United States Patent

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[54] **DIRECT REDUCTION PROCESS AND SIMULTANEOUS CONTINUOUS CASTING OF METALLIC MATERIALS IN A CRUCIBLE TO FORM RODS**

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[21] Appl. No.: **840,894**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 736,113, June 11, 1968, abandoned.

[52] **U.S. Cl.** **164/50,** 164/82

[51] **Int. Cl.** **B22d 22/02,** B22d 11/10

[58] **Field of Search** 164/49–52, 55–57, 164/82, 250–252, 266, 273

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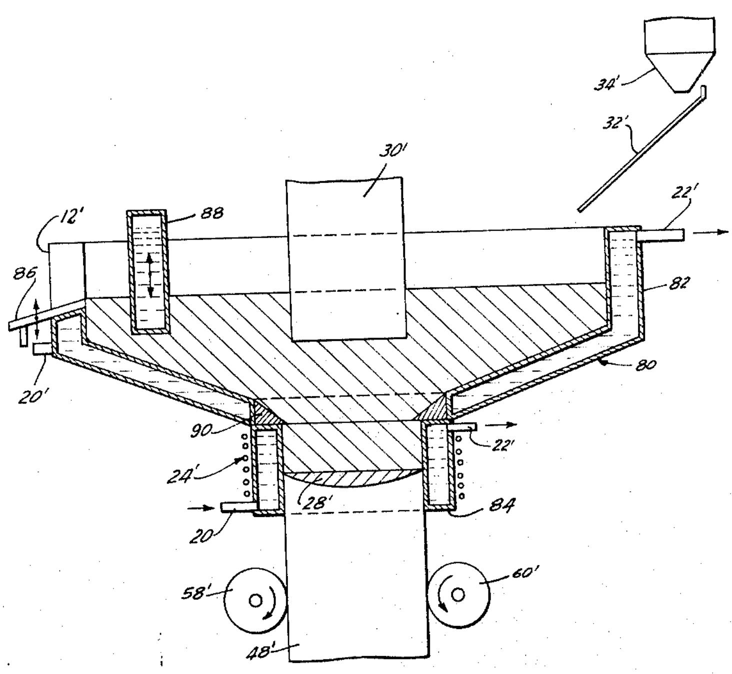
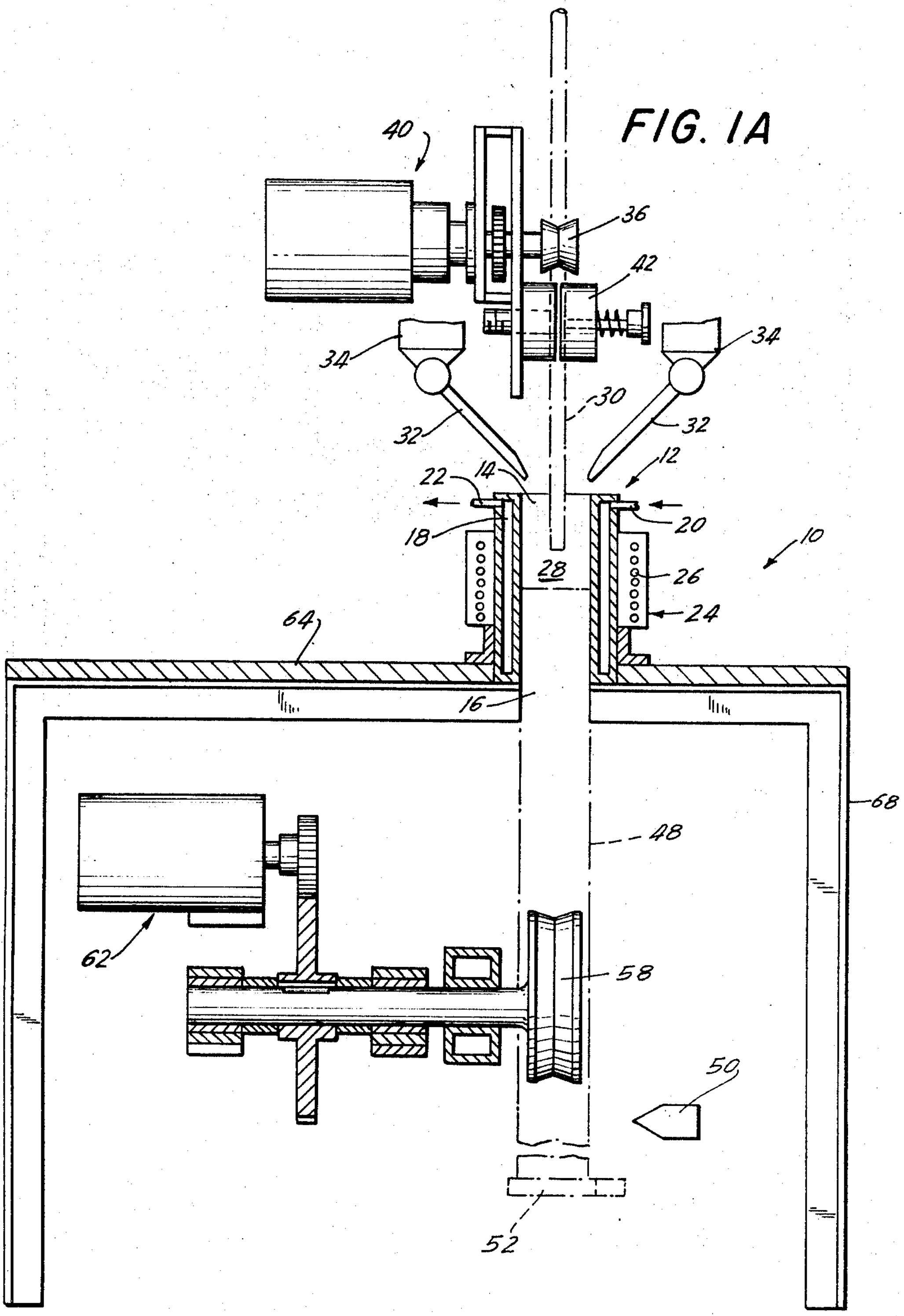
[57] **ABSTRACT**

A continuous casting technique of ferro-alloys is provided wherein a water-cooled copper crucible having a relatively enlarged upper portion and a reduced lower portion defining a relatively small reaction zone. One or more electrodes are introduced either of a consumable or non-consumable variety. In either of these approaches, metal oxide, reducing agent, flux and addition materials are dispensed in the crucible and the desired reaction is initiated between the lower end of the electrode and a conveniently located negative pole. Relatively high temperatures are attained and upon melting of the slag, the alloying reaction takes place in continuous fashion. This reaction is enhanced by induction stirring which ensures the uniform dispersion of the several ingredients introduced into the reaction zone. As the molten alloy is formed, it is separated and gradually lowered at a controlled rate. Provisions are made for cooling the alloy as it is produced and lowered from the crucible. The discharged alloy is in rod shape and is thereafter cut into predetermined lengths or placed in any other form for the selected application.

