmosphere inside the
 vessel in a zone enclosed with $P_S = 760$, $P_E = 40$ and $(P_S)^{1/2} - (P_E)^{1/2} = 3.06$ in two-dimensional rectangular
 15 coordinates, whose ordinate is P_S Torr and whose abscissa is P_E Torr.
3. The method of claim 2, characterized in that said pressure P_S and said pressure P_E are pressures P_S
 and P_E of atmosphere inside the vessel in a zone enclosed with $P_S = 760$, $P_E = 40$, $P_E = 400$ and $(P_S)^{1/2} -$
 $(P_E)^{1/2} = 3.06$ in the two-dimensional rectangular coordinates, whose ordinate is P_S Torr and whose
 abscissa is P_E Torr.
- 20 4. The method of claim 3, characterized in that said pressure P_S and said pressure P_E are pressures P_S
 and P_E of atmosphere inside the vessel in a zone enclosed with $P_S = 760$, $P_E = 40$, $P_E = 200$ and $(P_S)^{1/2} - (P_E)^{1/2} =$
 3.06 in the two-dimensional rectangular coordinates, whose ordinate is P_S Torr and whose abscissa is
 P_E Torr.
5. The method of claim 1, characterized in that the pressure P_S in the step of keeping a pressure and
 25 the pressure P_E in the step of reducing the pressure are pressures P_S and P_E of atmosphere inside the
 vessel in a zone enclosed with $P_S = 760$, $P_E = 40$, $P_E = 0$ and a line connecting points (40, 88) and (0.75)
 represented with coordinates (P_E , P_S) in the two-dimensional rectangular coordinates, whose ordinate is P_S
 Torr and whose abscissa is P_E Torr.
6. The method of claim 1, wherein said gas soluble in the molten metal in the step of bubbling is N_2 .
- 30 7. The method of claim 1, characterized in that said step of reducing the pressure includes stirring said
 molten metal by blowing inert gas into molten metal.
8. The method of claim 1, characterized in that said step of reducing the pressure includes bubbling the
 molten metal by blowing the gas soluble in the molten metal.
9. The method of claim 1, characterized in that said step of reducing the pressure includes turning a
 35 gas tight vessel having the molten metal therein, molten metal in a deep portion of molten metal bath
 moving to a portion on the side of the surface of the molten bath.
10. The method of claim 1, characterized in that said step of reducing the pressure includes decreasing
 a depth of the molten metal bath held in the gas tight vessel.

