The present invention relates to the art of treating nickel and copper sulfide ores, and, more particularly, to the art of autogenously smelting finely divided sulfide ores or concentrates containing iron, nickel and/or copper for the production of matte and slag.

A well-known procedure typical of conventional practice for the production of nickel-copper matte and blister copper from nickel-iron sulfide and copper-iron sulfide bearing ores, such as those of the Sudbury district, involves a flotation concentration of the ore into one or more nickel-iron sulfide concentrates (mainly pentlandite and pyrrhotite) and a high-grade copper-iron sulfide concentrate (mainly chalcopyrite). The nickel concentrate is roasted and the resulting calcine is smelted in a reverberatory furnace to obtain reverberatory matte which is beseamered to produce a substantially iron-free, nickel-rich matte also containing copper. Similarly, the copper concentrate is smelted in a reverberatory furnace, separately from the calcined nickel concentrates, to obtain reverberatory matte which is then beseamered to produce blister copper. Beseamering the reverberatory mattes produces nickel-rich and copper-rich slags which are treated for metal recovery by passing through the reverberatory furnaces.

Smelting by the foregoing and other conventional procedures has disadvantages in that costs of heating by carbonaceous fuel or electricity are high and in that difficulty may be encountered in securing discard slags as clean as desired. Various proposals have been made in the past for the suspension or flash smelting of sulfide ores and concentrates in order to decrease or eliminate the use of carbonaceous fuel or electric power. Thus H. H. Bridgeman in U. S. Patent No. 578,912 (1897) proposed flash smelting of pulverized sulfide ore and flux in a reverberatory-type furnace to produce matte and slag. Use of preheated air for flash smelting of sulfides was recommended in the Kleipinger, Kraee and Kussel U. S. Patent No. 1,164,653 (1915). J. W. Rysell and P. B. Brysk in British patent application 23,546/98, claim use of air preheated by the furnace exit gases and use of a downwardly directed burner. H. Freeman in 1930 disclosed having flash smelted copper sulfide flotation concentrate to produce matte, the only source of heat being the sulfide content of the concentrate. F. C. Zeisberg in U. S. Patent No. 2,088,261 suggests the flash smelting of pyrite with oxygenated air to yield sulfur dioxide-rich gas and a molten iron oxide. T. E. Norman in "Engineering and Mining Journal," October-November 1936, recommended oxygen or oxygenated air for flash smelting of copper and copper-nickel sulfide concentrates to produce matte and slag. T. R. Högland in his U. S. Patent No. 2,209,331 disclosed a process for the production of elemental sulfur by a reaction between sulfur dioxide and flash smelted sulfide particles suspended within the sulfur dioxide and mentioned the flash smelting of sulfides containing copper or nickel with flux and oxygen-rich gas to produce a molten bath. In the Kaling and Brannstrom U. S. Patent No. 2,355,219, separate preparation of a molten iron sulfide product prior to its use in slag cleaning operations is disclosed. The Brannstrom and Sundstrom Swedish Patent No. 118,892 (1947) disclosed the flash smelting of pyrite over slag wherein the "free atom" of sulfur in the pyrite (FeS2) is burned to assist in melting the remainder of the pyrite and thus to form a spray of molten iron sulfide for slag cleaning purposes. However, some of the above processes have serious shortcomings and others are not applicable to pyrrhotite nickel-containing ores.

We have discovered an improved process for the production of matte rich in nickel and/or copper, directly from nickel and/or copper concentrates, which involves a novel combination of operations and which produces compositantly a slag relatively low in nickel and/or copper.

It is an object of the present invention to provide an economical method for autogenously smelting sulfide ores and concentrates containing iron and nickel and/or copper to produce matte or metal and a slag relatively low in nickel and/or copper.

Another object is to provide a method for smelting sulfide ores and concentrates containing iron, nickel and/or copper by utilizing the material being treated as fuel to provide the necessary smelting temperatures to obtain a matte containing nickel and/or copper and, concomitantly, a slag low in nickel and/or copper and containing a
major portion of the iron originally present in the sulfide ore or concentrate.

A further object of this invention is to provide a satisfactory economic method for recovering nickel and/or copper from slag containing the same by autogenously smelting pyrrhotite concentrate over the slag, whereby said slag is washed with a shower of molten iron-rich matte drops.

The present invention contemplates as an additional object providing a process for autogenously smelting both nickel and/or copper sulfide concentrate and pyrrhotite concentrate to produce high-grade matte and low-grade slag, and, concurrently, producing gas containing high concentrations of sulfur dioxide.

