Patented Dec. 11, 1934

1,983,604

UNITED STATES PATENT OFFICE

1,983,604

PRODUCTION OF REFINED METAL

John W. Flannery, Portland, Oreg.

No Drawing. Application January 13, 1934, Serial No. 706,569

10 Claims. (Cl. 75—17)

This invention relates to a method of producing refined commercial ferro-alloys or pure metals, depending on the nature of the ore, in one operation. This application is a continuation in part of my prior application Serial No. 571,674, filed October 28, 1931.

The present invention is applicable to a variety of ores, particularly to oxide ores of chromium, iron, manganese and nickel and nickel sulphide ore, as will be apparent to those skilled in the art from the following explanation, but for the purpose of exemplification, the invention will be described more particularly as applied to the reduction of iron ores. It is to be expressly understood, however, that the invention is not limited to use with iron ores, but contemplates use with any ore to which the method is applicable.

An object of the present invention is to provide a method whereby refined commercial metal may be produced directly from its ore by a continuous process.

Another object of the invention is to provide a method of producing refined commercial metal directly from its ore that saves time and expense by eliminating the rehandling and reprocessing that have heretofore characterized the production of commercial metals from their ores.

Another object of the present invention is to provide a method of producing refined commercial metal directly from its ore which eliminates the need of a blast furnace or like equipment, such as at present used in the manufacture of pig-iron from iron ore, for example.

Another object of this invention is to provide a method of producing refined commercial metal from its ore which eliminates the production of intermediate products such as pig-iron in the production of steel.

Another object of this invention is to provide a method of producing refined commercial metal directly from its ore which avoids the introduction of an excess of carbon into the metal with the need for subsequently removing the same.

Another object of this invention is to provide a method of producing refined commercial metal directly from its ore which avoids the introduction of an excess of silicon into the metal with the need for subsequently removing the same.

Another object of this invention is to provide a method of producing refined metal directly from its ore which has improved physical properties over metal now produced with methods in general use.

Another object of this invention is to provide a method for reducing and refining ore in a reverberatory furnace such as now used for refining and reprocessing pig-iron to make steel.

Another object of this invention is to provide a method for the direct reduction and refinement of oxide ores that may be carried out in a non-reducing atmosphere.

Other objects will appear as the description of the invention proceeds.

Stated broadly, the present invention includes the method of intimately mixing properly comminuated ore and prepared comminuted reducing and refining or fluxing materials which have been selected with regard to the solid impurities to be removed; these refining or fluxing materials are of such composition that they combine with the solid impurities (silica, alumina, lime and magnesia) and form a soft viscous pasty mass at a temperature below or in the range at which the carbon will combine with the oxygen of the furnace atmosphere, confining the metallic oxide and carbon in intimate contact throughout the pasty mass, which mass will fully melt and become liquid at a temperature below the melting point of the metal; then charging the said mixture into any suitable furnace and heating the charge to a temperature slightly above the melting point of the metal. During the heating of the charge, which may take place very rapidly, the solid impurities and fluxing materials first combine and become soft viscous and pasty, protecting the carbon against oxidation by the furnace atmosphere but leaving the same free to combine with the oxygen of the metallic oxide, the carbon then reduces the metallic oxide, the pasty mass then liquefies and forms a slag before the melting point of the metal is reached, and finally the metal is melted forming a bath of substantially pure metal which is protected from oxidation by an ideal slag. As the metal particles melt, they sink through the liquid slag to the bottom of the furnace, combining into drops as they come into contact with each other and collecting into a body of pure metal at the bottom of the furnace. Before removing the metal from the furnace, the operator may proceed in the usual manner to bring the metal to the desired analysis through the addition of alloys while bringing it to the pouring temperature.

To obtain the maximum advantage and effectiveness of the present invention, the fluxing materials should, in the first place, have the property of combining with the solid impurities of the ore and forming a soft, viscous and pasty mass in or below the temperature range at which the carbon will combine with the oxygen of the furnace at-

mosphere, so that the pasty mass will be in intimate contact with and surround the ore and the reducing agent with which it has been intermixed, protecting the carbon against oxidation by the furnace atmosphere. The chemical reactions required for the reduction of the ore will take place throughout the entire charge as the required temperatures are reached, the gases formed in the reducing period combining and forcing themselves out of the charge into the furnace atmosphere. Alkali metal compounds such as sodium and potassium compounds have a low melting point and when incorporated with suitably comminuted ore and other fluxing materials, have the property of rendering the mixture soft, viscous and pasty at a low temperature, and will be found to be efficient when used as herein described; but any material which will render the charge soft, viscous and pasty during the reducing period may be used.