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FIG. 1

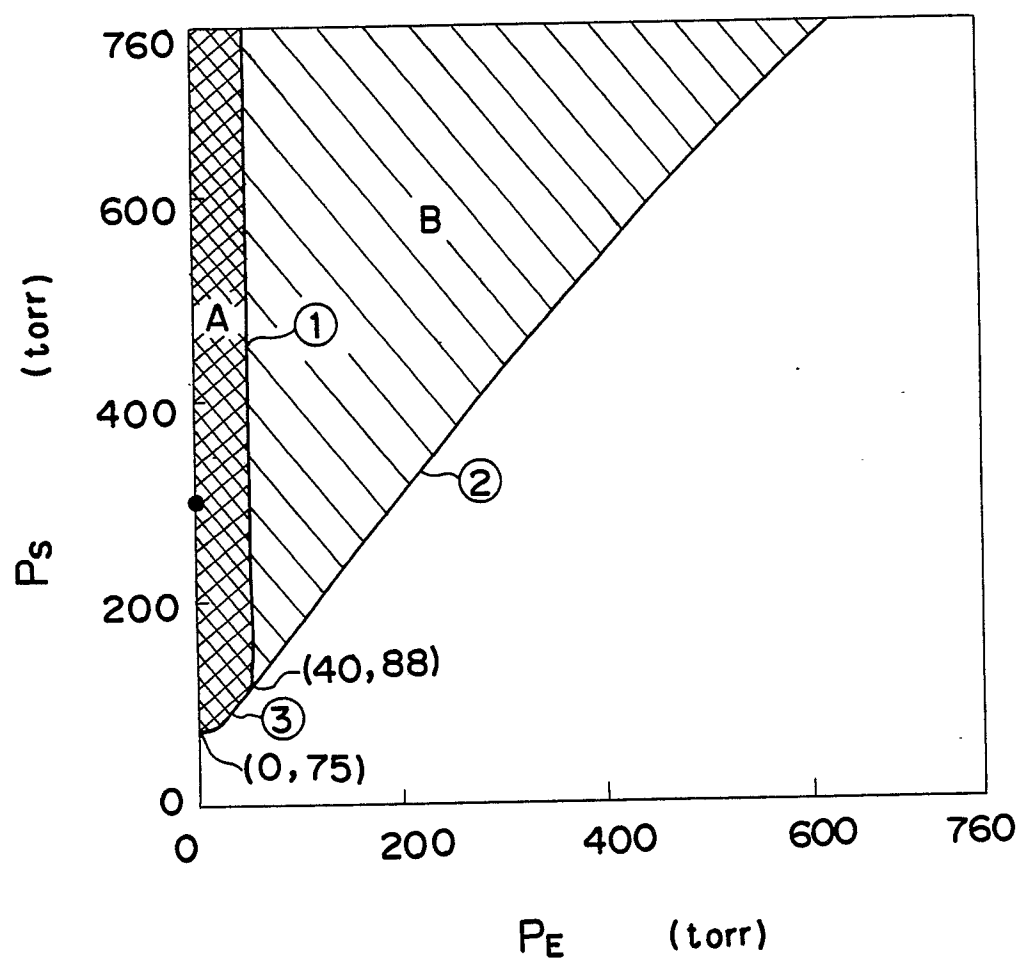


FIG.2

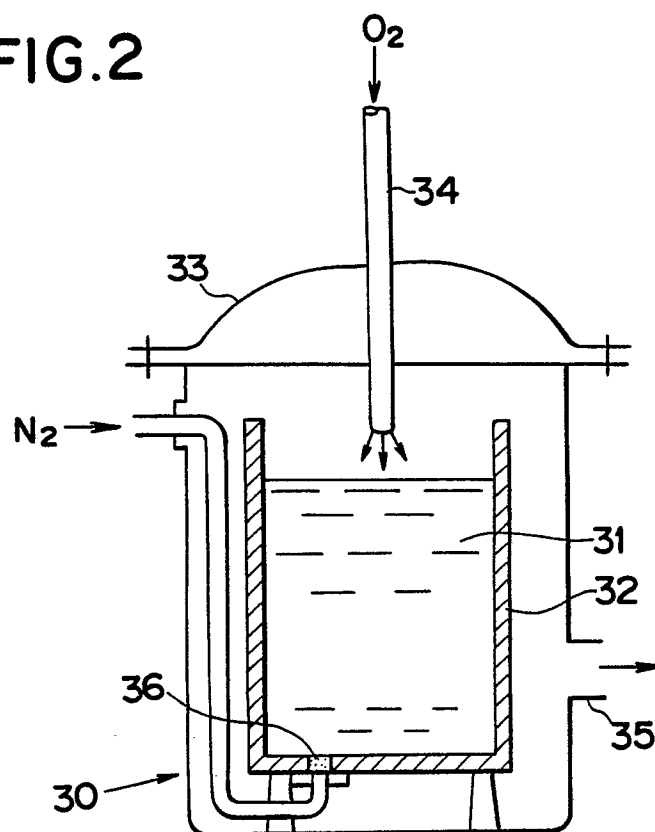


FIG.3

