This invention relates to the production of metals by smelting compounds thereof, particularly oxidic compounds with the aid of a reducing agent.

The object of the invention is to provide a method for the smelting of metals which can be carried on in a perfectly continuous operation; also to devise a smelting method permitting of a practically perfect control of the reduction temperature and condensation conditions; also to provide a method for melting or slagging left behind in the reduction chamber.

The invention refers in particular to smelting processes practised by the heating of an intimate mixture of the material to be reduced with a reducing agent, especially with a carboaceous reducing agent, to temperatures above the boiling point of the metal to be recovered, the temperatures being appropriately chosen in dependence on the working pressure used (reduced pressure, atmospheric pressure, or increased pressure). Outstanding examples of purposes to which the new method can be applied are the recovery of zinc or of zinc and cadmium from oxidic ores or metallurgical products of an oxidic nature, and especially the recovery of magnesium from sintered magnesia or mixtures of MgO and CaO such as calcined dolomite yields at sintering temperatures.

The present method consists in its essential nature in introducing the charge into the heated reduction chamber in the form of uniformly small and regularly fed consecutive portions while so correlating the quantities of metal in the unit of charge, the proportionate amount of reducing agent added, the rate of feed, and the supply of heat that the giving off of the gaseous products of reaction from the charge approximately keeps pace with the rate of feed of the latter, so that amassing of the charge in the reduction chamber is substantially avoided.

Smelting processes which are workable in practice only at temperatures above the boiling point of the metal concerned, and which therefore yield the metal not in a liquid state but in the form of vapor, have hitherto been mainly carried out periodically in tubes, retorts, and muffle furnaces of comparatively small capacity. More particularly in the reduction of magnesia oxide, the continuous method of working has not as yet proved capable of development to the point of practical applicability.

The proposals hitherto made to obtain magnesium by the reduction of magnesia oxide or minerals yielding the latter, with the aid of carbon, have been confined to working on electrothermic lines. However, the efforts made in this direction, which date back a very long time, have proved unsuccessful until quite recently, for the reason that the metallic magnesium is readily oxidized at temperatures but slightly below the reducing temperature, not only by carbon dioxide but also by carbon monoxide, which in the case of smelting with carbon, is formed from the carbon in equimolecular quantities. In spite of the reduction being effected in a current of inert or reducing gas, the reoxidation of the metal and the difficulties resulting therefrom in the condensation of the magnesium vapor, have proved an insurmountable obstacle for decades past. The problem here presented was solved for the first time by a process forming the subject matter of United States Patent No. 1,884,993, by which process the vaporous and gaseous reaction products are maintained, up to the point of leaving the reaction chamber, at so high a temperature that the equilibrium of the reaction

\[ MgO + C = Mg + CO \]

is practically displaced to the right-hand side, whereupon the said reaction products are diluted, by the addition of considerable quantities of cold inert or reducing gases, and at the same time suddenly chilled in the moment of leaving the reduction chamber, to a temperature at which metallic magnesium and carbon monoxide remain stable in the presence of each other.

The present invention provides a method suitable for both thermic and electrothermic processes of the above-described nature, which permits of a perfectly continuous working operation. At the same time, this method has the great advantage that in the reduction region the reversal of the equilibrium reactions of the general type of

\[ RO + CO_2 = RCO \]

is effectively avoided in a very simple manner by practically perfect control of the reduction temperature. Fluctuations in the temperature of the furnace are precluded, since the metal vapors evolved and the gaseous products of the reaction are disengaged almost instantaneously from each of the small portions of the charge passing one by one into the hot reduction chamber.

The difficulties met with in the condensing zone have recently led, in conjunction with the recovery of zinc, to intentionally causing the zinc vapor, by rapid cooling, to condense to a powdery deposit, whereas the formation of dust has hitherto been avoided as far as possible. In recent years it has become usual to work in two stages, zinc dust as poor as possible in oxygen being first produced, after which the dust is caused to unite to molten zinc by means of mechanical agitation (shifting or shaking) in a neutral or inert atmosphere.

In connection with the electrothermic reduc-
tion of magnesium, the condensation of magnesium vapors to dust has so far been effected only with the view of obtaining this dust (held to be incapable of being fused together) as a final product. It has not been considered feasible only with the complete exclusion of carbon monoxide from the reduction products, that is to say with the use of other than carbonaceous reducing agents. In this respect also, the art has entered on a new phase as the result of the research and experimental work done but recently, the surprising fact having been thereby established that the reduction of magnesium oxide with carbon can be rendered feasible, in spite of the formation of equimolecular quantities of CO, provided the magnesium vapors be condensed to dust by sudden cooling down to below the solidification point of metallic magnesium. Furthermore it has been found that, in direct contradiction to the statements hitherto made, this dust can then be caused to coalesce by heating or distillation (United States Patent No. 1,943,601).

