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Ramachandran et al.

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[54] **VACUUM DECARBURIZATION IN RH AND DH TYPE DEGASSING SYSTEMS**

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[51] **Int. Cl.** **C21c 7/10,** C21c 5/28

[58] **Field of Search** 75/49, 60, 46

[56] **References Cited**

UNITED STATES PATENTS

3,380,509	4/1968	Hentrich	75/49 X
2,893,860	7/1959	Lorenz	75/49
3,042,510	7/1962	Armbruster et al.	75/49
3,320,053	5/1967	Lehman	75/49 X
3,606,293	9/1971	Erdely	75/49 X
2,093,666	9/1937	Vogt	75/49 X
3,594,155	7/1971	Ramachandran	75/49 X

FOREIGN PATENTS OR APPLICATIONS

1,238,058	6/1960	France	75/49
1,014,827	12/1965	Great Britain	75/49
1,912,907	9/1970	Germany	75/49

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[57] **ABSTRACT**

A method for cyclically decarburizing a bath of molten metal such as steel by transferring the molten metal from a first vessel to a second vessel, evacuating the space above the molten metal in the second vessel while subjecting the metal bath in the second vessel to oxygen to decarburize the same, and returning the decarburized metal from the second to the first vessel. The foregoing cycle is repeated while the pressure within the second vessel is progressively reduced and the oxygen introduced into the second vessel varied to decarburize the molten metal bath in steps without substantial oxidation of metal constituents therein.

6 Claims, 3 Drawing Figures

FIG. 1.

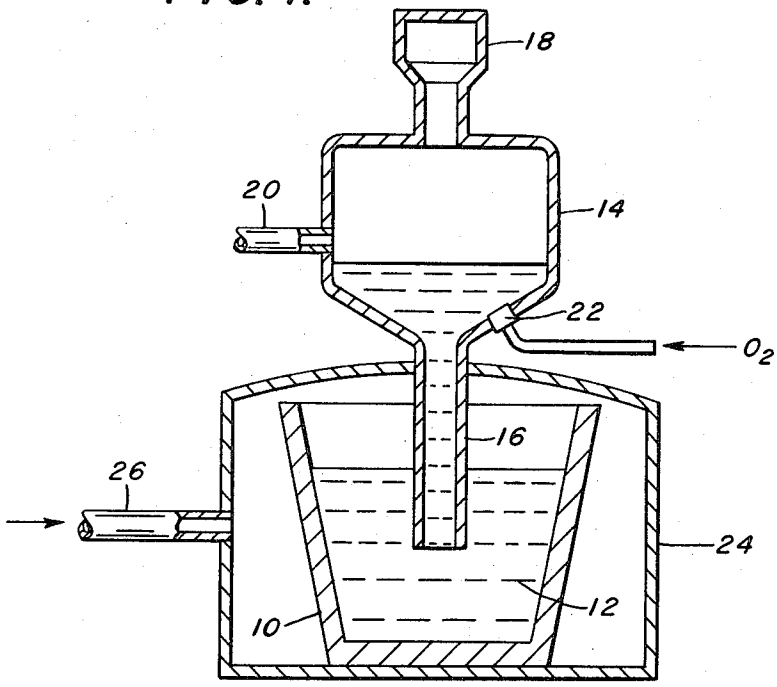

18
20
14
22
O_2
16
26
24
12
10

FIG. 2.