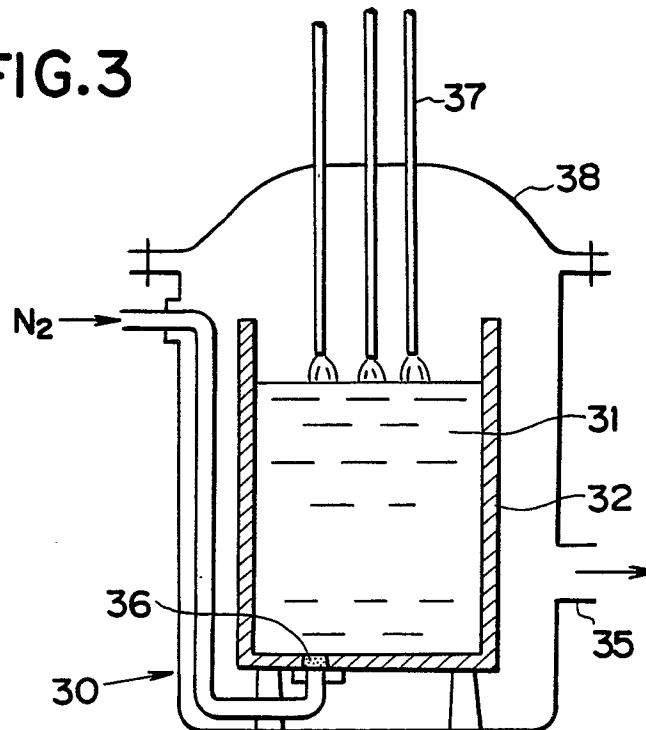


FIG. 4

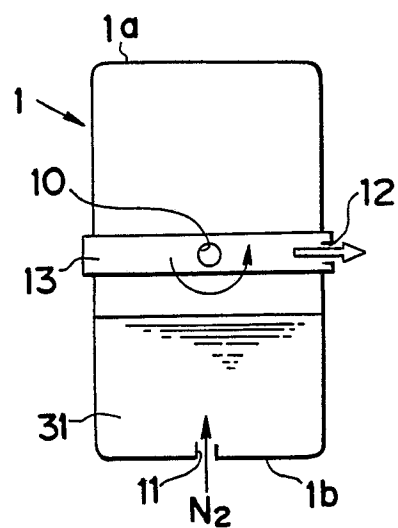


FIG. 5

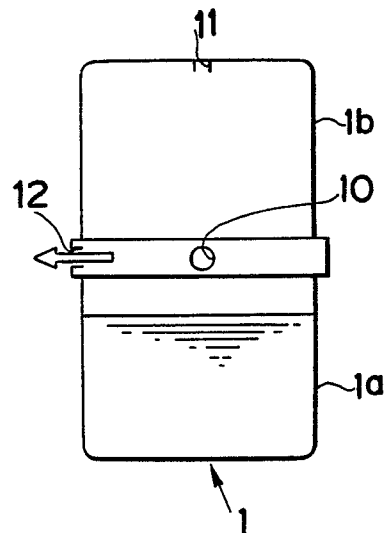


FIG. 6

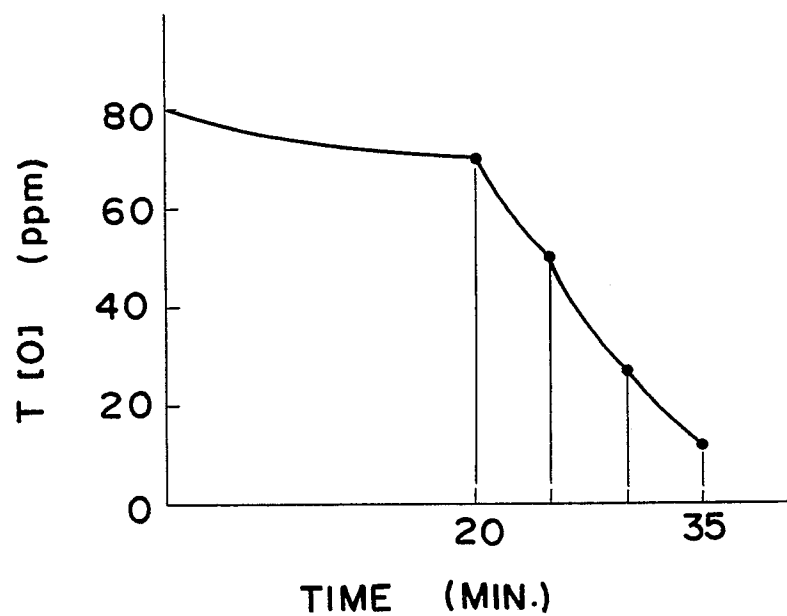