Other objects and advantages will become apparent from the following description taken in conjunction with the drawings, in which:

Fig. 1 is a schematic diagram of an embodiment of the present invention in which a nickel and/or copper sulfide concentrate is autogenously smelted to produce nickel and/or copper-rich matte and slag rich in nickel and/or copper and in which, alternately, pyrrhotite concentrate is locked out nickel and/or copper is autogenously smelted in the same furnace to produce a shower of molten low-grade matte and slag which removed nickel and/or copper from said rich slag.

Fig. 2 depicts a modification of the novel process in which the autogenous smelting of both nickel and/or copper sulfide concentrate and pyrrhotite concentrate can take place simultaneously through burners located at different positions in the same furnace, the nickel and/or copper-rich matte being tapped from the high-grade end of said furnace and the slag being tapped from the low-grade or pyrrhotite end of the furnace, whereby the rich slag is depleted of nickel and/or copper by the low-grade matte shower and by countercurrent flow of matte relative to slag.

Fig. 3 illustrates another modification of the process in which the furnace is provided with a hearth-particle or barrier to separate the molten low-grade matte from the molten high-grade matte but which permits the slag from the high-grade end of the furnace to flow over and into the low-grade end of the furnace for purposes of nickel and/or copper recovery from said slag; and

Fig. 4 shows still another modification of the present invention in which the production of molten low-grade matte by the autogenous smelting of pyrrhotite concentrate and the showering of said low-grade matte onto the molten slag, rich in nickel and/or copper occurs in a furnace separate from the furnace in which high-grade matte and rich slag are produced.

The present invention comprises a novel combination of operations for either simultaneously or cyclically autogenously smelting two sulfide materials of different compositions with flux, one sulfide-concentrate being rich in nickel and/or copper and the other sulfide-concentrate being low in nickel and/or copper sulfide but rich in pyrrhotite.

The novel process utilizes the exothermic reactions occurring between metal sulfides and gases containing a sufficiently high concentration of free oxygen to autogenously smelt said sulfides and flux to produce matte and slag or even metal and slag.

When the present invention is carried into practice, it involves coordinated control over various metallurgical and mechanical factors, including compositions, absolute and relative particle sizes and moisture contents of the sulfide concentrates and flux, the free-oxygen contents of the burner gas and the ratios of free oxygen and siliceous flux to sulfide concentrates, furnace dimensions, and furnace temperatures. For instance, great care must be taken to keep the ratio of the various components of the burner feed, including the oxygen, and also the rate of injection thereof into the furnace. Proper furnace and burner construction as described hereinafter are important in obtaining optimum operation. The ratio of siliceous flux to sulfide concentrate is predeterminative by the degree of iron sulfide oxidation desired, i.e., the amount of iron oxide formed, and the silica in the sulfide-flux mixtures must be in amount sufficient to form a suitable slag with the iron oxide produced.

In order to initiate the exothermic reaction between the iron sulfide fraction of the concentrate and the free oxygen of the gas, the furnace into which the mixture is injected must be preheated to over about 1500° F., and preferably over about 2000° F., by means of, for example, oil, coal, or coke dust.

In that part of the process involving the autogenous smelting of high-grade nickel and/or copper sulfide concentrate, it is desired that sufficient of the iron sulfide fraction be oxidized to form iron oxide and gaseous sulfur dioxide to produce the desired matte of matter, due consideration being given to maintenance of suitable furnace temperature, while at the same time it is also desired to have as little as possible of the nickel and/or copper sulfide concomitantly oxidized into the slag. However, separation of a major portion of the iron, as an oxide in the slag, from the copper and/or nickel matte is not commercially feasible without unavoidable production of slag sufficiently rich in nickel and/or copper to warrant recovery therefrom of these valuable elements. The present invention contemplates as an essential feature, in novel combination with the aforementioned autogenous smelting of nickel and/or copper sulfide concentrate, the operation of slag-cleaning by autogenously smelting pyrrhotite concentrate to produce a shower of low-grade matte and slag which falls on the aforementioned rich slag.

In order to produce a low-grade, iron-rich matte suitable for slag-cleaning purposes, and a portion of the pyrrhotite concentrate is oxidized in the presence of flux, the remaining portion being melted by combustion of the portion oxidized. The molten, unoxidized iron sulfide fraction of the autogenously smelted pyrrhotite concentrate upon coming into intimate contact with the high-grade rich slag obtained from the nickel and/or copper sulfide smelting operation recovers nickel and/or copper values from the rich slag so as to obtain as a final product, a slag impoverished in nickel and/or copper. Thus, smelting nickeliferous pyrrhotite in the present process serves a two-fold purpose: (1) to clean slag rich in nickel and/or copper and (2) to recover nickel from the pyrrhotite itself.