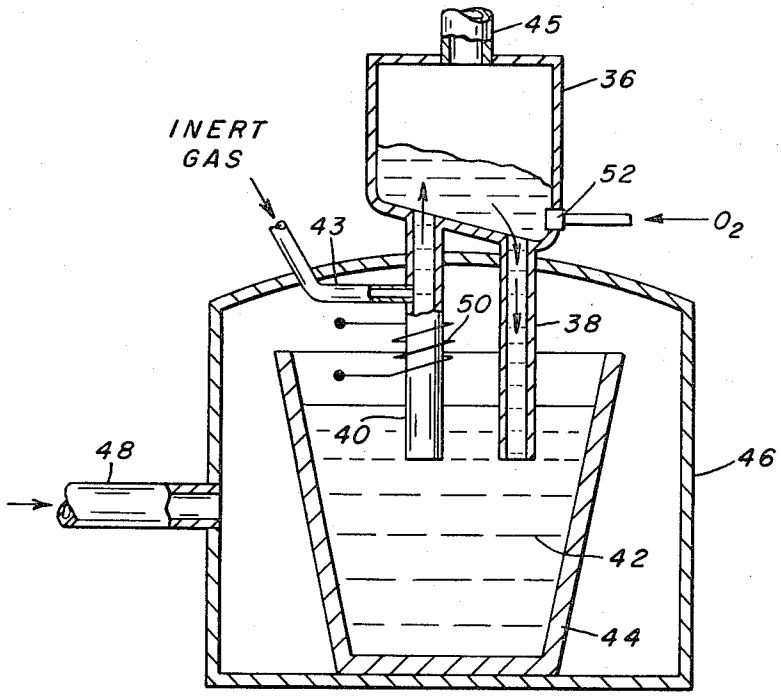
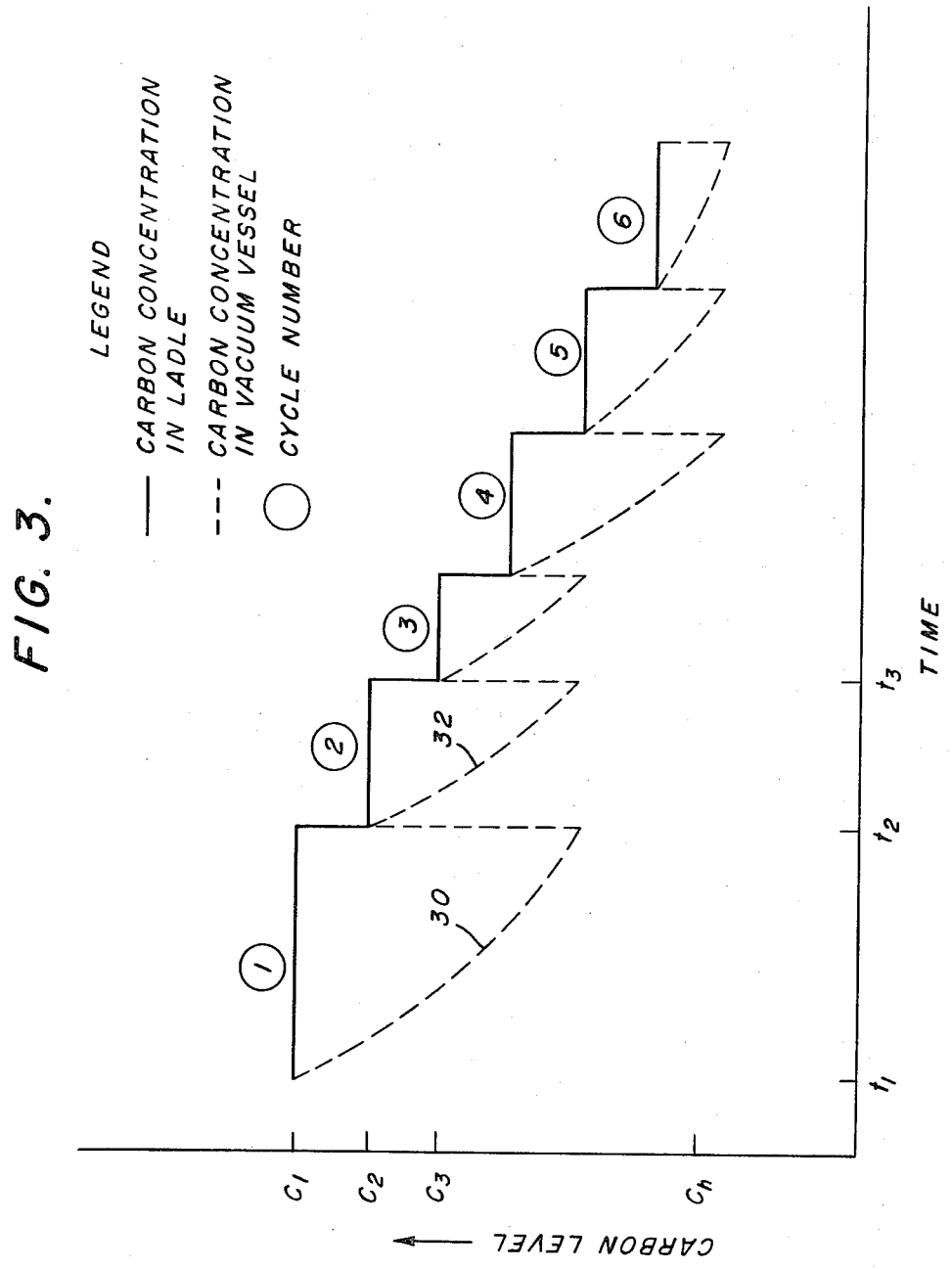

45
36
INERT GAS
52
O_2
43
50
38
40
48
46
42
44

FIG. 3.