FIG. 7

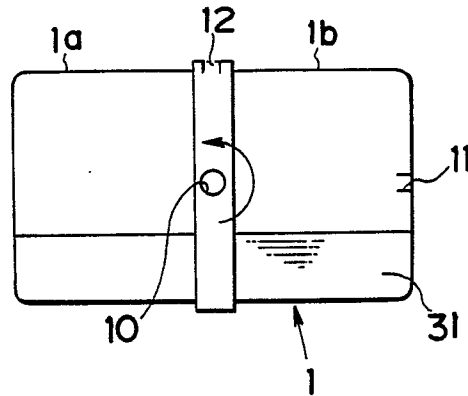


FIG. 8

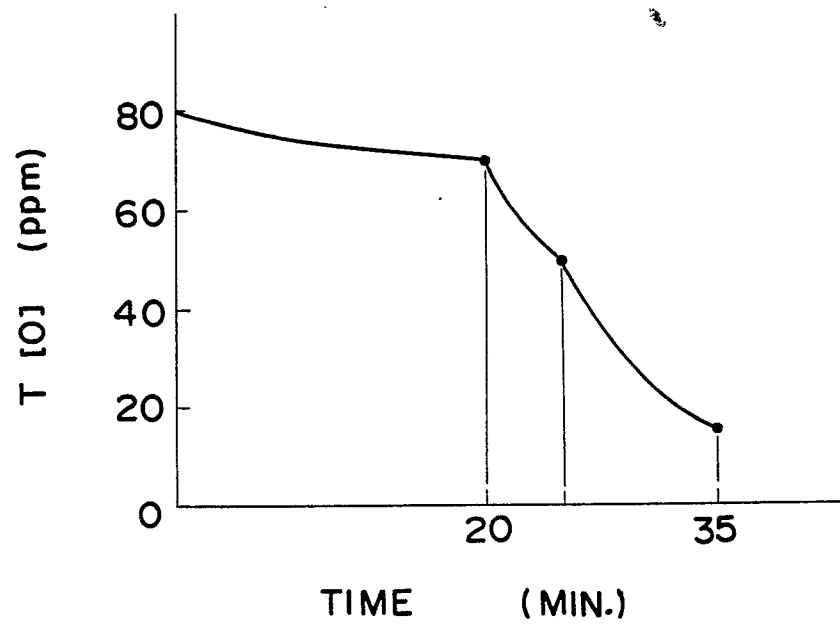


FIG. 9

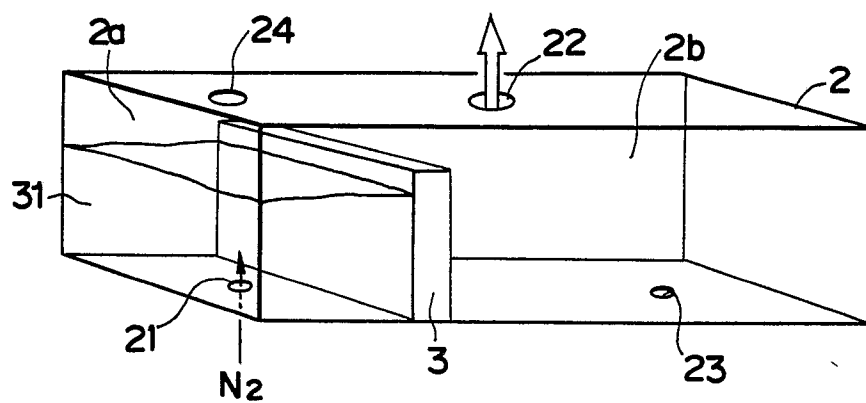


FIG. 10