The reducing and fluxing mixture should, in the second place, be of such character and composition as to remove the impurities without leaving an excess of any undesirable component thereof in the metal, so that a subsequent reprocessing is unnecessary in order to remove such excess material. For example, when coal or coke is used for the reduction of ores in the conventional manner, a portion of the carbon charged into the furnace is wasted by combining with the oxygen of the furnace atmosphere and passing off as a gas, and hence, under present practice, an amount of carbon in excess of that actually required for chemical combination with the oxygen in the ore is charged into the furnace and part of this excess of carbon is absorbed by the metal. In a process embodying the invention, the amount of carbon is always the chemical equivalent of the oxygen combined with the metal and substantially complete combustion is effected so that practically no carbon is absorbed by the metal.

The reducing and fluxing mixture should, in the third place, be composed of proper ingredients having chemical affinity for the impurities to be removed from the ore, and in amounts suitable for removing said impurities as predetermined by analysis of the impurity content of the ore. Taking iron oxide ores as an example, such ore usually contains such impurities as silica, alumina, phosphorus, sulphur, oxygen, lime, and magnesia, all of which are undesirable in the commercial metal. Carbon, calcium and magnesium compounds, potassium and sodium compounds and other elements have chemical affinity for one or more of these impurities, but the character and amount of these materials will vary with the character and constituents of the ore to be reduced and refined. Therefore the reducing and fluxing mixture should contain such character and quantity of reducing and fluxing materials as will effect the desired reduction and refinement of the particular ore under treatment.

Calcium and magnesium compounds have a very great affinity for impurities of ore such as silica, alumina, sulphur and also phosphorus when it is in the form of an oxide, and will combine with these impurities with great rapidity under suitable temperature conditions. Carbon has a great affinity for oxygen; sodium and potassium compounds also possess the characteristics of calcium and magnesium compounds to some extent, and hence compounds of sodium and potassium can be used to obtain some of the advantages of calcium compounds while at the same time sodium and potassium compounds have the effect of lowering the melting temperature of the fluxing materials of which they are a part. Therefore a preferred reducing and fluxing mixture will include one or both of sodium and potassium compounds in addition to calcium and/or magnesium compounds and carbon as above referred to. The fluxing mixture may be rendered acid, basic or neutral as desired.

When nickel oxide and sulfide ores are under reduction borax may be added to the fluxing material to aid in rendering the mass pasty at a low temperature. Borax may also be used with manganese and chrome ores to speed up the process but in none of these cases is it absolutely necessary. However, in the case of chromium oxide the use of borax is preferred to reduce the time required to render the mass first pasty and then liquid at the desired temperatures. From four to twenty-five percent by weight of the ore is usually added depending upon the refractoriness of ore as determined by analysis.

The carbon used in this reducing and refining operation should be confined in the soft, viscous, pasty mass of the mixture so that as little as possible of it will be wasted and all remain chemically active to combine with the oxygen of the ore, so that the exact amount of carbon required for the removal of oxygen can be predetermined and used with assurance that the desired reducing action will take place and no excess of carbon will be left in the metal. Also, if during the reducing period the carbon is exhausted and the slag maintained basic, the silicon content of the metal will be low.

The proportions of the ingredients of the reducing and fluxing mixture will vary according to the materials used and the analysis of the ore. As stated, the amount of carbon should be the chemical equivalent of the oxygen combined with the metal of the ore, and the term "chemical equivalent" will be understood to mean substantially that amount of carbon necessary to effect complete reduction of the ore without leaving any substantial excess of carbon to be absorbed by the metal. On the basis of perfect combustion (CO_2), which may be substantially attained, the ratio of weight of carbon to oxygen should be 3 to 8. Whether the reducing agent is coke, coal, charcoal, calcium carbide, or other carbon material, the amount should be sufficient to provide carbon in this ratio. If CO is formed, the amount of carbon required to effect complete reduction will be greater. The amount of calcium or magnesium compound may conveniently be such as to combine with the silica (and alumina) present in the ore, and in this case calcium oxide or magnesium oxide should be added in an amount practically equal in weight to the silica in the ore. The slag in this case will be substantially neutral. The carbonates of calcium and magnesium can also be used, the amounts being figured in terms of the content of CaO or MgO present when CO_2 is driven off. Where calcium or magnesium compounds are present in the ore, the amount to be added may be correspondingly less. The amount of sodium carbonate or other sodium or potassium compound added is determined so as to cause the mass to become first pasty and then liquid at the desired temperatures. With sodium carbonate, the amount may suitably be in the proportion of about one part to two parts of silica and lime when the reducing agent is in the form of coal, coke etc. If calcium carbide is used, more so-