For the purpose of giving those skilled in the art a better understanding of the invention, various embodiments of the present invention will be discussed in detail hereinafter. In all these embodiments the treatment of the raw sulfides is preliminary to autogenously smelting the sulfide concentrates obtained therefrom is substantially the same: Thus, as shown in Fig. 1, the raw material to be treated is a sulfide ore
containing copper-rich minerals and/or nickel-rich minerals and also containing pyrrhotite low in copper and/or nickel. The ore after comminution is first treated by flotation and, if desired, by magnetic separation operations to yield (1) a pyrrhotite concentrate 13 low in copper and/or nickel, (2) one or more high-grade sulfide concentrates 18 high in copper and/or nickel, (3) one or more other concentrates for treatment by other processes, and (4) a reject gangue tailing 4. The high-grade nickel concentrate 10, e.g., a concentrate containing about 10% to about 75% pentlandite and the balance mainly pyrrhotite, or a high-grade taining about 75% to about 85% chalcopyrite and the balance mainly pyrrhotite, and the iron-rich concentrate 13, e.g., a concentrate containing about 80% to about 95% pyrrhotite, are dried in operations 6 and 7, respectively, to a moisture content of less than about 0.5% free moisture, preferably less than about 0.25% free moisture.

If the concentrate is too coarse, it is further comminuted. For best results, the concentrate is preferably at least about 95% minus 65 mesh and about 50% minus 200 mesh. The sulfides must be fine enough and must remain in suspension for sufficient time to react with substantially all the oxygen present. On the other hand, too fine a particle size causes excessive dust losses. Satisfactory operation is obtained when smelting concentrates of the recommended particle size range in furnaces of the shape and size disclosed hereinafter. If the particle size of the siliceous flux and the high-grade concentrate are such that they settle to the furnace hearth at approximately the same rate, the slag being formed in various parts of the furnace will have a substantially uniform composition. An advantage of utilizing concentrated oxygen rather than pre-heated air for autogenous flash smelting lies in the smaller volumes of gases involved and in the facilitated control of furnace temperature which it permits. Such temperature control is important, both from the viewpoint of product temperatures and for the purpose of minimizing furnace accretions.

Thus, a preferred embodiment of the invention illustrated in Fig. 1 is a cyclic process involving, first, the autogenous smelting of high-grade nickel concentrate 18 rich in nickel and/or copper to produce molten, high-grade matte 33 and molten slag 24 rich in nickel and/or copper; second, the tapping of said high-grade matte only; third, the autogenous smelting of pyrrhotite concentrate 13 to shower molten, low-grade matte and molten, low-grade slag on the rich slag from which the iron-rich matte removes the major portion of the nickel and/or copper values to produce a low-grade slag; and fourth, the tapping of the impoverished, low-grade slag and, if desired, the tapping of the low-grade matte containing the nickel and/or copper values recovered from the high-grade slag. Satisfactory results are also obtained when the high-grade matte is allowed to remain in the furnace during at least a portion of the slag-cleaning part of the cycle.

More specifically, the embodiment illustrated by Figs. 1, 2 and 3 intimately mixes the dry, finely-divided, high-grade concentrate 18 with a fluxing agent 11, such as quartzite or sand, to which may be added some lime or other flux-modifying agent 12 if required. The controlled mixing of the sulfide concentrate and the flux, 24 containing about 30% to about 35% silica, with or without a flux-modifying agent, is accomplished by means of feeders, mixer 17, and a sealing feeder 18 to eliminate uncontrolled passage of air. When it is attempted to autogenously smelt a charge of the aforementioned composition using relatively pure silica flux, e.g., quartzite containing about 95% silica, without a modifying agent and at normal operating temperatures, a metallurgically unsatisfactory slag is usually produced and detrimental solid accretions tend to accumulate in the furnace 22. However, addition of flux-modifying agents 12 and 15, such as lime, magnesia or aluminia, to the flux may be omitted if a siliceous flux is chosen which already contains suitable modifying agents. Thus, while a 95% silica-quartzite flux may require the addition of as much as 10% lime or even more, a sand containing, for instance, only about 80% silica and the balance mainly aluminia, lime and other oxides, requires little or no additional modifying agents. The fineness of the siliceous flux is about minus 48 mesh and the free-moisture content is less than about 0.5%, preferably less than about 0.25%. The ratio of flux to sulfide concentrate on a weight basis is based on the silica content of the flux, the grade of matte product desired, and the production of a metallurgically suitable slag. A suitable slag normally contains about 30% to about 35% silica. In the autogenous smelting of nickel-rich pentlandite concentrates or copper-rich chalcopyrite concentrates, the weight of flux amounts to between about 15% and about 40% by weight of the sulfide concentrate.