LEGEND
CARBON CONCENTRATION IN LADLE
CARBON CONCENTRATION IN VACUUM VESSEL
CYCLE NUMBER
1
2
3
4
5
6
30
32
C_1
C_2
C_3
C_n
CARBON LEVEL
t_1
t_2
t_3
TIME

VACUUM DECARBURIZATION IN RH AND DH TYPE DEGASSING SYSTEMS

BACKGROUND OF THE INVENTION

While not limited thereto, the present invention is particularly adapted for use in decarburizing steels, especially stainless steels. This is achieved with the use of so-called DH and RH type vessels which are normally used for vacuum degassing. In the DH process for degassing, an upper vacuum vessel is lowered until a nozzle or snorkel extending downwardly from its bottom is introduced into a molten metal bath within a ladle. Vacuum is applied to the upper vessel such that metal is sucked into this vessel from the metal bath below, the amount of metal sucked into the vessel being controlled by the depth of immersion of the snorkel in the molten metal bath and the pressure (below atmospheric pressure) within the vacuum vessel. After the metal in the vacuum vessel is degassed, it is emptied by raising the vessel and the snorkel, permitting the degassed metal to flow back into the lower ladle. A new batch of molten metal is then brought into the vacuum chamber by lowering the vessel. The geometry of the vessel and ladle systems is such that satisfactory operation of the system is only possible with the chamber evacuated to a medium to low pressure.

The RH process uses a vacuum chamber which is fitted with two legs or snorkels which are immersed in a melt carried within a lower ladle. The bottom of the chamber is sloped with the inlet leg located at a higher elevation than the outlet. Part way in the inlet leg, provision is made for the insertion of inert gas. This gas operates as a gas lift device which pumps molten metal from the lower ladle into the vacuum vessel. As in the DH system, a low pressure is required within the vacuum vessel in order to elevate the metal to the level where the gas lift device is located.

It will be readily appreciated that the amount of metal drawn into the vacuum chamber in both the DH and RH processes is controlled by the vacuum level in the vessel. That is, more metal is sucked into the treating vessel as the vacuum level drops. This is desirable during degassing since normal degassing is more efficiently accomplished at low pressures. However, when decarburizing under vacuum conditions, it is desirable to conduct the process at variable pressures as is explained, for example, in Ramachandran U.S. Pat. No. 3,594,155. This is particularly true in the case of stainless steels where the process must be controlled precisely to avoid oxidation of chromium values. Hence, normal DH and RH vessels, as presently constituted, are not practical for use in decarburizing stainless steel because they are dependent upon the vacuum level within the treatment chamber in order to suck metal into that treatment chamber.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method is provided, using a modified form of the DH and RH systems, which enables the decarburization of steels at any pressure from atmospheric pressure down to low vacuums. Specifically, there is provided means, other than the vacuum level within the treating chamber itself, for causing molten metal to flow from a lower ladle up into the treatment chamber and thereafter be returned to the treatment chamber. In one embodiment

of the invention shown herein, the basic DH configuration is used; however instead of sucking molten metal up into the treatment chamber, the lower ladle containing the molten bath to be treated is surrounded by an air-tight chamber and air pressure used to force the molten metal upwardly through the treatment chamber snorkel.

In another embodiment of the invention using the basic RH configuration, air pressure can be used to force molten metal upwardly through both the entry and discharge legs of the vacuum vessel or by means of an electromagnetic pump coil surrounding the entry leg.

In both systems, whether the basic DH or RH system is employed, provision is made for the injection of oxygen into the vacuum chamber. Preferably, this is accomplished with the use of tuyeres projecting through the wall of the vacuum chamber and arranged such that they will be beneath the level of molten metal in the vacuum chamber during treatment.

Further, in accordance with the invention, the vacuum level within the treatment chamber is progressively increased (i.e., the pressure is decreased) as successive portions of the molten metal bath within the ladle are decarburized such as to achieve the minimum carbon level in the decarburizing vessel without oxidation of the metallic elements. In the DH system, the pressure is varied in steps for each batch of motlen metal brought upwardly into the vacuum vessel; whereas in the RH process, the pressure can be varied in steps or continually, depending upon requirements.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIG. 1 is a schematic illustration of one embodiment of the invention utilizing the basic DH system;

FIG. 2 is a schematic illustration of another embodiment of the invention utilizing the basic RH system; and

FIG. 3 is a plot showing the manner in which carbon content is reduced using the DH system.