1 Claim, 7 Drawing Figures





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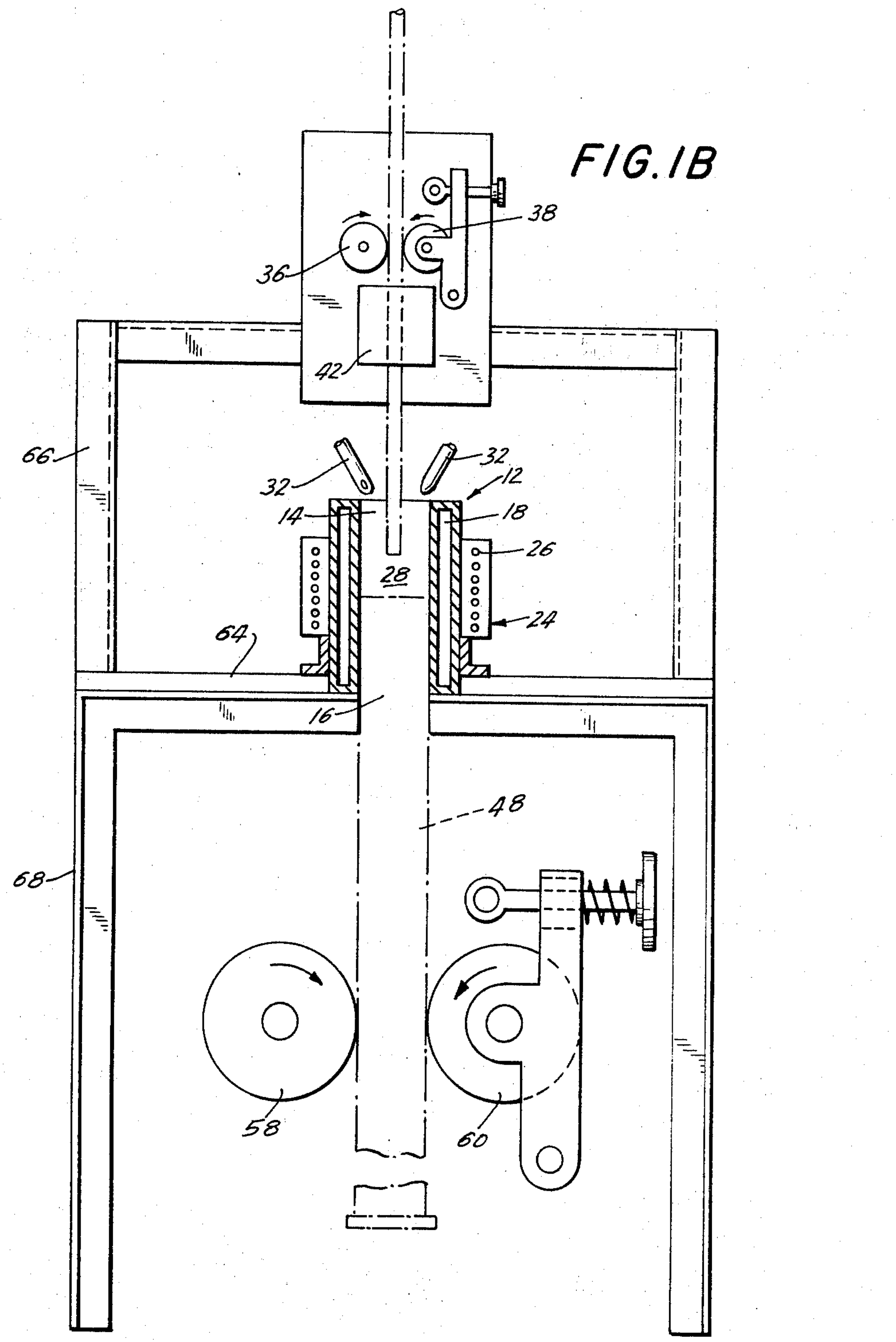

FIG. 1B

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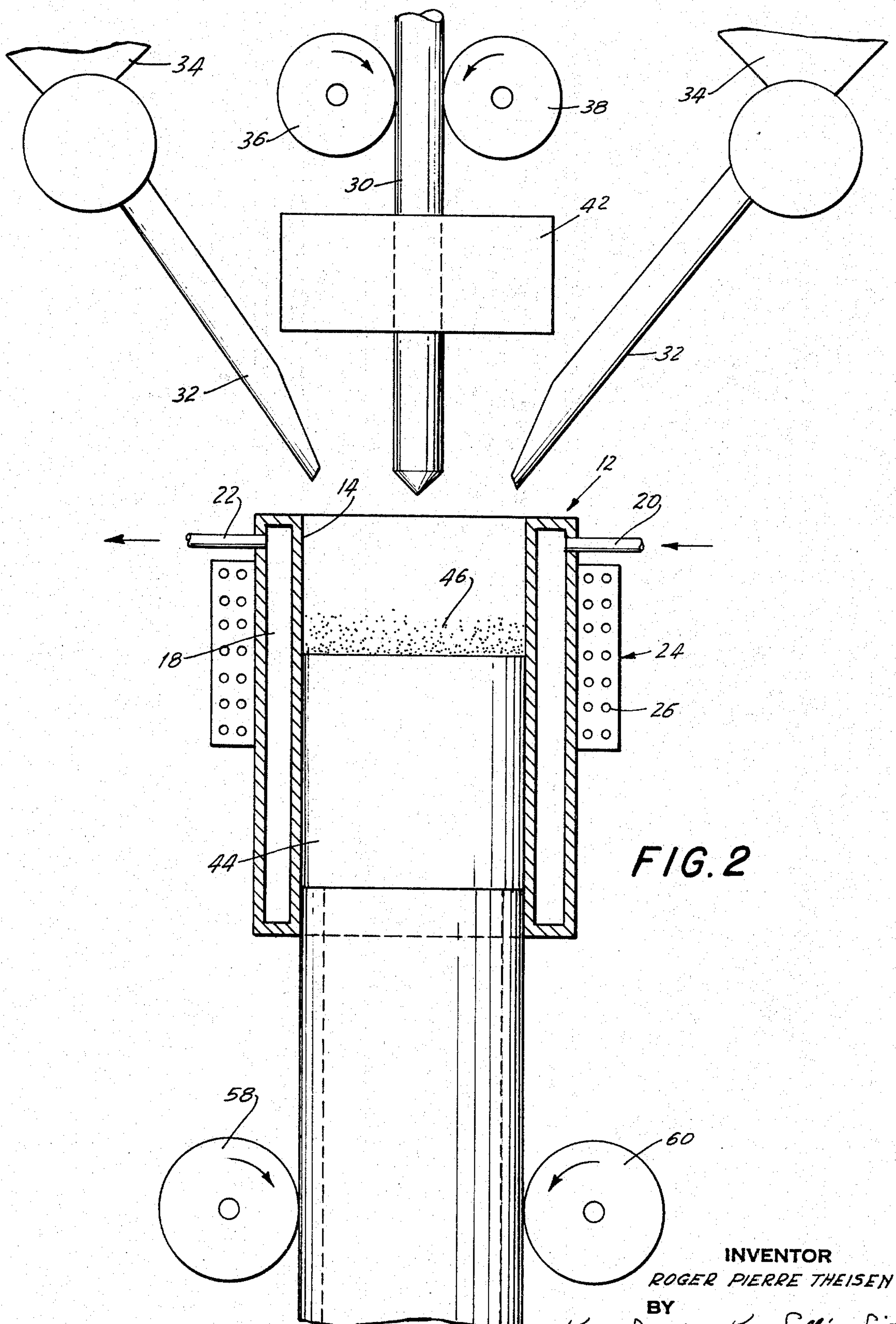

