

[54] **PROCESS FOR REFINING MOLTEN ALUMINUM**

[75] Inventor: **Andrew Geza Szekely**, Yorktown Heights, N.Y.

[73] Assignee: **Union Carbide Corporation**, New York, N.Y.

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[58] Field of Search **75/93 E, 68 A, 68 R; 266/34 R**

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Primary Examiner—Robert V. Hines

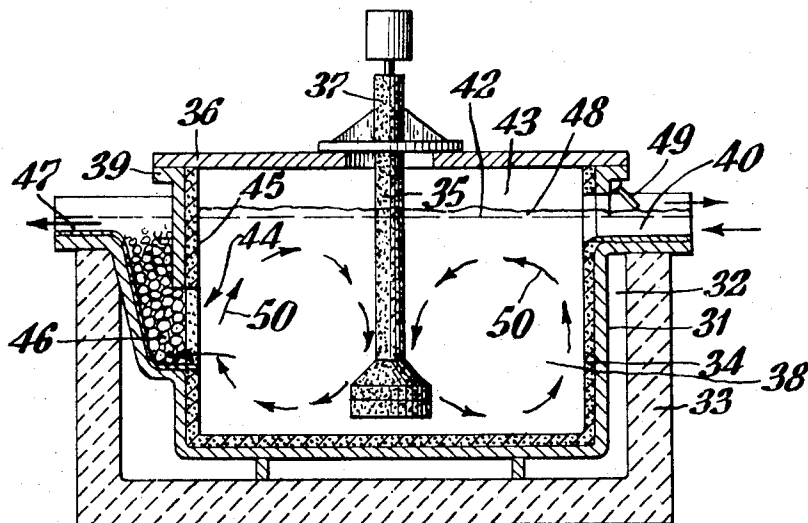
Assistant Examiner—Thomas A. Waltz

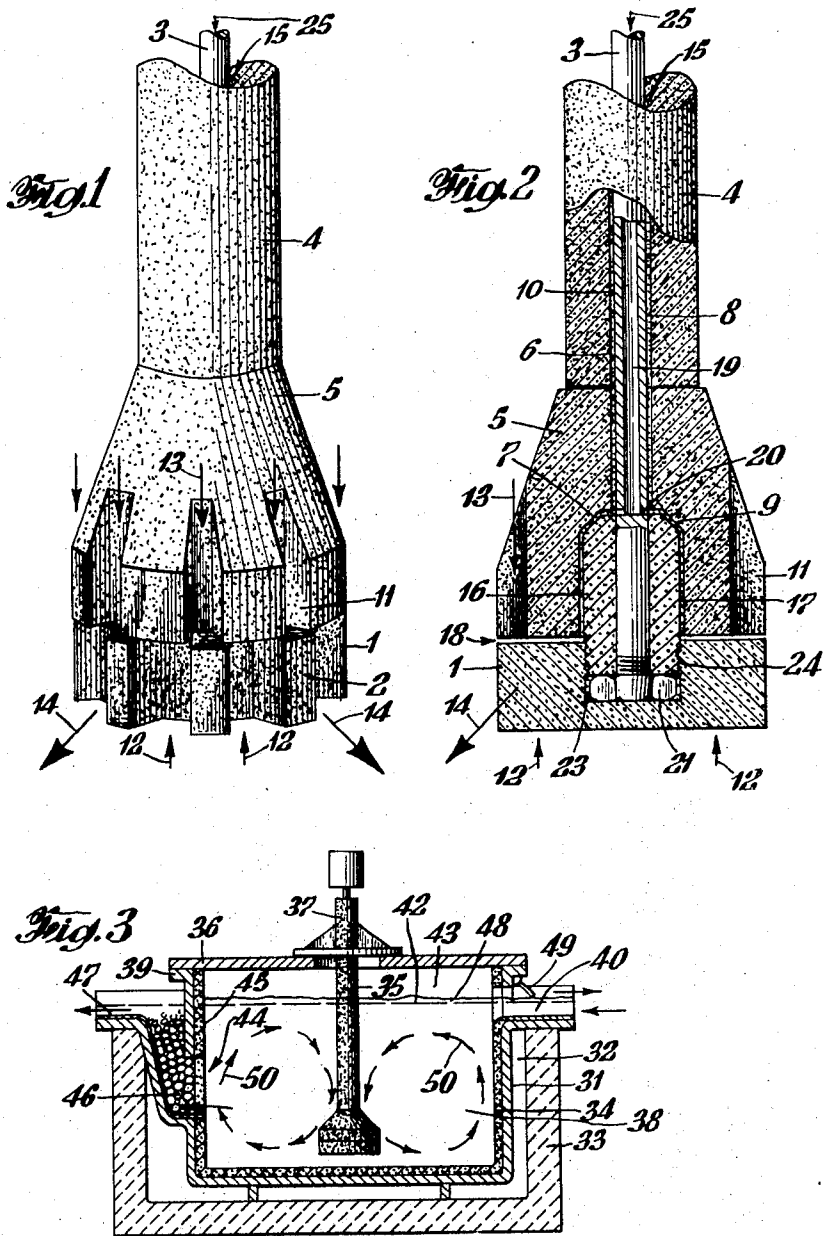
Attorney, Agent, or Firm—Bernard Lieberman

[57] **ABSTRACT**

The apparatus of the invention is capable of injecting gas in the form of small discrete bubbles into a mass of molten metal. The apparatus comprises a rotatable shaft coupled to drive means at its upper end and a vaned rotor at its lower end. Gas under sufficient pressure to be injected into the melt is fed into a passageway extending axially through the device whereby upon rotation of the rotor the gas is injected into the molten metal and subdivided into discrete gas bubbles. The process of the invention utilizes the above described gas injection apparatus for refining molten aluminum by introducing an inert gas into the metal beneath the surface of the melt.