dium carbonate is necessary because of the high melting point of calcium carbide. It will be understood, however, that calcium or magnesium compounds are to a certain extent interchangeable with sodium or potassium compounds. The relative proportions may therefore be varied considerably, provided always that the refining materials become pasty below the temperature at which the carbon begins to combine with oxygen of the furnace atmosphere. Ordinarily the amount of sodium carbonate, the most readily available of the sodium and potassium compounds, may vary from 4% to 20% by weight of the ore to be reduced. With low grade ores having a higher content of silica, the amount of alkali metal compound used should be greater. The effect of using lesser amounts of sodium carbonate is to increase the temperature at which the mass becomes pasty and this is permissible provided the mass becomes pasty at a temperature low enough to prevent oxidation of the carbon by the furnace atmosphere.

As a general example of the application of this method, consider the principal ores of iron, Fe_2O_3 and Fe_3O_4, having a melting point of 2800° F. Adding sodium carbonate (where the term sodium carbonate is used throughout this application, soda ash is implied) in varying proportions from four to twenty percent lowers the melting point of the gangue or solid impurities of the ore; the more sodium carbonate the lower the melting temperature, the amount necessary being determined by an analysis of the ore. To this is added enough powdered lime (CaO) to combine with the gangue of the ore (silica, alumina, lime, and magnesia) to make a liquid slag when melted, with enough carbon (in the form of coke, coal, etc.) to completely combine with the oxygen combined with the metal of the ore. The reducing agent is preferably comminuted to about 80 mesh; the ore however, need not be comminuted more than to 10 mesh; the ore and carbon and fluxing materials are then thoroughly intermixed. Suppose enough sodium carbonate added to reduce the melting point of the gangue of the ore to 2000° F., then as the mixture is heated it becomes pasty at about 1000° F. This pasty state prevents the loss of carbon through combustion by contact with the air and holds it in the mass until the temperature reaches the point where it combines with the oxygen of the metallic oxide. The oxygen is in a nascent state with powdered carbon evenly distributed throughout the mass. The oxygen having a greater affinity for the carbon than for the iron with which it has been combined, combines with the carbon and escapes as CO_2 and CO, leaving the metal free. Complete reduction will be accomplished when about 2000° F. is reached, at which point the mass becomes liquid with particles of pure metal in suspension. As the temperature increases to the melting point of the pure metal (pure iron 2700° F.) the particles of the iron coalesce and sink to the bottom of the hearth and are covered with a liquid slag carrying the solid impurities of the ore. This operation will take place under any and all conditions, without regard to the atmosphere whether reducing or not.

A more specific example is found in the application of the process to the ore hematite, 63% metallic iron (90% Fe_2O_3). 100 pounds of ore carries 63 pounds of iron, 27 pounds of oxygen and 10 pounds of silica (SiO_2). As a reducing agent 20 pounds of calcium carbide (CaC_2) are added, this amount containing carbon slightly in excess of the chemical equivalent to combine with the oxygen of the metallic oxide, necessitated by the instability of the compound. To render this mixture pasty at red heat (1200° F.) 20 pounds of sodium carbonate and 10 pounds of calcium oxide are added (the use of calcium carbide requires a large amount of sodium carbonate because of its high melting point). On application of heat the mixture becomes pasty at red heat, at which point reduction begins. Reduction is completed at 2500° F. (with calcium carbide as a reducing agent). At a temperature from 2700° F. to 2800° F., a temperature above the melting point of pure iron, the process is completed with 63 pounds of melted iron covered by an ideal slag for metallurgical operation. Practically no carbon is absorbed by the metal during the reducing and refining operation.