FIG. 2

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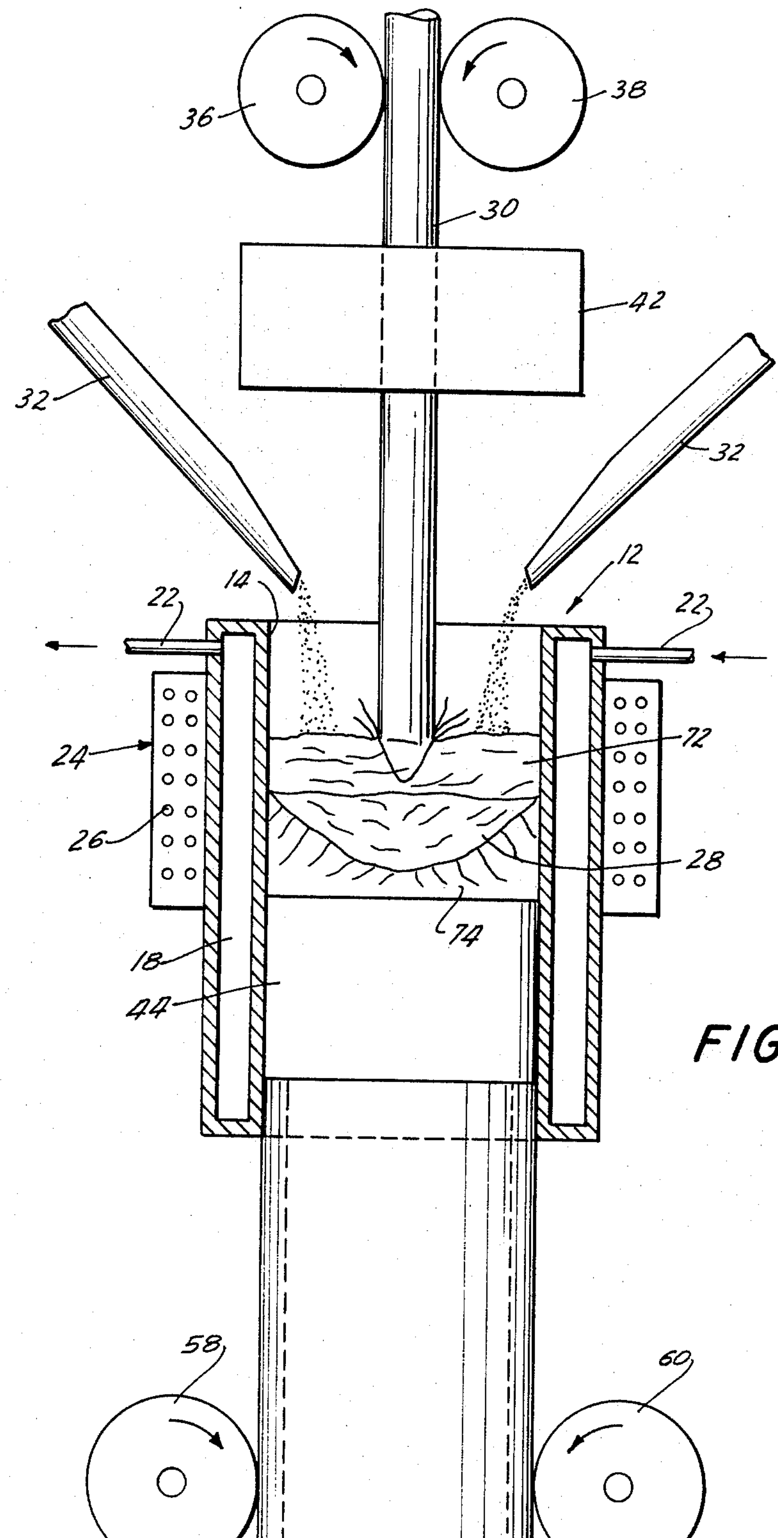

FIG. 3

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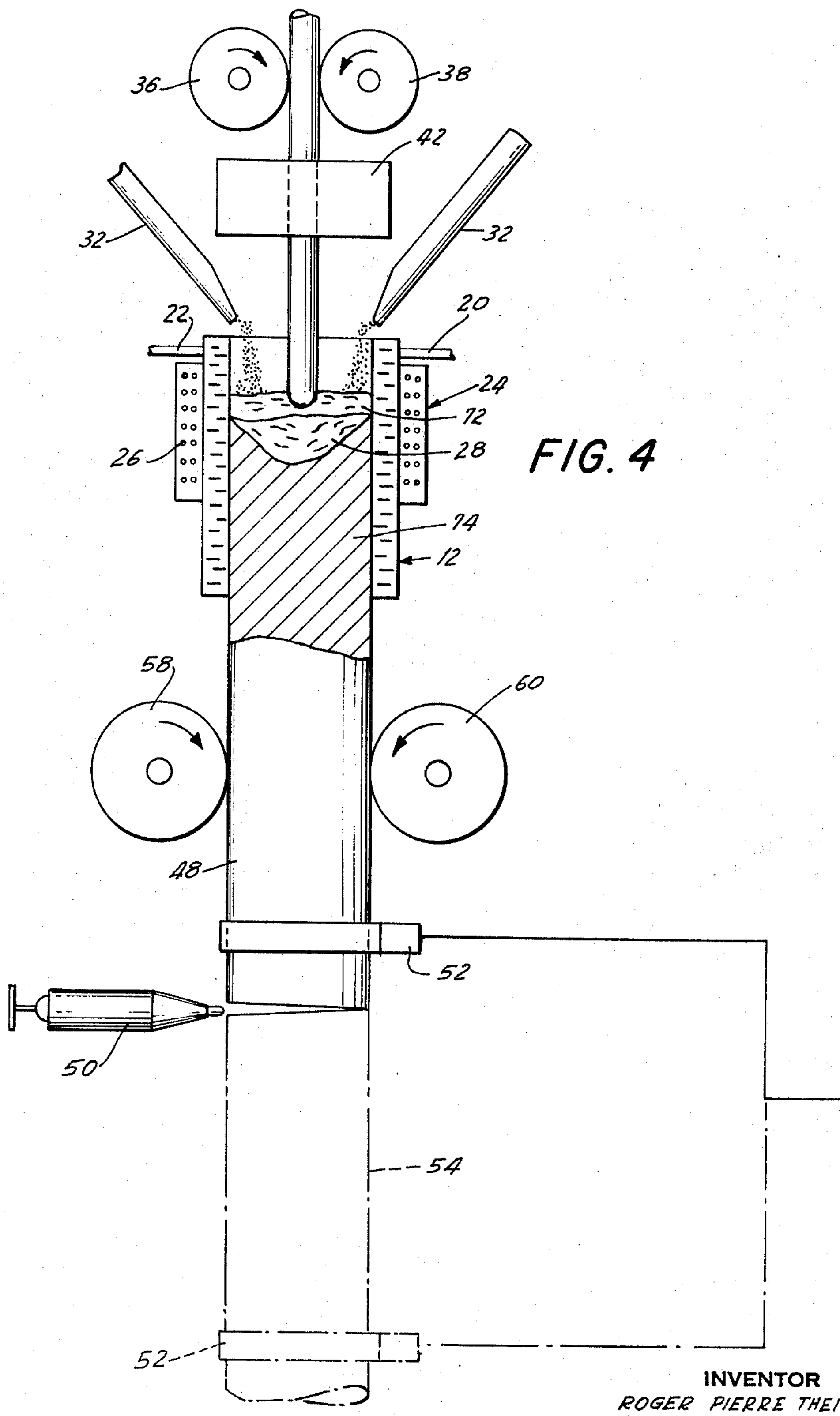