With reference now to the drawings, and particularly to FIG. 1, there is shown a reaction apparatus in accordance with the invention based upon the DH process. The system includes a ladle **10** containing a bath **12** of molten metal to be decarburized, such as stainless steel. Above the ladle **10** is a vacuum reaction vessel **14** having a downwardly-extending nozzle or snorkel **16** extending into the molten metal bath **12.** The reaction vessel **14** can be provided with an upper addition hopper **18** from which additives are added to the melt within the reaction vessel **14.** The interior of the reaction vessel **14** is connected through conduit **20** to apparatus for producing controlled vacuum conditions, such as a vacuum pump or steam ejectors. Projecting through the wall of the vessel **14,** near the bottom thereof, is a tuyere **22** through which oxygen can be injected into the molten metal within the reaction vessel **14** during decarburization. Surrounding the ladle **10** is a closed chamber **24** connected through conduit **26** to a source of pressure such that the pressure above the surface of the molten metal bath **12** can be varied. As will be understood, the chamber **24** can be opened by

suitable means to permit the ladle **10** to be removed and a new ladle inserted.

In operation, the interior of the chamber **24** will be pressurized via conduit **26,** thereby forcing the liquid metal bath **12** upwardly through the snorkel **16** into the reaction vessel **14.** At the same time, the area above the molten metal in the reaction chamber **14** is evacuated through conduit **20,** and oxygen is injected into the bath in the reaction chamber **14** to decarburize the steel contained therein. Following this procedure, the pressure within chamber **24** is reduced, whereupon the portion of the bath in the vessel **14** drains down into the ladle **10.** Then a new batch is forced upwardly into the reaction chamber **14** by again pressurizing the chamber **24;** and this procedure is repeated, with portions of the molten metal bath being decarburized in succession, until a desired carbon content is reached in the bath **12.** As the pressure in vessel **14** is reduced after each cycle, so also is the pressure in chamber **24** to maintain a constant level in vessel **14.**

If desired, an induction heating coil may be provided around the reaction vessel **14** in order to add heat to the melt therein. However, in most cases, this will not be required since the introduction of oxygen into the molten metal within the vessel **14** will generate heat. Additionally, an induction coil can be used around the vessel **14** in order to effect stirring of the melt during the decarburization cycle. Again, however, by proper placement of the oxygen injection tuyere **22,** sufficient mixing will result without the necessity for inductive stirring.

While a tuyere **22** has been shown in the embodiment of the invention of FIG. **1,** it will be appreciated that oxygen can also be introduced using a lance which blows oxygen onto the surface of the metal bath within the vessel **14.** Preferably, the tuyere or tuyeres **22** are placed at a level such that during the normal decarburization cycle, the metal level in the reaction vessel **14** is increased to the point where the tuyeres become submerged. However, when the metal within the reaction vessel **14** is returned to the ladle **10,** the tuyere or tuyeres will be exposed. In this way, there is no need to keep the tuyeres open, if the apparatus is used for degassing, by flushing with an inert gas.

As is explained in Ramachandran U.S. Pat. No. 3,594,155, it is necessary to lower the pressure in the vacuum system as the carbon concentration in the metal bath decreases. This can be done continuously or in steps; however there are some important differences, which are best illustrated by outlining the procedures on a step-by-step basis.

If it is assumed that a batch of molten metal from the bath **12** has been forced upwardly into the vessel **14** by pressurizing chamber **24,** the oxygen is forced through the tuyeres **22,** thereby causing oxidation of carbon and gas stirring. It will be assumed that the carbon concentration of the metal at the start of the decarburization cycle is about 0.4% carbon. It will also be assumed that the tuyeres are immersed to a depth of about 24 inches, that the melt temperature is 2,900° F and that the metal composition is 18.75% chromium, 8.5% nickel, and 0.1% silicon. It will also be assumed for illustration that a four-stage steam ejector is used to evacuate the vessel **14.**

For the particular analysis and temperature given above, the minimum carbon levels that can be reached without chromium losses can be calculated from the following equations:

$$C_n = C_{n-1}(1 - FT) + FT \cdot C_{SL}/(100 - FT[C_{n-1} - C_{SL}) \times 100$$

where

C_n = weight %C at end of nth cycle, in the ladle;

FT = fraction treated; and

C_{SL} = weight %C reached in chamber at end of treatment cycle.