19 Claims, 5 Drawing Figures





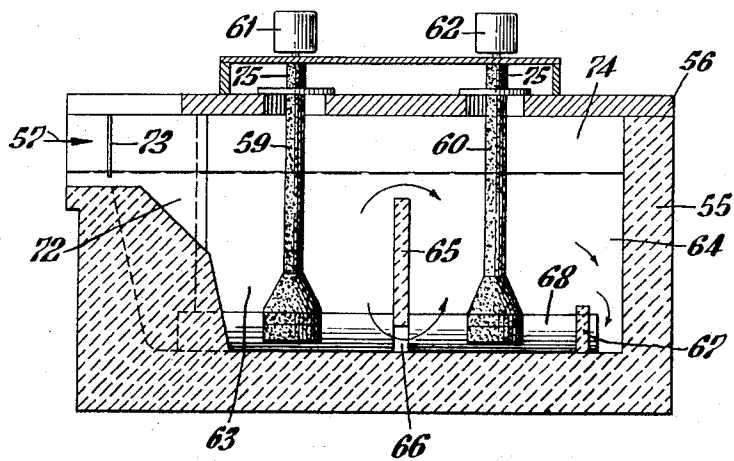


Fig. 4

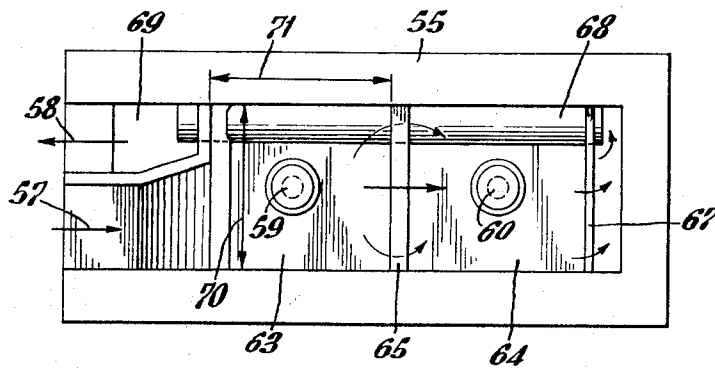


Fig. 5

PROCESS FOR REFINING MOLTEN ALUMINUM

This is a division of application Ser. No. 211,950, filed Dec. 27, 1971, now U.S. Pat. No. 3,743,263.

BACKGROUND

This invention relates in general to refining of molten aluminum, and more particularly, to a method and apparatus for removing dissolved gases and non-metallic impurities from molten aluminum and its alloys without the emission of corrosive or environmentally harmful gases and fumes.

Molten aluminum prior to casting, contains many impurities which, if not removed, cause high scrap loss in casting, or otherwise cause poor metal quality in products fabricated therefrom. In molten aluminum base alloys, the principal objectionable impurities are dissolved hydrogen and suspended non-metallic particles such as the oxides of aluminum and magnesium, refractory particles, etc.

The solubility of hydrogen in aluminum alloys decreases by about an order of magnitude when the metal solidifies. Consequently, hydrogen gas is released from the metal during casting if the hydrogen content of the molten metal is not reduced below the solid solubility limit of hydrogen in the metal. Hydrogen causes pinhole porosity in rapidly solidified metal such as direct-chill cast ingots, or fills shrinkage cavities in slowly solidified metal. Even hydrogen remaining dissolved in the metal after solidification is harmful, since it diffuses during heat treatment into voids and other discontinuities in the solid metal, thereby aggravating the harmful effects of these defect points on the properties of the metal. Excessive amounts of hydrogen cause bright flakes in forgings and blisters in rolled products.

Solid, non-metallic particles suspended in the molten metal cause serious difficulties during casting and fabrication of aluminum alloys. These particles consist mainly of oxides which are introduced into the melt with the scrap during the melting operation, or are produced by direct oxidation with air, water vapor, carbon dioxide and other oxidizing gases while the metal is processed in the molten state. Fine, broken-up oxide films stirred into the molten metal are particularly harmful, since in contrast to the more macroscopic oxides and other solid particles they cannot be skimmed off as dross and remain suspended in the molten metal. It has been suggested that buoyancy is provided for these oxide particles by microscopic hydrogen bubbles adsorbed on the particles. While this suggestion and others predicting some form of association between hydrogen and particulate solids in the melt lack convincing experimental proof, it is an established fact that an interaction between particulate solids and hydrogen does exist during casting of the metal. Solid particles dispersed in the metal act as nuclei for the formation of hydrogen bubbles during solidification of the metal. Furthermore, these non-metallic impurities may act as stress raisers that seriously impair the mechanical properties of the cast metal. In addition, non-metallic impurities cause difficulties in the fabrication of aluminum alloys, such as excessive tool wear in machining die castings, and show up as surface defects in rolled or extruded products.