The sulfide-flux-oxygen mixture is injected through one or more burners 21 into a reverberatory-type furnace 22 at a furnace temperature above about 1800°F, preferably between about 2100°F and about 3300°F, by means of a gas containing more than about 65% free oxygen, preferably a commercially-pure concentrated oxygen containing about 90% to about 98% free oxygen, delivered under pressure by pipeline 20 from an oxygen plant. The burners for injecting the sulfide-flux-oxygen mixture into the furnace are similar in operating principle to conventional pulverized-coal burners and are proportioned to impart a velocity of about 50 to about 100 feet per second to said mixture. The furnace is similar in shape to, but only about one-quarter the volume of, conventional reverberatory smelting furnaces per unit of solid feed rate. The burner or burners are located in the end wall and are directed in a substantially horizontal direction. A slightly downward inclination of the burner has been found valuable in avoiding the formation of accretions on the furnace bottom.

A sufficient proportion of free oxygen is used to yield a matte 23 containing between about 15% and about 65% total copper and nickel. The oxygen necessary to promote the reaction to the desired degree of oxidation and to obtain the desired furnace temperature is broad between about 15% and about 35% by weight of the sulfide concentrate and is controlled by a valve-metering device 25. When smelting concentrates in the normal flotation size range, the free oxygen present is almost entirely consumed. The molten matte 23 and the accompanying slag 24, at temperatures within the range of about 2000°F to about 2300°F. Autogenous smelting under the foregoing conditions usually produces rich slag
and containing up to as much as about 2% nickel plus copper.

When a sufficient matte bath has formed, it can be tapped from the furnace through port 55, the rich slag remaining in the furnace or, as disclosed hereinbefore, said matte bath can be permitted to remain in the furnace for a portion of the second part of the cycle. The second part of the cycle consists of pouring a molten low-grade matte and slag onto the rich slag. To accomplish this, pyrrhotite concentrate 13, obtained from the ore as described hereinbefore, is also flash smelted with oxygen and flux 14 (with or without the addition of flux-modifier 15) yielding a shower of matte and slag droplets high in iron sulfide and low in copper, nickel and other valuable metals. The weight ratio of oxygen to pyrrhotite is controlled to obtain an oxidation of about 1/3 to about 2/3 of the total iron sulfide content of the pyrrhotite concentrate to produce a molten matte containing from about 2% to about 4% total copper and nickel. The passage of the low-grade matte and slag droplets through the rich slag carries a substantial portion of the valuable material contained in the rich slag into the underlying matte layers. In actual practice, good results have been obtained when employing a weight of pyrrhotite concentrate equal to about 20% to about 35% of the weight of low-grade concentrates of copper and/or nickel.

In the cyclic process, illustrated in Fig. 1, the autogenous smelting of the nickel and/or copper sulfide concentrate is terminated for a period of about one-half to one hour prior to the removal of the slag from the furnace through port 27. During this period, amounting to roughly 1/3 of the total or overall time, pyrrhotite concentrate is smelted, preferably, although not necessarily, through the same burner or burners as are used for smelting the high-grade concentrate. Judicious blending of air or inert gas into the oxygen supply line may at times be desirable to permit control of the degree of oxidation rate of flame propagation, and flame temperature in smelting the low-grade or pyrrhotite concentrates.

The sulfur-dioxide-rich gases exhausting through port 25 are cleaned of their dust and, if desired, their moisture content, by means of settling chamber 29 and further gas cleaning equipment 30, prior to treatment by known means for production of liquid sulfur dioxide, elemental sulfur, and sulfuric acid, etc. The dust content of the exhaust gases will generally not exceed about 5% of the weight of concentrate being smelted. Additional of about 3% of total oxygen to the furnace exhaust gases results in the collected dust being relatively easy to handle, presumably as a result of oxidizing to sulfur dioxide the elemental sulfur present.

Molten converter slag can be charged into the furnace in conventional manner when operating according to the embodiment of the invention depicted in Figure 1, and satisfactory cleaning of said converter slag can be secured. It is preferred that the conversion in the furnace be completed at the high-grade concentrate, that is, before commencing the slag cleaning portion of the cycle.

Another embodiment of the present invention, depicted by Fig. 2, contemplates a simultaneous autogenous smelting of both high-grade concentrate and flux 42 and low-grade pyrrhotite concentrate and flux 43 by use of burners 54 and 55, respectively, placed at different locations in the furnace. By tapping the high-grade matte from that end of the furnace at which the nickel and/or copper concentrate is smelted, e.g., through port 55, and by tapping the slag 53 from that end of the furnace at which low-grade concentrate is smelted, e.g., through port 58, countercurrent movement between the matte bath and the covering slag is provided, thereby enhancing the slag-cleaning action.