Note that these are rigorous formulae, noting that

$$100/100 - FT(C_{n-1} - C_{SL}) \cong 1.0$$

One can rewrite the equation

Therefore

$$C_n = (1 - FT)\,C_{n-1} + FT \cdot C_{SL}$$

$$C_1 = (1 - FT)\,C_o + FT \cdot C_{SL}$$

$$C_2 = (1 - FT)\,C_1 + FT \cdot C_{SL} = (1 - FT)[(1 - FT)\,C_o + FT \cdot C_{SL}] + FT \cdot C_{SL} = (1 - FT)^2\,C_o + ([1 - FT] + 1)\,FT \cdot C_{SL}$$

$$C_3 = (1 - FT)\,C_2 + FT \cdot C_{SL} = (1 - FT)[(1 - FT)^2\,C_o + [(1 - FT) + 1]\,FT \cdot C_{SL}] + FT \cdot C_{SL} = (1 - FT)^3\,C_o + [(1 - FT)^2 + (1 - FT) + 1]\,FT \cdot C_{SL}$$

$$C_n = (1 - FT)^n\,C_o + [(1 - FT)^{n-1} + (1 - FT)^{n-2} \text{---} + 1]\,FT \cdot C_{SL}$$

Note

$$\sum_{m=1}^{n} ar^m = a\frac{1-r^n}{1-r}$$

Thus

$$\sum_{n=1}^{n-1}(1-FT)^m = \frac{1-(1-FT)^{n-1}}{1-(1-FT)} = \frac{1-[1-FT]^{n-1}}{FT}$$

$$C_n = (1 - FT)^n\,C_o + [1 - (1 - FT)^{n-1} + FT/FT]\,FT \cdot C_{SL} = (1 - FT)^n\,C_o + [1 + FT - (1 - FT)^{n-1}]\,C_{SL}$$

The resulting data for computed values of C_n are shown in the following Table I:

TABLE I

Minimum Carbon Concentration That can be Reached Without Metallic Oxidation of an 18.75% Cr, 8.50% Ni, 0.1% Si Melt at 2900°F as Predicted by Decarburization Model

No.	Pressure (mm. of Hg)	Predicted Min. C	Predicted Equil. C
1	760	0.44	0.36
2	500	0.33	0.25
3	400	0.28	0.21
4	300	0.24	0.16
5	200	0.18	0.11
6	150	0.16	0.08
7	100	0.13	0.06
8	90	0.120	0.052
9	80	0.115	0.046
10	70	0.108	0.040
11	60	0.102	0.035
12	50	0.098	0.029
13	40	0.090	0.023
14	30	0.084	0.018
15	20	0.078	0.012
16	10	0.071	0.006
17	5	0.068	0.003

Assumptions: Bubble diameter 0.5 cm., depth of injection = 24 inches, 100% oxygen.

Assuming that the fourth-stage ejector alone can operate efficiently down to 150 millimeters of mercury, it can be seen that the carbon level can be brought down to about 0.16% carbon and the carbon level can be reduced to about 0.078% using the fourth and third stage

ejectors which operate efficiently from 150 to 15 millimeters of mercury. If it is assumed that the end point carbon desired is around 0.08%, it can be seen that only the fourth and third-stage ejectors need be used.

The process is schematically illustrated in FIG. **3.** Between times t_1 and t_2, a first batch of metal is decarburized in the vessel **14.** During this time, the carbon concentration within the vessel **14** decreases along the broken line **30.** When this decarburized batch of metal is then returned to the ladle **10,** the carbon concentration in the ladle **10** decreases from C_1 to C_2. Between times t_2 and t_3, a second batch of metal is forced upwardly into the reaction vessel **14** and subjected to oxygen. Again, the carbon concentration in the batch being treated decreases along broken line **32** from carbon level C_2 to some lower level; whereupon the treated batch is returned to the ladle **10** and the carbon concentration of the total mass of metal then falls to level C_3. The cycle is repeated a number of times, in this case six times, until the total carbon concentration in the bath is reduced to C_n. Assuming a four-stage steam ejector is used to create the vacuum, only the fourth stage must be used during the first three cycles; however in the fourth, fifth and sixth cycles, when the pressure is reduced further, both the third and fourth stages must be used.