The purity required of the metal to be cast into ingots for fabrication of aluminum products depends on several factors, such as alloy grade, casting practice, subsequent fabrication procedure and the intended appli-

cation of the fabricated product. As used in the present specifications and claims, the term "sound metal" is used in reference to the quality of the molten metal immediately prior to casting, and is intended to mean that both dissolved hydrogen and non-metallic impurities are removed from the molten metal to an extent required for the production of substantially flawless castings or for fabrication of the particular alloy into a useful metal product. The soundness of the metal is determined by conventional testing procedures well known in the art, such as vacuum solidification test of the molten metal before casting, metallographic and ultrasonic examinations of the solid metal according to relevant standards, porosity tests, destructive testing, etc.

In the past, reduction of the dissolved gas content and non-metallic impurity content of the molten metal has been accomplished by keeping the temperature in the melting hearth and in other metal treating vessels as low as possible, and by holding the metal in the molten state for a prolonged period of time. Such time consuming practices have, however, been modified and largely superseded by various fluxing processes in which the molten metal is contacted with reactive gaseous or solid fluxing agents which generally contain halogens. The most universally used fluxing agent in aluminum processing is chlorine gas or chlorine gas generating compounds, such as hexachloroethane. Chlorine gas is generally injected into the molten alloy from enameled iron pipes or from graphite fluxing tubes specifically constructed for this purpose. Chlorine fluxing results in satisfactory hydrogen and nonmetallic impurity removal in most alloy grades. For high strength structural alloys, it has been found necessary to subject the metal to additional treatment, such as filtering. However, apart from these special cases, chlorine fluxing has satisfied the contemporary product standards set for sound metal quality.

Nevertheless, the use of chlorine presents problems due to its corrosive and toxic nature. Thus, although the use of chlorine for fluxing aluminum alloys has in the past been considered a commercially acceptable practice, increasing concern with air pollution has stressed the need for its elimination. As a result, the numerous drawbacks associated with chlorine fluxing have been brought into sharper focus.

One of the principal drawbacks of chlorine is its high reactivity with metals. Chlorine vaporizes aluminum in the form of aluminum chloride gas, and reacts with substantially all the alloying elements in aluminum alloys. This is undesirable from both an operational as well as economic standpoint. Furthermore, unreacted chlorine gas represents a health hazard for operating personnel. Therefore, the fluxing chamber is generally operated under negative pressure to prevent leakage of the toxic gas into the atmosphere. This, however, facilitates the entry into the chamber of air and moisture from the surrounding atmosphere which then come into contact with the molten metal. As a result, the metal can be recontaminated with hydrogen and oxygen during and after the fluxing operation.

One of the most serious problems caused by chlorine fluxing relates to the hydrolysis products of aluminum chloride. In the presence of moisture, aluminum chloride forms aluminum oxide fume and hydrochloric acid, both of which are considered serious air pollutants. In addition, the presence of hydrochloric acid makes the corrosion problems caused by chlorine even

more severe. Since the cost of removing these compounds, by means of gas cleaning equipment, is relatively high, there is an urgent need in the present state of the art for replacing chlorine as a fluxing agent for aluminum alloys.

In an effort to avoid the problems caused by the use of chlorine fluxing, inert gases, such as nitrogen and argon, have been suggested for the fluxing of aluminum and its alloys. However, comparative tests carried out with these inert gases at conditions similar to those used for chlorine fluxing have shown that the inert gases were inferior to chlorine in their fluxing ability, and in addition have caused operational difficulties. The problems encountered with the use of inert gas have included a less efficient degree of hydrogen removal, severe splashing of the metal at gas flow rates at which no splashing occurred with chlorine, poor non-metallic impurity removal and a significant increase in the metal content of the dross.

The use of porous media has been suggested for the introduction of the inert gas into the metal instead of conventional fluxing tubes. This suggestion was apparently aimed at improving the gas injection technique and, in fact, contributed in some cases to better utilization of the inert gas in removing hydrogen. However, this technique has not gained wide acceptance by the aluminum industry, due to the fact that only at relatively low gas flow rates can porous media efficiently disperse the gas into distinct gas bubbles in molten aluminum, and because at practical gas flow rates the degree of non-metallic impurity removal has been unsatisfactory. Thus, inert gases introduced through porous materials are used principally for degassing aluminum alloys under special plant conditions, where the production routine and economics justify a relatively slow metal treatment rate.

The prevailing view today in the aluminum industry, derived from the attempted use of inert gases, is that while the dissolved hydrogen level can be satisfactorily controlled in some aluminum alloys, these gases cannot successfully remove non-metallic impurities from the metal and cause high metal loading of the dross. This conclusion has led to the development of complicated and expensive fluxing techniques, combining inert gas sparging with molten metal filtering, or alternately, to less sophisticated fluxing techniques which utilize various gas mixtures containing substantial amounts of chlorine such that side effects of chlorine fluxing, namely, the emission of corrosive and harmful gases and fumes, are only moderated but not eliminated by the partial replacement of chlorine, or by the simple dilution of the effluent gas. Thus the use of chlorine-nitrogen and other gas mixtures containing substantial amounts of chlorine do not represent long-range solutions to the pollution problem of the aluminum industry.

OBJECTS

Accordingly, it is an object of this invention to provide a device capable of injecting inert gas into a molten metal bath, such as aluminum, in the form of small discrete bubbles at high gas flow rates in such manner as to cause the gas bubbles to come into intimate contact with the entire mass of the molten metal bath.

It is another object of this invention to provide an effective system for refining aluminum by removing hydrogen and other non-metallic impurities therefrom

without causing the emission of corrosive or toxic gaseous by-products.

It is yet another object of this invention to provide a process for refining aluminum with inert gas which efficiently removes hydrogen and other non-metallic impurities from the metal in a continuous process at high metal throughput rates.