Still another modification of the present process is shown in Fig. 3. Here a hearth partition or barrier 90 effectively separates the high-grade matte 71 from the low-grade mattes 72. Treatment of the rich slag 73 by autogenously smelting low-grade concentrate and flux 74 to produce molten low-grade matte for recovery of nickel and/or copper from slag 75 proceeds simultaneously with the autogenous smelting of nickel and/or copper sulfide concentrate and flux 75. For instance, pentlandite or chalcopyrite concentrate is mixed with silica flux (with or without a lime addition) and is autogenously smelted in furnace 77 with oxygen. High-grade matte 71 is tapped at intervals via port 71h to maintain the matte level below the top of the barrier 90. The slag 73, containing considerable nickel and/or copper, overflows the barrier. A stream of low-grade matte 79 and slag produced by the autogenous smelting of pyrrhotite concentrate and flux 74, mainly falls upon this portion of slag 73 and removes values contained therein. The resulting molten low-grade matte pool 72 is tapped via port 81 before said matte overflows the barrier; and the overlying cleaned slag 73 is stirred via port 92, allowing the rich slag from the other end of the furnace to replace it and in turn be cleaned. If desired, low-grade matte and cleaned slag may be removed together and subsequently separated by means of a settler.

Another embodiment of the present invention is shown in Fig. 4, in which the autogenous smelting of nickel and/or copper sulfide concentrate 90 to produce matte 94 and rich slag 95 is carried out in one furnace 96 and the slag-cleaning operation is carried out in a separate furnace 97. As an example, high-grade pentlandite concentrate 93 mixed in proper proportions with silica flux (with or without lime additions) is autogenously smelted in a furnace 95 with oxygen 99 to produce matte 94 and a rich slag 95. The molten slag 95 is transferred by known means to slag treating furnace 97 through port 105, and the matte is tapped at port 101. Other slags 98, such as converter slag, can also be cleaned in the slag cleaning furnace after introduction through port 106. Cleaned slag 102 and low-grade matte 103 are either tapped from furnace 97 through ports 104 and 105, respectively, or are transferred together to a settler from which matte and slag are removed separately.

Some benefit from countercurrent movement of matte and slag in furnace 97 may be obtained by removing them at opposite ends of the furnace, as shown in Figure 4.

The slag during the smelting of the raw sulfide ore, the moisture content of the various sulfide concentrates obtained therefrom, the particle size ranges of said sulfide concentrates and of flux, the composition of the injection gas, the furnace operating temperature range, etc., are similar for all embodiments of the present invention, including those discussed hereinbefore.
A copper-nickel-iron sulfide ore, of the type occurring near Sudbury, Ontario, Canada, is treated by flotation and by magnetic separation to yield (1) a reject gangue tailing; (2) a nickelferous pyrrhotite concentrate containing about 0.05% copper, about 0.90% nickel, about 5% silica, 0.2% gangue and the balance iron and sulfur; (3) a more nickel concentrate containing about 0.5% to about 1.5% copper, about 3% to about 20% nickel and the balance mainly iron, sulfur and siliceous gangue; and finally (4) a copper sulfide concentrate containing about 30% copper, about 1% nickel, about 3% siliceous gangue and the balance mainly iron and sulfur. The copper sulfide flotation concentrate is filtered, dried to a moisture content of less than about 0.5% and comminuted to substantially all minus 65 mesh by milling in closed circuit with an air classifier. Siliceous flux and lime are then added to less than about 0.5% free moisture content and are comminuted to minus 48 mesh.

The dried, finely-divided, copper sulfide concentrate and fluxes are fed into bins at carefully controlled rates, mixed, and then fed to a burner of the type mentioned hereinbefore. Commercially pure oxygen, containing about 98% oxygen, carries the mixed, finely-divided solids through the burners into the hot flash smelting furnace where iron and sulfur in the sulfide concentrate are burned in suspension in the oxygen to form iron oxides and sulfur dioxide. The iron oxides, siliceous flux and lime combine to form a fluid slag. This combination occurs partly while the material is still in suspension and is completed after it settles by gravity to the furnace hearth. The unburned, or partly burned, sulfides settle upon the hearth and form a molten matte layer beneath the slag.

After a period of time, smelting of the copper concentrate is discontinued, matte is tapped, and then smelting of the aforementioned pyrrhotite concentrate is commenced, using a procedure parallel to that described for the copper concentrate. After smelting pyrrhotite for a period of time about 15% to about 30% as long as the time during which the copper concentrate was smelted, slag is skimmed and the 4-part cycle is then repeated.