Another example of the process applied to the ore hematite is as follows: to 100 pounds of the ore of the above analysis is added 10 pounds of calcium oxide to combine with the 10 pounds of silica, 10 pounds of sodium carbonate to lower the melting point of the mixture, and as a reducing agent 11 pounds of coke (90% fixed carbon), the chemical equivalent (on the basis of combustion to CO_2) to reduce the 27 pounds of oxygen combined with the metal in the ore. This is preferred to the example above as there is a saving of 19 pounds weight per hundred pounds of ore, the mass softens at a lower temperature (about 1000° F.), and the gangue of the ore plus the added calcium oxide and sodium carbonate reach a liquid state at a lower temperature (about 2000° F.). The results are the same as in the example above with a saving in time and a more fluid slag.

The same proportions of materials in the reducing and fluxing mixtures are suitable for reducing and refining manganese ores, the conditions being substantially the same as in the case of iron ores.

As a further example, 100 pounds of a typical chrome ore contains 19 pounds of oxygen, 19 pounds of silica, 6 pounds of alumina, 8 pounds of calcium carbonate, and 4 pounds of magnesium carbonate. Eight pounds of coke (90% carbon) should be used to furnish 7.2 pounds of carbon, which will combine with 19 pounds of oxygen in the ratio of 3 to 8. Since the calcium and magnesium carbonates in the ore are equivalent to 7½ pounds of calcium and magnesium oxide, 11½ additional pounds of lime should be added to combine with the 19 pounds of silica in the ore. 19 pounds of sodium carbonate added to these materials will give the desired results. If desired, borax may be added to the fluxing materials to reduce the temperatures at which the mass becomes pasty and then liquefies with a consequent saving in time. The amount of borax may vary considerably, for example, between 4% and 25%. The procedure is the same as in the examples given above and the product is an alloy of chromium and iron practically free of carbon.

It will therefore be perceived that a novel method of reducing and refining ore has been provided which materially reduces the time, labor and expense of producing the refined commercial metal from ore. The reduction and refining of the ore takes place throughout the entire furnace charge and a quick and effective removal of the impurities from the ore and metal is accomplished. The impurities are removed or reduced to the desired extent, and a refined commercial metal is obtained by the single treatment of the

ore by means of the combined reducing, melting and refining action secured during the operation.

The principles of the invention may be applied to the production of sponge metal from ores by discontinuing the process at the point where the ore is reduced by being freed from oxygen.

It is to be expressly understood that the reducing and fluxing mixture may be acid, basic or neutral as required, and that the ingredients and proportions of the materials of the mixture will vary with different ores, different furnaces, different products to be obtained, etc., but one skilled in the art, in view of the foregoing disclosure, can readily apply the principles of the present invention to obtain the appropriate charge mixture, and bring the analysis of the metal to the desired requirements. The invention is not limited to the reduction of iron and chrome ores but is available for the reduction and refinement of manganese and nickel ores as well, and it will be understood that the expression "oxide ore" as used herein and in the appended claims includes other ores such as sulphide ores which have been oxidized by roasting or otherwise, the treatment of such oxidized ores in accordance with the foregoing description being within the invention. Reference is therefore to be had to the claims hereto appended for a definition of the limits of the invention.

What is claimed is:

1. A method for producing refined substantially carbon-free metal from iron, chromium, manganese, and nickel oxide ores in a single operation which includes the steps of intimately intermingling the ore with a mixture of reducing and fluxing materials, said mixture containing an amount of carbon that is substantially the chemical equivalent of the oxygen combined with the metal to be reduced and also containing fluxing agents including an alkali metal compound in amounts such that the fluxing materials and the gangue of the ore combine and form a soft, pasty, viscous mass at a temperature below that at which the carbon will combine with oxygen of the furnace atmosphere, charging the intermingled ore and mixture into a furnace and applying heat to the charge to increase the temperature to the melting point of the pure metal, the soft, pasty mass preventing combustion of carbon with the furnace atmosphere but leaving said carbon free to reduce the metallic oxide, the mass as the temperature increases forming a liquid slag before the melting point of the pure metal is reached, and the metal as it melts passing through the slag to the bottom of the furnace.