SUMMARY

The above objects and others which will be apparent to those skilled in the art are achieved by the present invention one aspect of which comprises: a device capable of subsurface injection of gas in the form of small discrete bubbles into a mass of molten metal contained in an enclosure, comprising in combination:

1. a rotatable shaft coupled to drive means at its upper end and fixedly attached to a vaned rotor at its lower end,

2. a stationary sleeve surrounding said shaft and fixedly attached at its lower end to a vaned stator containing a plurality of vertical channels between said vanes,

3. axially extending passageway for conveying and discharging said gas into said mass of metal, formed by the inner surfaces of said sleeve and stator and the outer surface of said shaft, and

4. means for providing gas to the upper end of said passageway under sufficient pressure to be injected into the melt,

whereby upon rotation of said rotor and provision of said gas flow, the gas is injected into said molten metal and subdivided into discrete gas bubbles, and a circulation pattern of said molten metal is induced which causes intensive stirring such that substantially the entire mass of molten metal in said enclosure comes into intimate contact with the gas bubbles.

The second aspect of the present invention is a system for refining molten aluminum comprising in combination: (1) a gas injection device as set forth above, (2) an insulated vessel provided with entrance and exit means for the continuous flow of molten metal through said vessel, means for the discharging of gas from said vessel and (3) a vessel cover which seals said vessel to prevent infusion of air and moisture into said vessel, which enables said vessel to be operated under positive pressure and which has an opening therein into which said gas injection device is inserted in a sealed manner.

The third aspect of the present invention is a process for removing dissolved hydrogen and non-metallic impurities from molten aluminum prior to casting comprising the steps of:

1. feeding molten aluminum into a refining zone,

2. maintaining a protective atmosphere above the surface of the molten metal at a positive pressure relative to the ambient pressure, thereby preventing infusion of air and moisture into said zone and contact of the molten metal therewith,

3. introducing an inert gas in the form of discrete bubbles into the molten metal beneath the surface of the melt,

4. stirring the molten metal in the refining zone to create a circulation pattern in the molten metal relative to the points of entry of the gas bubbles in the melt such that the gas bubbles introduced into the melt are transported substantially radially outward, relative to said points of entry of the bubbles, thereby prolonging the residence time of the gas bubbles in the melt and caus-

ing the gas bubbles to come into intimate contact with substantially the entire mass of molten aluminum in said refining zone,

5. withdrawing the spent inert gas containing hydrogen released by the metal, while collecting and separating the other non-metallic impurities in a dross layer on the surface of the molten aluminum, and

6. withdrawing the refined molten aluminum from said refining zone.

The term "inert gas" as used herein is meant to include gases which are inert towards molten aluminum. Argon and nitrogen or mixtures thereof are preferred for this purpose although, the inert gases of the periodic table viz., helium, krypton, xenon or mixtures of any of them are also suitable for the present invention.

The term "aluminum" as used throughout the specification and claims is meant to include pure aluminum metal as well as alloys of aluminum.

DRAWINGS

FIG. 1 is a perspective view of a preferred embodiment of the gas injection device of the present invention;

FIG. 2 is a cross-sectional view of the device shown in FIG. 1;

FIG. 3 is a schematic diagram in cross-section illustrating a preferred system for refining a metal stream in a continuous process in accordance with the present invention;

FIGS. 4 and 5 are a cross-sectional and a top view, respectively, of another preferred embodiment of apparatus suitable for refining molten metal in accordance with the present invention.

DETAILED DESCRIPTION

The gas injection device of the present invention is characterized by its ability to inject a gas at high flow rates into molten metal in the form of discrete gas bubbles and to achieve a high degree of gas dispersion throughout the melt. The device, when in operation, induces flow patterns in the metal in the vicinity of the device such that the gas bubbles which are formed, are transported along a resultant flow vector which is radially outward with a downward component relative to the vertical axis of the injection device. These flow patterns have several advantageous effects. First, essentially vertical stirring is provided for the entire body of the melt, whereby a downwardly directed flow along the device, in combination with the rotating vanes, causes subdivision of the gas into small discrete gas bubbles. Second, the rapid conveyance of the gas bubbles away from the point of introduction into the melt prevents bubble coalescence in the zone where the gas bubble concentration is the highest. Third, the gas residence time of the well dispersed gas bubbles in the melt is prolonged, because the gas bubbles do not immediately, upon formation, rise to the surface under the influence of gravity.

Another factor which contributes to maximization of the subdivision of the gas into small bubbles, and hence leading to a large metal-gas interfacial area, is the preheating of the gas before it enters the melt. Such preheating is provided in the present invention by conducting the gas through a passageway running the length of the device which is submerged in the hot molten metal. Thus, the initially cold gas is preheated by contact with the hot, heat conducting walls of the gas

passageway, whereby the gas is expanded before being subdivided into gas bubbles. Consequently, the number of bubbles generated from a given volume of gas is increased substantially, and thermal growth of the small bubbles in the melt is substantially prevented.

When used for injecting inert gas into molten aluminum, the injection device of the present invention produces an unanticipated improvement in the efficiency of the refining operation. In addition to being able to degas the metal at a high throughput rate, the vigorous stirring action produced by the device, coupled with the large gas/metal contact area of the well distributed gas bubbles, assure efficient removal of solid particulate impurities suspended in the melt — a major deficiency in the prior art of light metal refining with inert gases. As a result, the process of the invention can refine aluminum at an efficiency comparable to that achieved with chlorine, while eliminating the problems inherent with chlorine fluxing.