The sulfur dioxide gas passes from the furnace to the settling chamber, together with gaseous impurities present in the commercial oxygen and dust which amounts to about 5% of the solids charged into the furnace. Exit gas from the settling chamber, containing about 1% of the furnace solids, is then cleaned by passage through an open spray tower, a wet cyclone, mineral fiber bags, and finally a wet Cottrell. The dust leaving the wet cyclone amounts to less than 0.05% of the furnace charge. The greater part of the SO2 in the gas is then liquefied by methods known in the art.

The proportion of oxygen to sulfides is adjusted to yield a matte containing about 55% to about 65% total copper and nickel. The weight of oxygen used is about 25% to about 35% of that of the copper sulfide concentrate smelted. The proportion of siliceous flux used is about 25% to about 35% of the copper sulfide concentrate and is sufficient to form slag containing about 31% to about 33% silica.

Specific average results obtained over a representative one-week period of continuous testing using the foregoing combination of operations are as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper sulfide concentrate</td>
<td>30.6 Cu, 1.1 Ni, 34.9 S, and 1.3 SiO2</td>
</tr>
</tbody>
</table>
conventional reverberatory furnaces. Surfaces exposed to the flame are constructed, for example, of burned brick rich in magnesia and are backed by heat insulating material. An impermeable shell, for instance, sheet steel, normally entirely encloses the furnace apart from the necessary openings for the burners and for withdrawing matte, slag, and gases. This impermeable shell has been found necessary to avoid, on the one hand, leakage of concentrated sulfur dioxide gas from the furnace, or, on the other hand, infiltration of air with a resulting loss in thermal efficiency and a lowering in concentration of the sulfur dioxide in the exit gases. We have found that a furnace inside volume approximately 8 to 16 cu. ft. is required per ton of cold charge smelted per day. This is only about one-quarter the volume of a conventional reverberatory furnace of similar smelting capacity. While some variation in this factor can be accomplished by adjustment in the thermal insulation of the furnace and in the proportion of inert material added, such as flux, any wide deviation from the foregoing furnace volume range will result either in excessive heat loss if the furnace is too large or in rapid failure of the refractories if the furnace is too small. Burners for introduction of the mixture of sulfide, flux and oxygen are proportioned to yield a velocity to said mixture of about 50 to 100 feet per second. When oxygenated air is used in place of commercially pure oxygen, the burner exit velocity may be less than that mentioned before.

In the present specification and appended claims where the term "high-grade" is used in connection with "matte," "slag" or "concentrate," it is meant thereby that said matte, slag or concentrate is relatively rich in nickel and/or copper, e.g., the matte contains at least about 15% total nickel and/or copper, the concentrate contains at least about 3% total nickel and/or copper, and the slag contains at least about 0.5% nickel and/or copper, respectively. Conversely, where the term "low-grade" is used in connection with "matte," "sulfide" or "concentrate," it is meant thereby that said matte, slag or concentrate is poor in nickel and/or copper; e.g., the matte, concentrate and slag contain, respectively, less than the aforementioned amounts of copper and/or nickel. In the appended claims, where the terms "nickel" and "copper" and "nickel-copper" are used, it is meant to include cases where the product described, such as sulfide concentrate from copper-nickel ores or matte, contains up to about 100% as much of one of these metals as of the other. Where the term "nickel" is used, this is also meant to include "cobalt.

Although the present invention has been described in conjunction with certain preferred embodiments thereof, those skilled in the art will understand that variations and modifications thereof can be made. Such variations and modifications are to be considered within the purview and scope of the specification and the appended claims.

We claim:

1. An improved process for producing high-grade matte, low-grade slag, and gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression, which comprises: autogenously smelting above about 2000° F. a mixture of high-grade sulfide concentrate containing about 75% to about 85% chalcopyrite and having a free moisture content less than about 0.5%, a siliceous flux and an oxidizing gas containing about 65% to about 98% free oxygen to obtain a high-grade molten matte containing a major portion of copper, a high-grade molten siliceous slag rich in copper, and a gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression; autogenously smelting above about 2000° F. a mixture of low-grade sulfide concentrate having a free moisture content less than about 0.5% and containing about 80% to about 95% pyrrhotite, a siliceous flux and an oxidizing gas containing about 65% to about 98% free oxygen to oxidize a major portion of said low-grade concentrate to produce molten low-grade matte, rich in iron sulfide, a molten low-grade slag; and withdrawing said molten low-grade matte as molten droplets upon said high-grade molten siliceous slag to pass through the same and to remove therefrom the bulk of the copper values to produce an enriched matte; tapping at one point the high-grade matte prior to completion of the autogenous smelting of the low-grade concentrate; tapping at another point impoverished slag in such manner that the matte and slag are separately tapped in counter-current flow relative to each other; and withdrawing from the space above said molten slag and molten matte gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression.