2. A method for producing refined substantially carbon-free metal from iron, chromium, manganese, and nickel oxide ores in a single operation which includes the steps of intimately intermingling the ore with a mixture of reducing and fluxing materials, said mixture containing sufficient carbon to combine with the oxygen combined with the metal to be reduced and also containing fluxing agents including an alkali metal compound in amounts sufficient to combine with the gangue of the ore to form a soft, pasty and viscous mass at a temperature not more than about 1200° F., charging the ore and mixture into a furnace and applying heat to the charge to increase the temperature to the melting point of the pure metal, the soft, pasty mass preventing oxidation of the carbon by the furnace atmosphere but leaving said carbon free to reduce the metallic oxide, the mass forming a liquid slag before the melting point of the pure metal is reached which slag contains particles of unmelted metal suspended therein, the metal particles melting as the temperature further increases and passing through the slag to form a bath of pure molten metal at the bottom of the furnace.

3. A method for producing refined substantially carbon-free metal from iron, chromium, manganese and nickel oxide ores in a single operation which includes the steps of intimately intermingling the ore with a mixture of reducing and fluxing materials, said mixture containing sufficient carbon to combine with the oxygen combined with the metal to be reduced and fluxing agents to combine with the gangue and form a slag and including low melting alkali metal compounds, charging the intermingled ore and mixture into a furnace and heating the charge to increase the temperature to the melting point of the pure metal, the fluxing materials and the gangue combining and forming a soft pasty viscous mass at a temperature below that at which the carbon will combine with the oxygen of the furnace atmosphere, the metallic oxide being reduced and the mass forming a liquid slag as the temperature increases to a point below the melting point of the pure metal, and the metal melting as the temperature further increases.

4. A method for producing refined substantially carbon-free metal from iron, chromium, manganese and nickel oxide ores in a single operation which includes the steps of preparing a comminuted mixture of reducing and fluxing materials to combine with the gangue of the ore and form a slag, the reducing material comprising a comminuted carboniferous agent distributed throughout said mixture and containing an amount of carbon that is substantially the chemical equivalent of the oxygen combined with the metal to be reduced, said fluxing materials including low melting alkali metal compound whereby the combined fluxing materials and gangue form a soft pasty mass at a temperature below that at which the carbon will combine with the oxygen of the furnace atmosphere and a liquid slag at a temperature below the melting point of the metal to be reduced, thoroughly intermingling said comminuted mixture with the ore to be reduced, and charging the mixture into a furnace and applying heat to the charge to increase the temperature to the melting point of the metal, the soft pasty mass preventing oxidation of the carbon by the furnace atmosphere while the metallic oxide is reduced and forming a liquid slag with particles of unmelted metal in suspension as the reduction is completed, the metal melting and passing through the slag as the temperature further increases.

5. A method for producing refined substantially carbon-free metal from iron, chromium, manganese, and nickel oxide ores in a single operation which includes the steps of intimately intermingling the ore with a mixture of reducing and fluxing materials, said mixture containing an amount of carbon that is substantially the chemical equivalent of the oxygen combined with the metal to be reduced, a fluxing agent substantially equal in amount to the silica in the ore in excess of the calcium and magnesium oxides therein, and from 4% to 20% by weight of the ore of an alkali metal compound, charging the intermingled ore and mixture into a furnace and applying heat to the charge to increase the temperature to the melting point of the pure metal, the mass becoming soft and pasty at a temperature below that at which the carbon will com-

bine with the oxygen of the furnace atmosphere to protect the carbon against oxidation by the furnace atmosphere while leaving the same free to reduce the ore, the mass becoming liquid before the melting point of the metal is reached whereby a liquid slag is formed containing particles of unmelted metal in suspension, the pure metal as it melts passing through the slag and collecting at the bottom of the furnace.

6. A method for producing refined substantially carbon-free metal from iron, chromium, manganese, and nickel oxide ores in a single operation which includes the steps of intimately intermingling the ore with a mixture of reducing and fluxing materials, said mixture containing an amount of carbon that is substantially the chemical equivalent of the oxygen combined with the metal to be reduced, calcium oxide in sufficient amount so that the total calcium oxide in said mixture and in the gangue of the ore is approximately equal to the silica in the ore, and sodium carbonate in an amount substantially equal to the amount of silica in the charge, whereby said fluxing materials combine with the gangue of the ore to form a soft, pasty, viscous mass at a temperature below the point at which the carbon will combine with the oxygen of the furnace atmosphere, the carbon being distributed throughout said mass in intimate contact with the metallic oxide to be reduced, charging the intermingled ore and mixture into a furnace and applying heat to the charge to increase the temperature thereof whereby the mass becomes first soft and pasty and then liquefies before the melting point of the metal is reached, the liquid slag containing particles of unmelted metal which melt as the temperature increases and pass through the slag to the bottom of the furnace.