FIG. 4

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FIG. 5

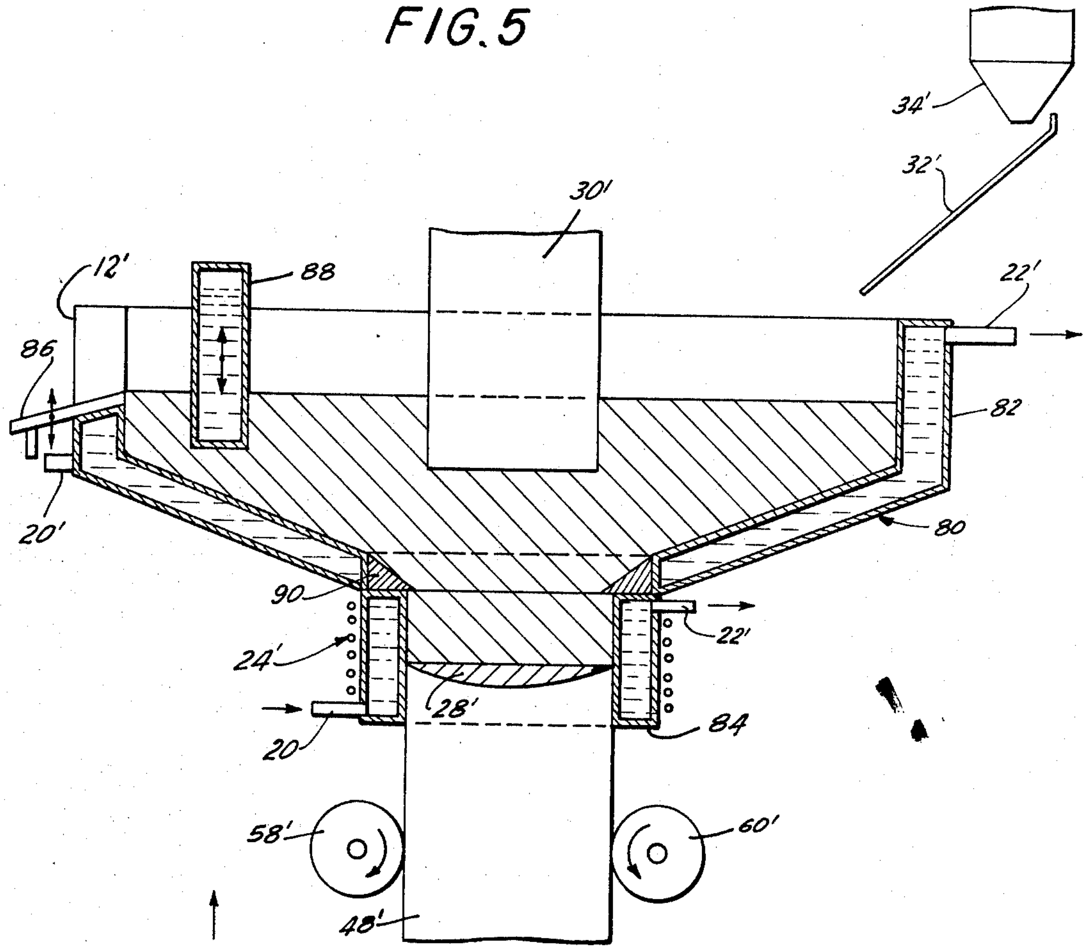
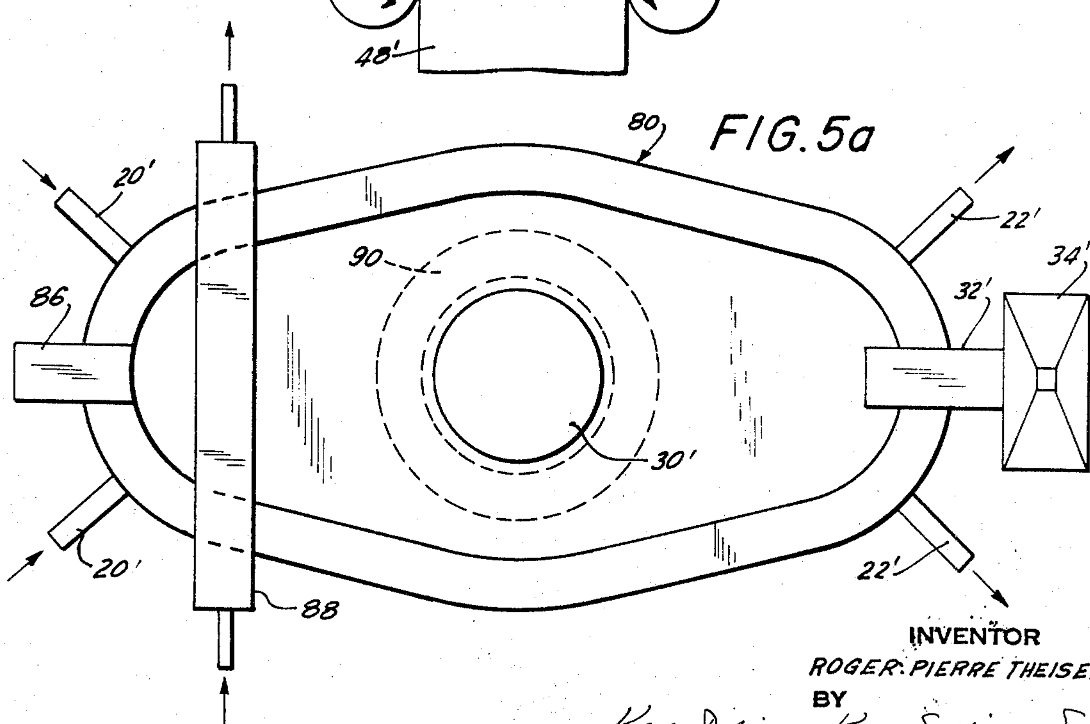


FIG. 5a



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DIRECT REDUCTION PROCESS AND SIMULTANEOUS CONTINUOUS CASTING OF METALLIC MATERIALS IN A CRUCIBLE TO FORM RODS

CROSS-REFERENCE TO A RELATED APPLICATION

This application is a continuation-in-part of earlier filed commonly assigned pending patent application Ser. No. 736,113, filed June 11, 1968 and now abandoned.