As shown in FIGS. 1 and 2, the gas injection device consists of rotor 1, equipped with vertical vanes 2, and rotated by means of a motor, such as an air motor or electric motor (not shown) through shaft 3. Shaft 3 which does not contact the melt during normal operation, may be constructed of steel, while the remainder of the equipment is preferably constructed from a refractory material, such as commercially available graphite or silicon carbide, materials which are inert toward aluminum and its alloys at the operating temperatures involved. Shaft 3 is shielded from the molten metal by sleeve 4, which is fixedly attached to stator 5. The abutting inner surfaces 6 and 7 respectively, of sleeve 4 and stator 5, and the abutting outer surfaces 8 and 9 respectively, of shaft 3 and rotor 1, form an annular, axial passageway 10 for the gas to be injected.

A plurality of vertical channels 11 are machined into stator 5. The combination of stator 5 and rotor 1, when in operation, induce an upper and lower flow pattern of molten metal around the injection device as indicated generally by the arrows 13 and 12, respectively. Specifically, the upper flow pattern 13 has a main velocity vector pointing essentially downward, i.e., it is coaxial with the axis of rotation of rotor 1, thereby forcing the molten metal through the channels 11 of stator 5; the lower, more localized flow pattern indicated by arrows 12, develops beneath the rotor 1 and is pointed essentially upward and perpendicular to the axis of rotation of the rotor 1. The resultant flow of these components is indicated by arrows 14, which show that the molten metal is forcefully discharged by the rotating vanes 2 radially and downwardly away from rotor 1. The resultant flow pattern causes a well distributed and uniform gas dispersion and a thorough agitation of the molten metal within the treating vessel.

An inert gas (indicated by arrow 15), such as argon or nitrogen, is introduced into the annular passageway 10 at a predetermined pressure and flow rate. The gas fills the bell shaped pocket 16 which is a continuation of passageway 10 surrounding neck 17 of rotor 1. Since the gas is supplied at a pressure greater than the pressure prevailing in the molten metal at a height indicated by arrow 18, the gas pocket 16 prevents molten metal from running back through the gas passage and from coming in contact with the metal shaft 3 of the gas injector. Neck 17 surrounds shaft 3 and is constructed from a material resistant to molten aluminum in order to protect shaft 3 from attack by molten aluminum. As

shown in FIG. 2, the torque from shaft 3 is transferred to rotor 1 by means of winged cross-piece 21 which is threaded to shaft 3. Cross-piece 21 is placed during assembly into cavity 23 of rotor 1, the cavity 23 having a shape corresponding to that of cross-piece 21. Thereafter, cavity 23 is sealed by threading and cementing neck 17 into thread 24 in rotor 1.

The introduction of inert gas 15 into annular passageway 10 need not necessarily be the sole means of providing the gas to be injected. An alternate embodiment of the invention may include a hollow shaft, wherein a passageway 19 extends axially through shaft 3 and is provided with a plurality of drillings 20 which provide communication with passageway 10 and gas pocket 16. Thus, inert gas (indicated by arrows 15 and 25) may be provided through either passageway 10 or passageway 19 or both.

It is important that the cold gas (indicated by arrows 15 and 25) entering the injector be preheated during its passage through passageway 10 or passageway 19, and gas pocket 16 by contacting the sleeve 4 and shaft 3 which are essentially at the temperature of the melt. The preheated gas is forced between the vanes of the rotor 1 where it is broken up into small discrete bubbles by collision with the vanes 2 and by the metal flow sweeping past the vanes. The forced circulation of the metal around the injector device rapidly disperses the gas bubbles as they are formed in a direction essentially along the main flow velocity vector, indicated by arrows 14. The initial trajectory of the gas bubbles follows the direction of the arrows 14 until the buoyancy force prevails and causes the gas bubbles to rise to the surface of the melt.

The beneficial effects of the forced circulation pattern of the metal around the injection device include the following: (1) the provision of an efficient mechanism for small gas bubble formation, (2) the prevention of bubble coalescence by dispersing the small gas bubbles almost simultaneously with their formation, (3) the provision of efficient circulation of the metal, and (4) prolonged residence time of the gas bubbles in the melt beyond the time they would remain in the melt if gravity were the sole force acting upon them.

The process of the invention can be carried out in a batch-type operation, or in a continuous operation by using a refining system such as shown in FIG. 3. The refining system comprises a cast iron shell 31 which is maintained at its operating temperature by conventional heating means which may be located in well 32, and is insulated against heat loss by an outer refractory shell 33. The inner surface of shell 31 is lined with graphite 34 or with other refractory materials which are inert to molten aluminum and non-metallic impurities likely to be present. Shell 31 is provided with a cover 36 which rests upon flanges 39. A gas-tight seal is provided between flanges 39 and cover 36 which may be bolted or otherwise fastened thereto, thereby allowing the system to be operated without the infiltration of air. A gas injection device 35, such as that shown in FIG. 1, is fastened to cover 36 and supported therefrom.

Inert gas (indicated by arrow 37) is injected into molten metal 38 by gas injector 35. The gas after passing through the molten metal, collects in head space 43 to form an inert gas blanket over the melt and leaves through metal inlet port 40 counter-current to the incoming flow of metal. The free cross-sectional area of

the gas passage, and hence the pressure in the system, is regulated by damper 49 located in port 40. The slightly pressurized inert gas in head space 43 prevents air leakage into the vessel.