7. A method for producing refined substantially carbon-free iron from iron oxide ores containing iron oxide and silica which consists in intimately intermingling the ore with a mixture of reducing and fluxing materials, said mixture containing sufficient carbon to combine with the oxygen combined with the metal to be reduced, calcium oxide in an amount substantially equal to the silica content of the ore, and sodium carbonate substantially equal to the silica in the charge, charging the intermingled ore and mixture into a furnace and applying heat to the charge to increase the temperature to the melting point of the pure metal, the fluxing materials combining with the gangue of the ore and forming a soft, pasty, viscous mass at about 1000° F. through which the carbon and iron oxide are distributed in intimate contact, the soft, pasty mass protecting the carbon against oxidation by the furnace atmosphere while permitting the reduction of the iron oxide, the mass forming a liquid slag having particles of reduced unmelted metal in suspension therein at about 2000° F., and the metal melting as the temperature is increased and forming a bath of pure molten metal at the bottom of the furnace.

8. A method for producing refined substantially carbon-free metal from chromium oxide ore containing chromium oxide, silica, alumina, calcium carbonate and magnesium carbonate which consists in intimately intermingling the ore with a mixture of reducing and fluxing materials, said mixture containing sufficient carbon to combine with the oxygen combined with the metal to be reduced, calcium oxide sufficient to provide, together with the calcium carbonate and magnesium carbonate of the ore, a fluxing agent substantially equal in amount to the silica in the charge, and sodium carbonate in an amount substantially equal to the silica in the charge, charging the mixture into a furnace and applying heat to the charge to increase the temperature to the melting point of the pure metal, the fluxing materials combining with the gangue of the ore and forming a soft, pasty, viscous mass at a temperature below that at which the carbon will combine with the oxygen of the furnace atmosphere, the soft, pasty mass protecting the carbon against oxidation by the furnace atmosphere while permitting the reduction of the metallic oxide, the mass forming a liquid slag with particles of reduced unmelted metal in suspension therein as the temperature increases to a point below the melting point of the pure metal, and the metal melting as the temperature further increases and forming a bath of pure molten metal at the bottom of the furnace.

9. A method for producing refined substantially carbon-free metal from chromium oxide ore containing chromium oxide, silica, alumina, calcium carbonate and magnesium carbonate, which consists in intimately intermingling the ore with a mixture of reducing and fluxing materials, said mixture containing sufficient carbon to combine with the oxygen combined with the chromium, calcium oxide sufficient to provide, together with the calcium carbonate and magnesium carbonate of the ore, a fluxing agent substantially equal in amount to the silica in the charge, sodium carbonate in an amount substantially equal to the silica in the charge, and from 4% to 25% of borax, charging the mixture into a furnace and applying heat to the charge to increase the temperature to the melting point of the pure metal, the fluxing materials combining with the gangue of the ore and forming a soft, pasty, viscous mass at about 1000° F. through which the carbon and metallic oxide are distributed in intimate contact, the soft, pasty mass protecting the carbon against oxidation by the furnace atmosphere while permitting the reduction of the metallic oxide, the mass forming a liquid slag having particles of reduced unmelted metal in suspension therein at about 2000° F., and the metal melting as the temperature is increased and forming a bath of pure molten metal at the bottom of the furnace.

10. A method of reducing oxide ores to refined metal which includes the steps of intimately intermixing ore with a reducing agent including calcium carbide and an alkali metal compound fluxing agent which will soften and become pasty at temperatures below the point at which the reducing agent combines with the oxygen of the ore, charging said ore and mixture into a furnace, applying heat to the charge until the reducing agent and the oxygen are exhausted while maintaining the metal unmelted and the mixture soft and pasty, then increasing the heat to form a slag with unmelted metal suspended therein, then further increasing the heat to melt the metal and permit the molten metal to pass through the slag and accumulate in the furnace, and removing the slag from the refined metal.

JOHN W. FLANNERY.