BACKGROUND OF THE INVENTION

In the past, alloys and in particular ferro-alloys have been produced by reduction processes in accordance with somewhat standardized techniques. For example, it was widely recognized as standard practice to employ crucibles or electric furnaces into which electrodes are deployed for participation in the generation of the prescribed reaction temperatures. Selected reaction products together with appropriate fluxing agent and sometimes slag-forming material was introduced. With time and under the established conditions, the alloy would settle to the bottom and be periodically drained or removed.

These techniques do have inherent limitations and disadvantages. For example, refractory oxide materials are generally employed. By reason of the short life of the refractory oxide linings, the production of the alloys was frequently interrupted and production consequently reduced. Refractories are not only partially responsible for introducing contaminants into the ultimately formed alloy by entering the reaction, but in so doing limit the life of furnace or crucible. Relatively high reaction temperatures are generally required; and high temperatures of the order involved induce losses and volatilization and, by the same token, increase the rate of the reaction with the refractories. In all cases, the resultant alloy did include contaminants, tramp elements and/or other impurities which either limited the eventual use and effectiveness of the alloy or required the alloy to be subjected to further purification.

Of course, the use of the reduction processes and techniques discussed in the above were somewhat limited in, if not incapable of producing, at least on a production basis, essentially compounds and alloys of pure elements such as materials with high melting points and particularly titanium, manganese, nickel, chromium, niobium, vanadium, tungsten, molybdenum and the like. Elements of these groups also have application in the processing of steel.

As will be appreciated, all of the intermetallic compounds and materials discussed above inherently lack ductility and are readily disintegrated or crumbled when reworked or reshaped. Heretofore, it was beyond comprehension, if not an impossibility, to produce metallic alloys and compounds of elements in accordance with the above techniques in the form of rods which, in this shape, would inevitably be in great industrial demand, particularly by the steel industry.

SUMMARY OF THE INVENTION

It is a principal object of this invention to provide an improved technique for producing by direct reduction alloys and compounds of these elements.

Another object is to provide a process of the above type in which the product obtained is continuously cast in the form of a rod for innumerable applications, such as their deployment as electrodes for certain industries as, for example, in the manufacture of steel.

A further object is to provide such a process at a lower cost and with the capability of readily and rapidly attaining relatively high temperatures to induce and stimulate the desired reaction and to maintain it over prolonged periods of time, all of which are accomplished along with the following attendant advantages:

a. Consideration need not be given to temperature or temperature limitations, and relatively high local reaction temperatures are actually employed, tolerated and contained.

b. The intended reaction is enhanced by induction stirring at these high temperatures to cooperate in uniformly dispersing the reaction ingredients in assuring a homogeneous end product.

c. Provisions are made for a relatively reduced reaction zone within which the reactant materials need only be introduced and combined under optimum and stirred conditions.

d. Volatilization, losses and introduction of contaminants, deleterious ingredients, tramp elements or other impurities are eliminated because of the relatively small reaction zone, effective slag sealing and the complete elimination of refractories and avoidance of any known conditions, including chemical environment, whether basic or acidic, under which purity of the end product may be detrimentally affected or even thermodynamically impossible.

e. The ultimately formed product is immediately solidified by a rapid cooling technique, thereby assuring optimum purity and grade of the product and, above all, reduction of evaporation losses.

Still another object is to provide apparatus for accomplishing the above processes.

Other objects and advantages will become apparent from the detailed description of the invention which may be briefly summarized as a continuous casting technique of metallic alloys, compounds and particularly ferro-alloys. This technique takes advantage of a vertically disposed water-cooled copper crucible defining a relatively small reaction zone, which in the case of alloy production, is adapted to receive a metal oxide, reducing agent, flux and addition materials through its upper inlet end. An electrode is also introduced into the upper crucible end in a coaxial fashion and may be of a non-consumable type or, on the other hand, a consumable electrode. In the latter case, the metallic oxide and reducing agent may be uniformly and evenly dispersed in a manner well known in the art. The desired reaction is initiated by striking an arc between the lower electrode end and a conveniently located negative pole; and the flux and addition materials are thereafter introduced into the reaction zone of the crucible. Relatively high temperatures are attained rapidly and upon melting of the slag producing material, the arc is extinguished and the alloying reaction takes place. This reaction is enhanced and stimulated by induction stirring which ensures the uniform dispersion of the several ingredients introduced into the reaction zone. As the molten alloy is formed, it is separated and gradually lowered at a prescribed rate. Inasmuch as the copper crucible is water cooled, the molten alloy is immediately subjected to these cooling conditions. Accordingly, the alloy will rapidly cool and solidify to set at once physically, chemically and metallurgically. Discharged under these circumstances, the alloy will be in rod shape or form. This rod may thereafter be cut into predetermined lengths for eventual use as electrodes, or perhaps may be immediately or subsequently crushed if it be desired to supply the material in this form.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1*a* is a schematic front elevational view partly in section of the apparatus employed for accomplishing the process of this invention, with the electrode, flux and addition material introduced into the top of the crucible being shown in phantom, as is also the case with the eventually formed rod;

FIG. 1*b* is a schematic side elevational view thereof;

FIG. 2 is a fragmentary elevational view in section showing the rod supporting plate disposed in the crucible and the electrode lowered prior to the ignition of the arc for starting the process;

FIG. 3 is a similar fragmentary sectional view after the ignition of the arc and introduction of the slag forming materials showing after extinction of the arc and the formation of the molten slag and of the formation of the molten alloy in the reaction zone as well as the generation of the solid alloy in rod form;

FIG. 4 is a similar view showing the production of the desired length of rod and, by means of phantom representations, the cutting and gripping of the rod to maintain the conductive current path and to assure the lowering of the length of rod in a relatively safe manner with the lowered alloy rod being directed away from the reaction area to a location at which it may be scraped clean of slag and polished and eventually removed for further processing.

FIG. 5 is a schematic and fragmentary elevational view in section of an apparatus having a preferred crucible particularly suitable for carrying out the process of the present invention with greater efficiency and with non-consumable electrodes; and

FIG. 5a is a top view in cross-section of the crucible of FIG. 5.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the drawings, a direct reducing and rod-forming apparatus **10** incorporating the teachings of this invention will include an essentially tubular crucible **12** having an upper open end **14** and an open bottom end **16**. In accordance with the contemplated applications, this crucible will preferably be formed of copper and will generally include a central bore of substantially circular configuration, although it will be appreciated that other cross-sectional shapes and geometrical forms are possible.