2. An improved process for producing a high-grade matte, a low-grade slag and gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression which comprises: autogenously smelting a mixture of siliceous flux, an oxidizing gas containing about 65% to about 98% free oxygen and a high-grade sulfide concentrate containing about 75% to about 95% chalcopyrite and having a free moisture content of less than about 0.5% in a refractory-lined impermeably encased chamber being at a temperature above about 2000° F., having ports for withdrawing matte and slag and for exhausting gas and having at least one burner for injecting said mixture to obtain a high-grade molten matte rich in copper, a high-grade siliceous slag rich in copper, and a gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression; autogenously smelting a mixture of a siliceous flux, a low-grade sulfide concentrate having a free moisture content of less than about 0.5% and containing about 80% to about 95% pyrrhotite, and an oxidizing gas containing about 65% to about 98% free oxygen in amounts sufficient to oxidize about one-fourth to about two-thirds by weight of said low-grade concentrate by injecting the low-grade mixture into said chamber by means of at least one burner to produce molten low-grade matte, rich in iron sulfide, and low-grade slag, said burner being directed to shower said molten low-grade matte in the form of molten droplets upon said high-grade molten siliceous slag to pass through the same to remove therefrom the bulk of the copper values and to produce an enriched matte and an impoverished slag; withdrawing enriched matte and impoverished slag; and withdrawing through the gas exhaust port, gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression.

3. An improved process for producing a high-grade matte, low-grade slag and gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression which comprises: autogenously smelting above about 1500° F. a mixture of high-grade sulfide concentrate containing about 75% to about 95% chalcopyrite, a
siliceous flux and an oxidizing gas containing about 65% to about 98% of free oxygen to obtain a high-grade molten matte rich in copper, a high-grade molten silicic acid slug rich in copper, and a gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression; autogenously smelting above about 1500° F., a mixture of low-grade concentrate containing about 80% to about 95% pyrrhotite and at least one sulfide of the group consisting of nickel sulfide and copper sulfide, a siliceous flux and an oxidizing gas containing about 90% to about 98% of free oxygen in an amount sufficient to oxidize one-fourth to about two-thirds by weight of said low-grade concentrate to produce molten silicic acid slag, rich in iron sulfide, and low-grade slag; showering said molten silicic acid slag as molten droplets upon said high-grade molten silicic acid slag to pass through the same and to remove therefrom of the bulk of the nickel values to produce an enriched matte; taping at one point the high-grade matte, prior to completion of the autogenous smelting of the low-grade concentrate; tapping at another point impoverished slag in such manner that the matte and slag are separately tapped in countercurrent flow relative to each other; and withdrawing from the space above said molten slag and molten matte gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression.

An improved process for producing a high-grade matte, low-grade slag and gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression which comprises autogenously smelting above about 1500° F., a mixture of substantially dry, finely divided, high-grade sulfide concentrate containing about 10% to about 75% pentlandite, a siliceous flux and an oxidizing gas containing about 65% to about 85% of free oxygen in an amount sufficient to oxidize one-fourth to about two-thirds by weight of said low-grade concentrate to produce molten low-grade matte, rich in iron sulfide, and low-grade slag; showering said molten low-grade matte as molten droplets upon said high-grade molten silicic acid slag to pass through the same and to remove therefrom the bulk of the nickel values to produce an enriched matte; taping at one point the high-grade matte, prior to completion of the autogenous smelting of the low-grade concentrate; tapping at another point impoverished slag in such manner that the matte and slag are separately tapped in countercurrent flow relative to each other; and withdrawing from the space above said molten slag and molten matte gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression.
weight of said concentrate to obtain a high-grade molten matte rich in nickel, a high-grade molten siliceous slag rich in nickel, and a gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression; autogenously smelting above about 2000°F. a mixture of substantially dry, finely divided, low-grade sulfide concentrate, essentially of iron sulfide, a siliceous flux, and about 15% to 40% by weight of said low-grade concentrate and an oxidizing gas containing between about 90% to about 98% free oxygen in amounts sufficient to oxidize between about one-fourth to about two-thirds by weight of said low-grade concentrate to produce molten low-grade matte, rich in iron sulfide, and low-grade slag; showering said molten low-grade matte as droplets upon said high-grade molten siliceous slag to pass through the same and to remove therefrom the bulk of the nickel values to produce an enriched matte and an impoverished slag; withdrawing enriched matte and impoverished slag; and withdrawing from the space above said molten slag and molten matte gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression.