In this connection also, the method according to the present application represents a very considerable improvement over previous methods of working. Owing to the excessive, regularly intermittent feeding in of the charge in uniformly small portions which are, so to say, instantaneously reduced in the furnace, a constant stream of the gaseous reduction products leaves the reduction chamber, so that for the maintenance of completely invariable condensation conditions there is no necessity for varying the cooling effect, e. g. the quantity of diluting and cooling gas added, to accord with varying output of the reduction process. When once the supply of cooling gas has been set proportionately to the quantity of gaseous reduction products evolved per unit of time, no further regulation is necessary to ensure the maintenance of perfectly uniform working.

Starting materials containing in the form of oxide the metal to be recovered can be directly subjected to the reduction process. Starting materials containing carbones or sulphides of the metal are generally first calcined or roasted. Oxides or minerals or metallic products of an oxidic nature must equally be subjected to preliminary heating, as is otherwise usual, if they contain water or other volatile foreign matter. According to a preferred embodiment of the invention, the charging is effected with material in the shape of small briquettes which are thrown into the highly heated reduction chamber. The briquettes are molded and baked in the usual manner, from a mixture of the finely pulverized material containing metallic oxide and finely pulverized carbonaceous material, with the employment of a binding agent which becomes carbonized under heat. If a rapidly carbonizing binding agent, for example tar pitch, be employed in the production of the briquettes, the latter can be introduced into the reduction chamber in the unbaked state, provided they are free of water and volatile foreign matter.

If the starting materials used be sufficiently rich in the metal to be recovered by reduction, that is to say contain only slight quantities of concomitant substances which are non-volatile at the temperature of working, the further advantage of the present method becomes apparent, that, on the explosive bursting of the portions of the charge by the suddenly evolved metal vapors, the non-volatile concomitants (for example iron, aluminum, calcium, and silicon, in the form of Fe, Al2O3, CaO, and SiO2) are carried along with the disengaged metal vapor, so that they leave the reduction chamber in the form of fine clouds of dust mixed with the gaseous reduction products. This is the case, for example, when starting from sintered magnesia which contains on an average 89-90% of MgO. This phenomenon is favored by effecting the reduction as a result of the sudden injection of inert or reducing gas. When carried out in this manner the present method affords the further very considerable advantage that the reduction takes place without leaving any residue or slag in the reduction chamber. The non-volatile substances are preferably separated out, either before the condensation of the metal vapor evolved in the reducing process or after the condensation process.

The reduction chamber can be heated indirectly or by internal electric heating (resistance or electric arc heating or combined arc and resistance heating), it appearing to be advantageous, as far as at present can be seen, for the charge itself not to serve as a current carrying conductor. If the reduction process is carried out at a high pressure, the charge is admitted into the reduction chamber through lock chambers. Apparatus suitable for carrying out the method according to the present invention is shown diagrammatically in side elevation and partly in section in the accompanying drawing.

Into the top of the electric furnace which is equipped with electric arc heating, there issues a tube the upper end of which is connected to a bucket conveyor. In the constructional example shown, the conveyor consists of a disc provided with buckets and projecting partly into a briquette storage container. The briquettes dropping from the buckets into the tube 2 are required to traverse a lock chamber which is equipped with two plate-shaped closure members 6 and 7. These closure members are actuated by means of two systems of levers 8 and 9 which are so controlled by eccentrics 10 and 11 that the one closure member intercepts the passage before the other begins to open. At the lower end of tube 2 there is provided a gas supply pipe 19.