The walls of the crucible are preferably water-cooled in order to sustain the relatively high reaction temperatures contemplated. For such purposes a substantial concentric cavity **18** is defined, having one or more inlets **20** and outlets **22** for facilitating the constant circulation of the cooling medium to provide for the desired temperature reduction. This cooling system not only cools the walls of the crucible **12** to preserve the longevity of this unit, but also serves to rapidly cool the formed metal, ferro-alloy or other metallic alloy, as the case may be.

The alloying reaction contemplated is stimulated and enhanced such that the desired reaction will occur relatively quickly and at a substantially constant and somewhat rapid rate by providing an induction stirrer **24**. Induction stirrers are well known in the art and generally include concentrically arranged spiral or helical electric coils **26** which, when carrying a current, will induce a magnetic field which serves to mix and evenly disperse the alloying materials. In this connection, in the reaction zone the materials will be evenly dispersed so that the reaction will occur quickly and the ultimately formed product will be substantially uniform and homogeneous. Naturally, where desired, magnetic shielding may be employed to reduce the effects of the generated magnetic fields in locations other than the reaction zone. In the drawings, this zone is generally designated by the numeral **28**.

For purposes of the present detailed description, it should be understood that metal alloys and particularly ferro-alloys will be produced (especially in rod form), reference being made to the parts of the equipment in FIGS. 1–5 and 5a, the apparatus of FIGS. 5 and 5a being numbered similarly to the to the parts of FIGS. 1–4 but being furnished with primes. Therefore, in the description below, each of the parts is identified, for example, by **28** for the reaction zone of FIGS. 1–4 and by **28'** for the reaction zone of FIGS. 5 and 5a, and wherever the prime is used, it signifies the operation of FIGS. 5 and 5a.

The input materials are introduced into the reaction zone **28** or **28'** of the crucible **12** or **12'** in several ways, including the illustrated technique which includes the introduction and lowering of an electrode **30** or **30'**, which may be of the non-consumable type. In this case, the metallic oxide, reducing agent, flux and other additives are introduced through one or more metering or valve controlled outlets **32** or **32'**. The material may be continuously or intermittently discharged, but in either case in a controlled fashion to introduce the desired amount of the reagents into the reaction zone. These materials entering into the outlets **32** or **32'** may emanate from a common or a separate hopper **34** or **34'**. Of course, these hoppers may include a level sensing control to ensure an adequate supply of the reagents.

On the other hand, the electrode **30** or **30'** may be of the consumable type, in which case the metal oxide and reducing agent may be uniformly dispersed throughout. Under these circumstances, the flux and other slag-producing additives would be separately introduced into the reaction zone through the hopper outlets **32** or **32'**. Consumable electrodes will be of predetermined lengths and may be either manually or continuously attached in sequence in a fashion well known to the art, so that a continuous supply of rods will be available and introduced into the reaction zone **28** or **28'**; in accordance with an exemplary embodiment of the invention, by rolls **36** and **38**, one of which may be driven by means of a gear reduced motor **40**. The electric arcing to initiate the alloying reaction and to continue the supply of electric current while the reaction is continuously taking place may be accomplished by means again known to the art, including the schematically illustrated positive electrical clamping means **42**.

Ordinarily the process is initiated in the manner depicted in FIG. 2. A support plate **44** will be disposed within the crucible **12** and will be suitably coupled with a negative electrical pole as part of the arcing circuit. Conductive powder which in the case of ferro-alloy production will be iron powder **46** is deposited on the top surface of the plate **44** directly below the lower end of the electrode **30**. The electrical circuit will be closed and upon striking of the arc, slag-forming material will be introduced into the reaction zone **28** through the outlet **32**. For purposes of the present description, it will be assumed that the electrode **30** will be of the consumable type and, under these circumstances, will be composed of the metallic oxide and reducing agent. Within a relatively short period of time, the slag-forming materials will melt **72** and extinguish the arc. The electrical circuit will now be completed through the molten material between the lower end of the electrode **30** and the plate **44**. When this occurs, the alloying reaction will commence. The plate **44**, the top surface of which supports the molten alloy, will be lowered through the internal bore **14** and the crucible **12**. As the formed alloy leaves the reaction zone, it will be immediately and rapidly cooled to form a substantially cylindrical rod of the alloy material. Homogeneity and even dispersion of the reactant materials is enhanced by means of the induction stirring means **24**. As the solid alloy **74** emerges from the reaction zone **28** and is directed downwardly out through the lower end **16** and the crucible **12**, it is in rod form, having an essentially circular cross-section. Thus, the solid alloy rod **48** is lowered at a prescribed rate and when a predetermined length of the rod is formed, cutting means **50** is either manually or automatically activated to cut the rod **48**. Before this cutting action is performed, a rod gripper is placed into engagement with the rod **48** above the point of severance in order that the electric circuit remains completed following the severance of the rod.

It should be understood that, where desirable, more than one electrode may be employed as, for example, an array of three electrodes may be symmetrically arranged in the crucible. The crucible, as shown in FIGS. 5 and 5a, having an enlarged upper portion is particularly appropriate for carrying out the process with several electrodes.

Although the successful applications of this invention have proved otherwise, where necessary or desirable, supplementary heating means may be introduced into the reaction zone **28** or **28'**. Such supplementary heating means may take the form of high frequency heating.

The molten alloy formed within the reaction zone **28** or **28'** is initially supported by means of the crucible plate or lid **44**, as shown in FIG. 2. However, as the solid alloy rod **48** or **48'** is formed, it will serve to support the molten alloy. This rod **48** or **48'** is lowered at a substantially controlled rate by means of a pair of wheels or rollers **58** and **60** or **58'** or **60'**, one of which may be spring biased and the other driven by means of a gear reduced motor **62**, as shown in FIG. 1.

Thus, rods **48** or **48'** of predetermined length are formed. Prior to severance by means of the cutter **50**, shown only in FIG. **4**, the rods **48** or **48'** will be adequately grasped by gripping means in an automatic fashion and lowered on to a suitable conveyor for removal. During this course of travel, the first formed rod **48** or **48'** will be relieved of the crucible support plate or lid **44**, shown in FIGS. **2** and **3**. In addition, this rod **48** or **48'** and all those subsequently formed will be suitably treated as, for example, by means of a sand blasting technique to remove whatever slag material may be present at their circumferentially extending periphery. Where it is necessary or desirable, these rods will be eventually polished for rendering them commercially acceptable for subsequent marketing and consumption. The cycle of operation for forming the alloy material in rod shape and gripping the predetermined length of the rod and then severing it at the desired location will be continuously repeated while maintaining the desired current path through the positive pole, the electrode **30** or **30'**, the molten material in the reaction zone **28** or **28'**, the solid alloy rod **48** or **48'**, and the negative pole **52**, shown only in FIG. 4.