Entry of the metal 38 into the refining system is through metal inlet port 40. Inside the vessel, metal 38 is sparged by the uniformly distributed small bubbles of inert gas and is agitated by the action provided by the rotating gas injector 35. Hydrogen dissolved in the melt diffuses into and is carried away by the bubbles of inert gas as they rise through the melt to the melt surface 42. The large surface area of the finely dispersed gas bubbles also serves as an efficient transport means for suspended oxide particles to dross layer 48 at the melt surface 42 from where they can be removed by skimming. The major overall circulation pattern developed in the molten metal are schematically shown by arrows 50. It is this induced flow pattern of metal in the vessel which continues to bring fresh metal into contact with the gas bubbles which are being discharged from the space between the rotor and stator of the injection device.

The refined molten metal leaves the refining vessel through discharge port 44 situated below the metal surface 42 in wall 45. The metal then passes through well 46 and leaves the system through exit trough 47 to a casting station. Well 46 may contain a conventional filtering medium, such as, graphite or solid refractory chips.

Skimming of the metal surface 42 may be accomplished by stopping the inlet flow of metal to the refining vessel while maintaining the flow of inert gas 37 through gas injector 35 so as to push the dross layer 48 into inlet trough 40 from where it may be removed by mechanical means. Alternatively, metal surface 42 can be skimmed by means of a hand tool inserted into shell 31 through inlet trough 40 or through an opening (not shown) in cover 36.

The refining operation is not restricted to being carried out in a single refining zone as shown in FIG. 3; rather, the vessel may contain a plurality of individual refining compartments or zones through which the molten metal passes in series. FIGS. 4 and 5 illustrate such an alternate arrangement.

The refining vessel 55, shown in FIGS. 4 and 5, is constructed from a refractory which is inert to molten aluminum, and is insulated against heat losses with high temperature insulating materials. If necessary, the vessel may also be provided with electric heating elements (not shown) to compensate for heat losses. Refining vessel 55 is provided with a cover 56 which is attached to vessel 55 gas-tight leaving only the metal inlet trough 57 unsealed. Gas injectors 59 and 60 which are of the type described in FIG. 1, and their respective drives 61 and 62 are supported by cover 56. Arrows 75 indicate inert gas entering gas injectors 59 and 60 through their respective inlet ports.

The refining vessel 55 is intended to be used in continuous operation, i.e., molten metal is continuously supplied through inlet trough 57 into the vessel 55, the metal is refined by continuous agitation and gas injection through injectors 59 and 60, and the refined metal is continuously withdrawn from the vessel via exit trough 58. Reference to FIG. 5 shows that refining vessel 55 is provided with two refining zones 63 and 64 separated by a baffle plate 65. The metal first enters refining zone 63 where it is agitated and sparged with an inert gas provided by gas injector 59. The metal leaves

the refining zone 63, in part by overflow over the top of baffle plate 65, and partly by underflow through ports 66 provided in baffle plate 65. The metal is further refined in the second refining zone 64 where it is similarly agitated and sparged with inert gas provided by gas injector 60. The metal leaves refining zone 64 by overflowing the bottom baffle plate 67 and entering exit pipe 68. Exit pipe 68 is fabricated from a refractory material, such as graphite or silicon carbide and serves to conduct the refined molten metal from refining zone 64 to exit well 69 where it leaves the refining vessel through exit trough 58.

The refining gas introduced into the system passes through the molten metal, collects in head space 74 above the metal and leaves the refining vessel 55 through inlet trough 57 above and in counter-current flow to the entering molten metal. The pressure in the refining vessel 55 may be adjusted by a hinged damper 73, located in inlet trough 57, by regulating the free cross-sectional area of the gas passage in inlet trough 57. Thus, it is possible to provide, in addition to the static seal provided by cover 56, a dynamic gas seal for the refining vessel by operating vessel 55 slightly above the ambient pressure so as to prevent air from entering the vessel.

The degree of refining which is necessary will, of course, vary with the intended use of the cast product. For high strength structural alloys, the addition of a salt flux may be advantageous during refining to promote oxide-metal separation. Preferably, the flux is selected from the group consisting of halides of alkali and alkali-earth metals. This chemical flux may be charged into the inlet trough 57 when the flow of metal is initiated through the refining vessel or through a port (not shown) provided in the cover 56. In addition, the exit well 69 may be filled with a suitable filtering medium, preferably one having a density lower than that of molten aluminum or its alloys, such as coke or crushed graphite, to insure removal of the flux from the metal as it leaves the refining vessel 55.

An efficient and convenient alternate method of providing an "in situ" fluxing agent to the bath is the addition of a small amount of chlorine to the inert gas. When chlorine is introduced into a molten aluminum alloy containing magnesium, part of the chlorine reacts with magnesium forming magnesium chloride, an efficient fluxing agent, the remaining part reacts with aluminum forming aluminum chloride gas. It has been discovered that in the presence of a large excess of inert gas, magnesium chloride is preferentially formed relative to aluminum chloride, to the extent that substantially all the chlorine supplied with the inert gas reacts with magnesium. It is therefore possible to generate an efficient "in situ" fluxing agent in magnesium containing aluminum alloys by introducing chlorine into the melt, in a highly diluted form with an inert gas, through the injection device of the present invention. The intimate mixing of the injected gas and the molten metal, which is provided by the injection device, enhances the formation of magnesium chloride, thereby preventing the emission of unreacted chlorine or aluminum chloride from the system. The concentration of chlorine in the inert gas is generally regulated in the range of 0 to 5 volume percent depending upon the magnesium content of the alloy, but in no case is it allowed to exceed the amount which results in the emission of harmful by-products from the system.