The discharge opening of the furnace 1, the top of which is traversed by two electrodes 12 and 12', is lined with a water-cooled jacket 14, and is connected by a tube 15 with a filtering apparatus 16. coaxially within the discharge opening there is arranged a water-cooled cylinder 17. The casing of this cylinder is provided with nozzles 18 for the escape of cooling and diluting gas. From the bucket conveyor there drops at regular intervals one briquette at a time, which is arrested by the plate 6. As soon as the plate 7 reaches the position of closure the plate 6 is retracted and the briquette allowed to drop on to the plate 7 which in its turn begins to be retracted as soon as the plate 6 resumes the position of closure. The briquette then drops into the furnace. Non-oxidizing gas is introduced through pipe 19 to serve as a carrier and at the same time to prevent the gaseous and vaporous reduction products evolved in the furnace from rising through pipe 2. Together with the non-volatile pulverulent concomitant substances present in the charge the said products of reaction pass out through the discharge opening where they are diluted and rapidly cooled off by a cold.
inert or reducing gas escaping from the nozzles 18. In the filtering plant 16 the magnesium dust is separated out, while the gas freed from magnesium is conducted off and returned into circulation after suitable cleaning.

The charging is so regulated, as to nature and rate of feed, that the interval between the admission of one briquette and the next into the furnace approximately corresponds to the time required for the evolution of the vaporous and gaseous reaction products of one briquette. In this manner any amassing of the charge in the furnace is avoided. What I claim is:

1. The process for the production of magnesium which comprises forming into a mixture of a reducible compound of magnesium, a carbonaceous reducing agent, and a freely carbonizing binding agent, forming said mixture into compacted bodies of small and substantially uniform size, introducing said bodies in a non-baked state piece by piece into a reduction chamber maintained, by electric heating, at a temperature above the boiling point of magnesium, without the charge substantially participating in the carrying of the current, to liberate magnesium vapor from each individual body during its stay in the reduction chamber without the charge being amassad to a substantial extent therein; thereafter passing the evolved metal vapor into a condenser and cooling it to condensation point.

2. The process for the production of magnesium, which comprises forming into detached uniformly small compacted bodies a mixture of a reducible compound of magnesium and of a solid carbonaceous reducing agent, in an amount sufficient for effecting reduction of the magnesium compound without a co-operative gaseous reducing agent being used, causing said detached bodies to drop one by one at regular intervals into a reduction chamber maintained at a temperature above the boiling point of the magnesium; thereafter passing the evolved magnesium vapor into a condenser and cooling it to condensation point.

3. The process for the production of magnesium, which comprises forming into detached uniformly small compacted bodies a mixture of a reducible compound of magnesium and of a solid reducing agent in an amount sufficient for effecting reduction of the magnesium compound without a co-operative gaseous reducing agent being used, causing said detached bodies to drop one by one at regular intervals into a reduction chamber maintained at a temperature above the boiling point of the magnesium; thereafter passing the evolved magnesium vapor into a condenser and cooling it to condensation point.

5. The process for the production of magnesium, which comprises forming into detached uniformly small compacted bodies a mixture of a reducible compound of magnesium and of a solid carbonaceous reducing agent in an amount sufficient for effecting reduction of the magnesium compound without a co-operative gaseous reducing agent being used, causing said detached bodies to drop one by one at regular intervals into a reduction chamber maintained, by electric heating, without the charge substantially participating in the carrying of the current, at a temperature above the boiling point of the magnesium, to liberate and vaporize the magnesium content of each detached body so suddenly as to avoid any substantial accumulation of the charge in the reduction chamber; thereafter passing the evolved magnesium vapor into a condenser and cooling it to condensation point.

6. The process for the production of magnesium, which comprises forming into detached uniformly small compacted bodies a mixture of a reducible compound of magnesium and a solid carbonaceous reducing agent, with the aid of a freely carbonizing binding agent, the said reducing agent being present in an amount sufficient for effecting reduction of the magnesium compound without a co-operative gaseous reducing agent being used, causing said detached bodies in a non-baked state to drop one by one at regular intervals into a reduction chamber maintained, by electric heating, without the said bodies substantially participating in the carrying of the current, at a temperature above the boiling point of the magnesium, to liberate and vaporize the magnesium content of each detached body so suddenly as to avoid any substantial accumulation of the charge in the reduction chamber; thereafter passing the evolved magnesium vapor into a condenser and cooling it to condensation point.

7. The process for the production of magnesium, which comprises forming into detached uniformly small compacted bodies a mixture of a reducible compound of magnesium and of a solid reducing agent in an amount sufficient for effecting reduction of the magnesium compound without a co-operative gaseous reducing agent being used, causing said detached bodies to drop one by one at regular intervals into a reduction chamber maintained at a temperature above the boiling point of the magnesium; thereafter passing the evolved magnesium vapor into a condenser and cooling it to condensation point.

8. In a process of the nature defined in claim 2 the step of subjecting the compound of magnesium to be reduced to a pre-treatment for the purpose of first removing volatile foreign matter therefrom.

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