8. An improved process for producing a high-grade matte, low-grade slag and gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression which comprises autogenously smelting above about 2000°F. a mixture of siliceous flux; an oxidizing gas containing about 65% to about 98% free oxygen, and a high-grade metal sulfide concentrate comprising at least one sulfide selected from the group consisting of copper sulfide and nickel sulfide and the balance essentially iron and sulfur in the form of sulfide, said copper sulfide corresponding to a concentrate having between about 75% to about 95% chalcopyrite and said nickel sulfide corresponding to a concentrate having between about 10% and about 75% pentlandite, to obtain a high-grade molten matte rich in at least one metal of the group consisting of nickel and copper, a high-grade molten siliceous slag rich in at least one metal of the group consisting of nickel and copper and a gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression. autogenously smelting above about 2000°F. a mixture of siliceous flux, a low-grade sulfide concentrate containing about 80% to about 95% pyrrhotite and an oxidizing gas containing between about 65% to about 98% free oxygen in an amount sufficient to oxidize between about one-fourth to about two-thirds by weight of said low-grade concentrate to produce molten low-grade matte, rich in iron sulfide, and low-grade slag; showering said molten low-grade matte as droplets upon said high-grade molten siliceous slag to pass through the same and to remove therefrom the bulk of the metal values from the group consisting of nickel and copper to produce an enriched matte and an impoverished slag; withdrawing enriched matte and impoverished slag; and withdrawing from the space above said molten slag and molten matte gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression.

9. An improved process for producing a high-grade matte, low-grade slag and gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression which comprises autogenously smelting a mixture of siliceous flux, an oxidizing gas containing about 65% to about 98% free oxygen and a high-grade metal sulfide concentrate comprising at least one sulfide selected from the group consisting of copper sulfide and nickel sulfide and the balance essentially iron and sulfur in the form of sulfide, said copper sulfide corresponding to a concentrate having between about 75% to about 95% chalcopyrite and said nickel sulfide corresponding to a concentrate having between about 10% and about 75% pentlandite, in a refractory-lined impermeably encased chamber being at a temperature above about 1500°F. having ports for withdrawing matte and slag and for exhausting gas and having at least one burner for injecting said mixture to obtain a high-grade molten matte rich in at least one metal of the group consisting of nickel and copper, a high-grade molten siliceous slag rich in at least one metal of the group consisting of nickel and copper and a gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression; autogenously smelting a low-grade mixture of siliceous flux, a low-grade sulfide concentrate consisting essentially of iron sulfide, and an oxidizing gas containing about 65% to about 98% free oxygen to oxidize between about one-fourth to about two-thirds by weight of said low-grade concentrate by injecting said low-grade mixture into said chamber by means of at least one burner for low-grade matte, rich in iron sulfide, and low-grade slag, said burner being directed to shower molten matte in the form of molten droplets upon said high-grade molten siliceous slag to pass through the same and to remove therefrom the bulk of the metal values from the group consisting of nickel and copper to produce an enriched matte and an impoverished slag; withdrawing enriched matte and impoverished slag; and withdrawing through the gas exhaust port gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression.

10. An improved process for producing a high-grade matte, low-grade slag and gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression which comprises autogenously smelting a mixture of siliceous flux, an oxidizing gas containing more than about 65% free oxygen and a high-grade metal sulfide concentrate containing more than 3% of at least one element from the group consisting of nickel and copper and the balance essentially iron and sulfur in the form of sulfide to obtain a high-grade molten matte rich in at least one metal of the group consisting of nickel and copper, a high-grade molten siliceous slag rich in at least one metal of the group consisting of nickel and copper and a gas sufficiently rich in sulfur dioxide as to be suitable for direct liquefaction by compression; autogenously smelting a mixture of low-grade sulfide concentrate consisting essentially of iron sulfide, a siliceous flux and an oxidizing gas containing more than about 65% free oxygen in an amount sufficient to oxidize between about one-fourth to about two-thirds by weight of said low-grade concentrate to produce molten low-grade matte, rich in iron sulfide, and low-grade slag; showering said molten low-grade matte as droplets upon said high-grade molten siliceous slag to pass through the same and to remove therefrom the bulk of the metal values from the group consisting of nickel and copper to produce an enriched matte and an impoverished slag; withdrawing enriched matte and impoverished slag; and withdrawing from the space above said molten slag and molten matte gas sufficiently rich
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in sulfur dioxide as to be suitable for direct liquefaction by compression.

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