In view of the relatively high temperatures generated within the reaction zone **28** or **28'** of the crucible **12** or **12'**, it will be apparent that the ambient will also be subjected to relatively high temperatures. This will also be true for those zones through which the solid alloy rod **48** or **48'** and cut lengths of rod **54**, shown only in FIG. **4**, travel. With this in mind, one zone or section may be heat insulated or shielded from another and from the ambient or surroundings in an effort to render it as comfortable as possible for attending personnel. Accordingly, the crucible **12** or **12'** and associated structure may be located at one level above a platform or floor **64** within an enclosure **66**, shown in FIG. 1B, both of which will be designed to provide a heat insulating function. Below the floor **64** may be located the mechanism and equipment for regulating the rate of descent of the alloy rod **48** or **48'** and its direction or path of travel following its severance by means of the cutter **50**, as shown in FIG. **4**. This zone may also be confined within the enclosure **68**, as shown in FIG. **4**. With an arrangement of this type, a bank of machines or apparatus **10** may be arranged side by side in series within a plant for the continuous manufacture of rod shaped metals, metallic alloys, ferro-alloys, as the case may be, of similar or different composition.

Thus, a method is provided for producing ferro-alloys by reaction of metallic oxides, oxides and metal with reducing agents, such as carbon, silicon, calcium or their compounds. These latter agents in combination with given alloying elements under the contemplated conditions will yield ferro-alloys and other special metallic alloys not otherwise producible in desired rod shapes as that possible by this invention.

In view of the miniturization of the entire apparatus and in particular the confines of the reaction zone, the entire alloying reaction may be controlled and stirred within relatively accurate limits without losses and concern over contamination. This action is continuous and rapid, with immediate cooling of the formed alloy into the desired shape and inclusive of the desired constituents further assuring the optimum in purity of the formed rod. Needless to say, rods of this type and particularly those bearing ferro-alloys with the degree of purity actually accomplished by the present invention are in demand and are advantageously adapted to the steel producing industry. Thus, the rod shaped ferro-alloys may be introduced into the steel forming process as electrodes, a technique the value and importance of which will be really appreciated by those skilled in the art.

Although reference is made, particularly in FIG. 1–4, to a cylindrical crucible in describing the process of the present invention, it is to be understood that this configuration of the crucible is merely given for purpose of simplification. In particular, the central bore is not limited to a circular configuration, but can also be of other cross-sectional shapes depending on the cross-section of the ingot to be produced. It must be noted that the efficiency of the process of the present invention is largely dependent on slag/liquid metal ratio (which may be up to 4:1) and on the reaction surface. Therefore, it will be convenient to provide a crucible **80** which is designed in such a way to permit the process to be carried out under the optimum conditions. A crucible of this type is shown in FIGS. **5** and **5***a*. The crucible shown in those figures comprises an enlarged upper portion **82** and a narrower bottom portion **84**. The configuration of such a crucible enables the use of several electrodes or one or several electrodes having a great cross-section permits the production of ingots having a lesser cross-section than the electrodes and provides a greater reaction surface. Although a crucible having an enlarged upper portion is particularly suitable for carrying out the process of this invention with non-consumable electrodes, it is to be understood that it can also be used in the process with consumable electrodes.

In carrying out the process of the present invention, the continuously changing composition of the slag must be taken into consideration with the direct reduction process going on, i.e., the amount of unreacted slag decreases while the amount of reacted slag increases. With these variations in the composition of the slag, the electric resistivity of the slag changes, thereby providing variations of one of the most important process parameters. Therefore, in order to maintain the optimum and constantly identical operation conditions, it will be necessary to remove or tap off continuously the major part of the reacted slag. This can conveniently be achieved by providing in the crucible a slag tapping device **86** as shown in FIG. **5**. Since the level of the slag in the crucible changes depending on the operation conditions, the slag tapping device is preferably vertically slidable as indicated by the arrows in this figure by means of any known mechanism for accomplishing this end.

In order to prevent the unnecessary loss of input raw material by outflowing with the slag during the slag tapping operation, particularly in the process with a non-consumable electrode, a similarly vertically displaceable steel baffle may be employed separating the slag from the input raw material. This action can be enhanced by feeding the input raw material opposite to the slag tapping device, as shown in FIGS. **5** and **5***a*. Where desired, the steel baffle can conveniently be water cooled. This may be operable to continuously tap off the major part of the reacted slag or to intermittently do so at selected intervals. In all other respects, the apparatus of FIGS. **5** and **5***a* is similar to the previous embodiments and will be similarly numbered with accompanying primes.

It is preferred that the temperature of the slag material not be appreciably different from that of the molten alloy. In this connection, the temperature difference should not be too large because of the loss of energy which results in not only inefficiency and waste, but also in environment contamination by evaporation of the disassociated calcium fluoride. In addition, a large temperature difference will upset the desired current path. On the other hand, if the difference is too small, the desired sharp interface between and separating the slag and molten alloy will not be present and suspension of the alloy within the slag will occur. This is not desired. It is preferred that the slag be maintained on top of the alloy to assure that the alloying reaction takes place. In accordance with several of the successful applications of this invention, the temperature difference was between 50° and 150° C. and generally in the order of about 100° C.

In actual practice, the desired reaction temperatures needed for given starting materials and end product are available in the metal handbooks and texts. When this temperature is ascertained, the electrical energy supplied at the lower end of electrode **30** or **30'** is regulated and set to provide this temperature at reaction zone **28** or **28'**. An inspection of the eventually formed rod **40** or **40'** will indicate whether the reaction temperature has been reached. In the event inclusions are present across a part of a cross-section of the rod, this is an indication that the temperature should be elevated. It is also important that the temperature gradient across the entire cross-section of the reaction along the interface of the slag and molten metal be kept at a minimum and consequently the temperature difference between slag and molten alloy across the entire reaction zone **28** or **28'**. This, of course, is enhanced by the induction stirring. If homogeneity is not present in the ultimately formed rod **40** or **40'**, the stirring action should be increased. This stirring action can be viewed and if not enough stirring is taking place, the current supply means **24** or **24'** is increased. If too much stirring is taking place, turbulence and spillage out of end **14** will be noticed. In other words, the stirring must be effective to provide a temperature across the entire interface between slag and metal for a complete equilibrium of reaction between melt and flux.

It should be noted that if a crucible **80** having an enlarged upper portion **82** as shown for example in FIG. *5a* is used for carrying out the process of the present invention, it will be necessary to maintain the interface slag/liquid metal in the upper portion of the lower reduced crucible portion. If the interface slag/liquid metal moves upwardly in the enlarged upper portion **82** of the crucible **80**, the liquid metal would be allowed to solidify in the upper enlarged portion thereby interrupting the continuous process. In order to enhance the flow of the material from the upper enlarged portion **82** of the crucible **80** into the narrower reduced portion **84** of the crucible **80**, a graphite ring, as shown by the reference **90** of FIG. **5**, may be provided at the bottom of the enlarged portion of the crucible, thereby reducing the cooling effect of the cooling water at that critical point.