A distinct advantage of the system of the present invention is that it can be readily adjusted to supply the refining gas requirements for different alloy grades and the speed of refining can be matched to a wide range of casting rates. The specific refining gas requirement, generally expressed as volume of gas at normal temperature and pressure per unit weight of metal to be treated, is a function of the composition of the alloy and the degree of purity required in the finished product. The flow rate of metal through the refining system is governed by the required speed of casting, i.e., by the type of casting machines used and by the number of ingots cast simultaneously from the refined metal. The following examples illustrate a convenient way by which operating conditions in the system may be adjusted depending upon the particular alloy to be refined and the desired rate of refining in accordance with the present invention.

Initially, the flow rate of the refining gas per gas injection device is calculated from the following formula:

$$V = W \cdot C/N \quad (1)$$

where:

V = the flow rate of the refining gas through the device, normal cu. ft./min;

W = the metal flow rate or refining rate, lbs/min;

C = the specific refining gas requirement, normal cu. ft./lb metal;

N = the number of gas injection devices in the system.

The specific refining gas requirement, C is determined by experimentation or, for purposes of start-up, it can be estimated based on the amount of chlorine used for fluxing that particular alloy in conventional chlorine practice. For example, alloys which are known to be relatively easy to degas or have no critical application can be refined with $c = 0.005$ cu. ft. gas/lb metal, while high strength structural alloys may require $C = 0.040$ cu. ft. gas/lb metal to satisfy the more stringent purity requirements of the product.

After having determined the necessary gas flow rate through the injection device, the speed of rotation of the rotor is adjusted in accordance with the following formula:

$$R = (300 + 750V + 83r^2)/d \quad (2)$$

where:

R = the speed of rotation of the rotor, (RPM);

V = the gas flow rate through the device as calculated from formula (1), normal cu. ft./min;

r = the ratio of the least cross-sectional dimension of the refining zone around the rotor to the diameter of the rotor (calculated with consistent units); for example, in the refining system shown in FIG. 5, the least cross-sectional dimension of refining zone 63 is the smaller of the two dimensions indicated by arrows 70 and 71;

d = the diameter of the rotor, inches.

This formula yields an approximate RPM for the rotor which ensures a satisfactory dispersion of the refining gas and a good stirring of the metal bath under most operating conditions. From the formula it can be seen that the speed of the rotor must be increased with

increasing refining gas flow rates. It should be noted, however, that it is possible to operate the device at significantly lower speeds than predicted by this formula, the optimum speed being dictated primarily by the desired degree of refining.

EXAMPLE I

1,640 lbs of alloy selected from the 6,000 series is to be refined in 12 minutes. The specific refining gas requirement of the alloy is $C = 0.0146$ normal cu. ft. gas/lb metal. The system contains one gas injection device and is characterized by the following dimensional constants: $r = 4$ and $d = 8$ inches. The refining rate, W , defined in formula (1) is calculated as $W = 1,640 \text{ lbs}/12 \text{ minutes} = 137 \text{ lbs/min}$.

From formula (1): $V = 2$ normal cu. ft. gas/min. By substituting this value together with the dimensional constants into formula (2), the necessary rotational speed is calculated as $R = 391$ revolutions per minute. In practice, 300 RPM has been found adequate to refine this particular alloy at the described conditions.

EXAMPLE II

A high strength structural alloy selected from the 7,000 series is to be refined in a continuous operation, i.e., while the metal is being transferred to a casting station where several fabricating ingots are cast simultaneously from the refined alloy, at a total rate of 37,000 lbs metal/hour. The specific refining gas requirement of the alloy was determined by experimentation as $C = 0.019$ normal cu. ft./lb. The system contains two gas injection devices and is characterized by the following dimensional constants: $r = 3.2$ and $d = 7.5$ inches.

For a refining rate of $W = 617 \text{ lbs/min}$, the solution of formula (1) yields a gas flow rate of $V = 5.86$ normal cu. ft./min and, in accordance with formula (2), a satisfactory refining is achieved by rotating the gas injection devices at a speed of 739 RPM.

What is claimed is:

1. A process for refining molten aluminum comprising the steps of:

1. feeding molten aluminum into a refining zone,
2. maintaining a protective atmosphere above the surface of said molten aluminum at a greater than atmospheric pressure, thereby preventing contact of the melt with air or atmospheric moisture,
3. providing a gas injection device submerged in said molten aluminum comprising (a) a shaft fixedly attached to a vaned rotor at its lower end, (b) a stationary sleeve surrounding said shaft, and (c) a passageway for conveying and discharging inert gas into the molten metal running the length of said gas injection device,
4. introducing an inert gas into the upper end of said passageway under sufficient pressure to be injected into the melt,
5. preheating the inert gas by contact thereof with the hot walls of the passageway, whereby the gas is expanded, before being sub-divided into gas bubbles, to the point where thermal growth of said bubbles in the melt is substantially prevented,
6. directing the preheated gas to the vanes of said rotor of said gas injection device,
7. sub-dividing the inert gas into discrete gas bubbles by rotating said vaned rotor at a speed sufficient to create a circulation pattern in the molten aluminum such that the gas bubbles are transported sub-

stantially radially outward with a downward component relative to their points of entry into the melt thereby coming into intimate contact with substantially the entire mass of molten aluminum in said refining zone, resulting in the removal of dissolved hydrogen and substantially all non-metallic impurities from said melt,

8. withdrawing the spent inert gas containing hydrogen while collecting other non-metallic impurities in a dross layer on the surface of the molten aluminum, and

9. withdrawing the refined molten aluminum from said refining zone.