One advantage of the DH system is that the carbon removal process can be accomplished rapidly. That is, if the rate of carbon removal is plotted against carbon content, it will be seen that the removal rate is relatively constant at a high value until the carbon content reaches a predetermined level, below which the removal rate falls off rapidly. In decarburizing the melt in batches, each of which has a relatively high carbon content, the decarburization of each batch can be carried out in the range of high carbon removal rate. These individual batches, when returned to the ladle **10,** then serve to lower the carbon content of the total bath to that level where the removal rate is low.

With reference now to FIG. **2,** an embodiment of the invention is shown wherein an RH type system is employed. In this case, an upper reaction chamber **36** is provided with two downwardly-extending snorkels **38** and **40** which extend beneath the surface of a molten metal bath **42** contained within a ladle **44.** In the usual case, the snorkel **40** is provided with an inlet **43** for the injection of an inert gas. The upper reaction vessel **36** is lowered until the ends of the two snorkels **38** and **40** are submerged beneath the molten metal bath in the ladle **44,** after which the reaction vessel **36** is evacuated via conduit **45** which leads to a pump or steam ejectors. As in the embodiment of FIG. **1,** a chamber **46** surrounds the ladle **44** and is connected through conduit **48** to a pump, not shown, which pressurizes the area within the chamber **46.** In this manner. the combined effect of the pressure within chamber **46** and the vacuum created above the bath in the vessel **36** causes the liquid metal in bath **42** to rise through the snorkels **38** and **40** into the reaction vessel **36.** Argon or another inert gas can be injected via inlet **43** to decrease the density of the column of liquid metal in snorkel **40** and cause a pumping action resulting from imbalance between that column and the denser column of liquid metal in the other extension. Alternatively, an inductive coil **50** can be placed around the snorkel **40** to cause the liquid metal to rise therein.

In the embodiment of FIG. **2,** the molten metal more or less continuously circulates through the reaction vessel **36;** and as it passes through the reaction vessel **36,** oxygen is injected via tuyere **52.** As the decarburizing process continues, the pressure within the reaction vessel **36** is gradually reduced below atmospheric pressure. At the same time, the pressure within chamber **46** is reduced to maintain a more or less constant level in the vessel **36.** The minimum carbon level which can be reached without chromium oxidation at each pressure level should be increased by a value equal to that carbon loss expected in the metal stream, assuming that all of the oxygen in the input gas is consumed as carbon monoxide. Again, the process is controlled in accordance with the teachings of U.S. Pat. No. 3,594,155.

Although the invention has been shown in connection with certain specific embodiments, it will be readily apparent to those skilled in the art that various changes in process steps may be made to suit requirements without departing from the spirit and scope of the invention.

We claim as our invention:

1. In the method of decarburizing a bath of molten metal, the steps of (1) transferring a portion of the molten metal in a first vessel to a second vessel, (2) evacuating the space above said portion of the molten metal in said second vessel to achieve a first predetermined pressure below atmospheric pressure, (3) subjecting the metal while in said second vessel to oxygen to oxidize the carbon content thereof while preventing substantial oxidation of metallic elements in the molten metal, (4) returning said portion of the molten metal from the second vessel to the first vessel, repeating steps (1) to (4) above until the carbon content of said bath of molten metal has been reduced to a desired level and progressively reducing the pressure in said second vessel below atmospheric pressure in successive repetitions of step (2) of the method.

2. The method of claim **1** wherein a batch of molten metal is transferred to the second vessel, subjected to oxygen, and then returned to the first vessel to complete a cycle, and wherein the pressure is reduced in said second vessel in steps and at the completion of each cycle.

3. The method of claim **2** wherein said second vessel is above the first vessel and connected thereto through a single snorkel which extends into a molten metal bath contained in said first vessel.

4. The method of claim **3** including the step of pressurizing the surface of the metal bath in said first vessel to force metal from the first vessel upwardly through said snorkel into the second vessel.

5. The method of claim **4** wherein the pressure on the surface of the metal bath in the first vessel is reduced as the pressure in the second vessel is reduced.

6. The method of claim **1** wherein the molten metal continuously flows from said second vessel to said first vessel and is continually returned to said first vessel, and wherein said pressure is continually reduced in said second vessel as the metal moves from the first vessel to the second vessel and then back to the first vessel, until a desired carbon level is reached in said molten metal bath.

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