In order to facilitate the continuous operation of the process and to assure a process under optimum operation conditions, particularly in the process with a crucible **80** having an enlarged upper portion **84**, control means are provided with which the optimum operation conditions can easily be maintained throughout the duration of the process. Thus, the power input will be controlled by predetermined working current and voltage which are maintained by regulating the immersion depth of the electrodes in the slag. The level of the interface slag/liquid metal will be regulated by varying the rate of withdrawal of the cast rod **48'** from the crucible **80** in accordance with the position or immersion depth in the slag of the non-consumable electrode or with induction coils when the process is carried out with a consumable electrode. With respect to working current, voltage and associated immersion depth, together with the rate withdrawal of the formed alloy rod, it should be understood that these parameters depend essentially on the intended production rate, the fluxing slag composition and the raw materials to be melted. With respect to this embodiment, it is preferred that induction coils be used as a means of control for the consumable electrode application. On the other hand, for non-consumable electrode applications, the immersion depth is generally adequate for the control of the electrical parameters. In the latter case, induction coils would only have the function of additional steering, if necessary.

In order to further facilitate the continuous operation of the process and minimizing automatic or personal attention, it is found desirable to feed to a slightly excess extent the slag forming material.

As will be observed, the temperature of the walls of the copper crucible or crucible of other selected material having the desired properties for carrying out the present process should be below the reaction temperature present within the reaction zone **28** or **28'**. This is accomplished by means of the cooling system including the duct **18**, as shown in FIGS. **1–4**, or cooling inlets **20'** and outlets **22'**, as shown in FIGS. **5** and **5a**, for receiving the circulating water coolant. It should be understood and particularly noted that refactories are not employed at any time during the initiation or carrying out of the contemplated alloy producing technique.

It should be noted that the configuration of the crucible **80** of FIG. **5**, particularly the configuration of the enlarged upper portion **82**, is merely given for illustration purposes. Other appropriate configurations readily appear to those skilled in the art. It will also not be necessary to provide the upper portion **82** and the reduced portions **84** of the crucible **80** with distinct cooling systems.

Suitable electrodes in the process with a non-consumable electrode could be water-cooled steel or copper electrodes, graphite electrodes, refractory metal and refractory metal compound electrodes.

Several representative examples follow for carrying out the teaching of this invention:

EXAMPLE 1

Vanadiferous products are capable of being directly reduced to yield high purity ferro-vanadium. Thus, a mixture of 40 percent V_2O_5 and 60 percent of a standard vanadiferous slag containing about 29 percent V_2O_5 crushed to mesh −30, are mixed in stoichiometric amounts with a reducing material consisting of 62.5 percent carbon and 37.5 percent ferro-silicon Fe Si 70 (an alloy with 70 percent Si) and intimately mixed for 15 minutes. The mixture is extruded in a hydraulic press to form cylindrical electrodes 30 of 12 mm diameter. A mixture of the fluxing slag was prepared containing calcium fluoride CaF_2 with 4 percent standard ferro-manganese Fe Mn 80 (an alloy with 80 percent Mn). A water cooled double walled copper crucible **12** having an inner diameter of 10 cm and length of 25 cm was employed. In a furnace installation being limited in power to 100 KVA, an arc was struck between the crucible lid **44** covered with about 20 gr of iron powder and the electrode operating at a current of 850 A and a voltage of 40 V (direct current). Then a small quantity of fluxing slag was added and melted. The arc was subsequently extinguished by submersing the electrode in the liquid fluxing slag. The resulting production rate was 60 kg per hour. The stirring effect was obtained by a standard induction coil **26** fitting tightly the water cooled double walled copper crucible with an inner diameter of 10 cm and length of 25 cm and operating at a direct current of only 4 ampere. The resulting ferro-vanadium bar with a diameter of slightly less than **10** cm was produced to length of 1.2 m. After the desired length was obtained, the bar was sectioned by an acetylene cutting device, the cutting being below the connecting electric junction of the produced bar. The warm bars were gripped by a mechanical device and transferred to horizontal steel rolls where they were sand blasted to remove a residual coating of fluxing slag. The thickness of the slag coating was in all counts smaller than 2 mm. Consumption of fluxing slag Ca. 50g/kg of ferro-vanadium.

EXAMPLE 2

A non-consumable electrode 4 inches of graphite was employed in an arrangement corresponding to FIG. **5**. The metal oxide and reducing of Example 1 was introduced along with fluxing slag. The reacted slag consisting principally of a calciumsilicate is continuously evacuated by passing under the water-cooled steel baffle through the tapping device at the bottom of the enlarged crucible. The evacuation of the reacted slag (low thermal conductivity) enhances the stability of the electric parameters, lower power consumption and increased production rates. In all respects, the procedure followed was essentially the same except the manner in which the materials were added to the reaction zone. The results were also essentially the same.

EXAMPLE 3

"Direct reduction and refining of ferro-titanium eutectic alloy."

The electrodes were formed as in Example 1 by mixing:

65.5 percent of titanium sponge, containing 96 percent titanium, about 3% aluminum, **0.5%** iron, 4.5 percent of rutile, 30 percent of iron powder or crushed iron sponge.

The fluxing slag was identical to Example 1, e.g., CaF2 + 4 percent FeMn 80 (an alloy with 80 percent Mn).

The electrical operational data were:

Intensity 650 Amperes
35 Volts
Direct Current.

The stirring effect was produced by a standard induction coil under 4 ampere direct current. Production rate: 85 kg/h. The initiation and proceeding of the melting process is identical to Example 1. The end product was a high grade eutectic ferro-titanium 70 with an aluminum concentration below 0.2 percent al. The residual gases and tramp elements either remain at the same level or are reduced. The remaining aluminum is transferred to the slag by a local alumino-thermic reaction corresponding to

$$3\ TiO_2 + 4\ Al - 2\ Al_2O_3 + 3\ Ti.$$

The present direct reduction process and equipment have application to the production of other ferro-alloys of molybdenum, tungsten, vanadium, niobium, chromium, manganese, nickel and titanium, all of a relatively high degree of purity and reduced gas content. The formed product is homogeneous through the entire cross section and entire length of the rods.

Thus, the several aforenoted objects and advantages are most effectively attained. Although a single somewhat preferred embodiment of the invention has been disclosed and described in detail herein, it should be understood that this invention is in no sense limited thereby and its scope is to be determined by that of the appended claims.

I claim:

1. The process for the direct reduction and the continuous casting of metallic alloys in the form of a rod comprising:

providing a substantially tubular crucible having an open top end and an open bottom end and comprising an en-

larged transversely elongated upper portion and a reduced lower portion and embracing a high temperature reaction zone;

disposing at least one electrode in the passageway and through the top end such that the bottom end of the electrode is disposed proximate the reaction zone;

continuously introducing into the reaction zone at one side of the elongated upper portion of the crucible reactant materials including metal oxides, reducing agents and slag forming material;

generating and maintaining a current path between the electrode through the reactant materials to produce relatively high predetermined temperatures at the reaction zone;

generating and maintaining a slag, a part of which is above the reaction zone at the open top end and about the electrode;

tapping off the major part of the reactor slag at the side of the upper enlarged portion of the crucible which is opposite the side where the reactants were introduced, the slag flowing from the side of the introduction to the side opposite to the tapping at the top of the crucible while the liquid metal collects in the reduced lower portion;

maintaining the interface slag/liquid metal essentially in the upper portion of the reduced lower crucible portion;

cooling the metallic alloy within the reduced lower portion of the crucible; and

continuously directing the formed alloy downwardly through the bottom end of the crucible.

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