2. The process of claim 1 wherein said inert gas is argon.

3. The process of claim 1 wherein said gas inert with respect to aluminum is nitrogen.

4. The process of claim 1 wherein said inert gas is a mixture of argon and nitrogen.

5. The process of claim 1 further including the step of adding a solid chemical fluxing agent to the molten metal, said chemical fluxing agent being selected from the group consisting of halides of alkali metals and alkali-earth metals.

6. The process of claim 1 wherein said molten aluminum is a magnesium containing aluminum alloy and said inert gas contains from about 0 to 5 volume percent of chlorine.

7. The process of claim 1 wherein said molten aluminum is a magnesium containing aluminum alloy and said inert gas contains chlorine in an amount sufficient to form a magnesium chloride flux but less than an amount which results in the emission of harmful by-products from the system.

8. The process of claim 1 wherein said passageway is formed by the outer surface of said shaft and the inner surface of said stationary sleeve.

9. The process of claim 1 wherein said passageway extends axially through said shaft.

10. A process for refining molten aluminum comprising the steps of:

1. providing a refining vessel for containing molten aluminum, said vessel containing at least one refining zone,
2. feeding molten aluminum into the refining vessel,
3. maintaining a protective atmosphere above the surface of the molten metal at a greater than atmospheric pressure, thereby preventing contact of the molten metal with air or atmosphere moisture,
4. providing at least one gas injection device in said refining vessel submerged in said molten aluminum comprising (a) a shaft fixedly attached to a vaned rotor at its lower end, (b) a stationary sleeve surrounding said shaft, and (c) a passageway for conveying and discharging inert gas into the molten metal running the length of said gas injection device,
5. introducing an inert gas into the upper end of said passageway under sufficient pressure to be injected into the melt, the flow rate of said inert gas being defined by the following formula:

$$V = W \cdot C/N$$

where:

V = flow rate of gas through each injection device, normal cu. ft./min.

W = the feed rate of molten aluminum into said refining vessel, lbs/min.

C = the specific refining gas requirement, having a value of from 0.005 to 0.040 normal cu. ft./lb. metal

N = the number of gas injection devices in said refining vessel,

6. sub-dividing the inert gas into discrete gas bubbles by rotating said vaned rotor at a speed sufficient to create a circulation pattern in the molten aluminum such that the gas bubbles are transported substantially radially outward with a downward component relative to their points of entry into the melt, resulting in the removal of dissolved hydrogen and substantially all non-metallic impurities from the aluminum melt.

7. withdrawing the spent inert gas containing hydrogen while collecting other non-metallic impurities in a dross layer on the surface of the molten aluminum, and

8. withdrawing the refined molten aluminum from said refining vessel.

11. The process of claim 10 wherein said gas injection device is operated at a speed approximately as defined by the following formula:

$$R = (300 + 750V + 83r^2) / d$$

where:

R = rotational speed of the rotor, RPM;

V = gas flow rate through the injection device, normal cu. ft./min;

r = the ratio of the least cross-sectional dimension of the refining zone to the diameter of the rotor (dimensionless); and

d = diameter of the rotor, inches.

12. The process of claim 10 wherein said inert gas is argon.

13. The process of claim 10 wherein said gas inert with respect to aluminum is nitrogen.

14. The process of claim 10 wherein said molten aluminum is a magnesium containing aluminum alloy and said inert gas contains from about 0 to 5 volume percent of chlorine.

15. The process of claim 10 wherein said molten aluminum is a magnesium containing aluminum alloy and said inert gas contains chlorine in an amount sufficient to form a magnesium chloride flux but less than an

amount which results in the emission of harmful by-products from the system.

16. A process for refining molten aluminum comprising the steps of:

1. feeding molten aluminum into a refining zone,

2. maintaining a protective atmosphere above the surface of said molten aluminum at a greater than atmospheric pressure, thereby preventing contact of the melt with air or atmospheric moisture,

3. introducing an inert gas into said melt beneath the surface thereof,

4. preheating said inert gas before being subdivided into gas bubbles by expanding the gas to the point where thermal growth of said bubbles in the melt is substantially prevented,

5. sub-dividing the inert gas into discrete gas bubbles,

6. creating a circulation pattern in the molten aluminum such that the bubbles of said inert gas are transported substantially radially outward with a downward component relative to their points of entry into the melt, whereby said gas bubbles come into intimate contact with substantially the entire mass of molten aluminum in said refining zone, resulting in the removal of dissolved hydrogen and substantially all non-metallic impurities from said melt,

7. withdrawing the spent inert gas containing hydrogen, while collecting other non-metallic impurities in a dross layer on the surface of the molten aluminum, and

8. withdrawing the refined molten aluminum from said refining zone.

17. The process of claim 16 wherein said inert gas with respect to aluminum is selected from the group consisting of argon, nitrogen and mixtures thereof.

18. The process of claim 16 wherein said molten aluminum is a magnesium containing alloy and said inert gas contains from about 0 - 5 volume percent of chlorine.

19. The process of claim 16 wherein said molten aluminum is a magnesium containing alloy and said inert gas contains chlorine in an amount sufficient to form a magnesium chloride flux but less than an amount which results in the emission of harmful by-products from the system.

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