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# RECOVERY OF COPPER FROM COPPER ORE

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## ABSTRACT OF THE DISCLOSURE

Copper metal is advantageously obtained from copper sulfide ores, without the production of air-polluting $SO_2$, by contacting the ore either simultaneously or step-wise with hydrogen and water vapor at a temperature from about 700° C., preferably above about 750° C., to above the melting point of the ore.

This invention relates to the recovery of copper from copper ores. More particularly, this invention relates to the obtaining of metallic copper from copper bearing ores without the production of air-polluting $SO_2$ as a by-product.

Copper sulfide ores are a major source of metallic copper in the world today. It has long been known that copper could be refined and obtained from various copper sulfide ores by a process of aerating the copper sulfide to thereby oxidize the impurities leaving substantially pure copper in the wake of the process. While this oxidation technique is relatively successful in producing substantially pure metallic copper, i.e., copper which may be conventionally refined to nearly 100% copper, one of the detriments associated with it is the conversion of the sulfur, present as the sulfide, into sulfur dioxide and the economic necessity of venting this sulfur dioxide as an off-gas into the atmosphere. The polluting effects of sulfur dioxide vented into the atmosphere are well known and need not be elaborated upon herein. It is sufficient to say that the oxidation process for forming copper from copper sulfide ores is no longer acceptable from an environmental point of view, at least until more successful means of $SO_2$ removal are perfected and adapted.

From the above, it is apparent that there exists a need in the art for a process of refining copper ores of all types and particularly of the sulfide type which does not decrease the quality of our environment, and at the same time produces metallic copper economically and in significantly high and pure yields.

While oxidation of copper sulfides as described above is a prevalent process for obtaining metallic copper, it is also known in the art that metallic copper may be obtained from pure copper sulfide by reducing same with hydrogen by using a scavenging agent like CaO. See, for example, Transactions of the Metallurgical Society of AIME, Vol. 245, August 1969, p. 1727 et seq. Such a process, wherein copper sulfide may be reduced with hydrogen gas, if the equilibrium is favorable, would provide a significant improvement over the oxidation process from an environmental point of view, if adaptable to ores, since in the reducing process, hydrogen sulfide rather than $SO_2$ is formed and techniques for removing hydrogen sulfide from effluent gases are well known, such as, for example, the conversion of hydrogen sulfide to sulfur and water.

In accordance with this invention, the need in the art for a copper beneficiation process which does not emit sulfur dioxide to the environment is satisfied by an economical process of producing substantially pure elemental copper from copper bearing ores with significantly high yields.



According to an aspect of this invention, there is contemplated a process for obtaining metallic copper from copper ore concentrates, such as, for example, an ore concentrate containing a sulfide of copper, by reacting or contacting this material with either a mixture of hydrogen and water vapor simultaneously or by hydrogen first and then water vapor in a stepwise process at temperatures in excess of about 700° C., and preferably in excess of about 750° C. up to in excess of the melting point of the ore material. According to another aspect of this invention, this process is conveniently performed at substantially atmospheric pressure, e.g., at several (1–5) inches of water, but if desired negative pressures and superatmospheric pressures may be employed. The ore material may be reacted or contacted with the hydrogen and water for any convenient period of time to reduce the desired amount of copper to its metallic state. Preferably, however, this contact proceeds for a sufficient period of time to convert substantially all sulfur (present as sulfide) to hydrogen sulfide.

Yet another aspect of this invention contemplates the reduction of copper and iron bearing sulfide ore concentrates of the type wherein the iron and copper may be present as complex sulfides and/or as individual copper sulfide and iron sulfide compounds. When this iron is present, the water vapor is a reactant with the iron, apparently first formed as metallic iron, to ultimately convert the iron present to a higher oxidation state. This higher oxidative iron state is the magnetic compound $Fe_3O_4$. As a result of the water reaction, additional hydrogen is evolved for further ore reduction.

While not wishing to be limited to any theory, it is believed that the chemical mechanism of the above process proceeds according to the following reactions:

$$H_2+Cu_2S \rightarrow 2Cu+H_2S$$

$$H_2+FeS \rightarrow Fe+H_2S$$

$$3Fe+4H_2O \rightarrow Fe_3O_4+4H_2$$

The benefits of carrying out the process by using both hydrogen and water either simultaneously or hydrogen followed by water are manifold. Firstly, it is apparent that substantially no $SO_2$ is formed during the process. Thus, $SO_2$ is eliminated as an environmental contaminant. The $H_2S$, which is formed according to well known techniques, may be readily removed from the vent gases and, e.g., converted into water and sulfur. The recovered sulfur is a known and valuable by-product useful in many areas of industry. As a second advantage of the above technique, which contemplates the simultaneous use of both hydrogen and water vapor, it is believed that the reaction rate is accelerated by the water facilitating the removal of the $H_2S$ from the reaction sites. The removal of $H_2S$ from the reaction sites, of course, results in improved conversions. As indicated above, the water also provides additional hydrogen formation.

Any of the known copper sulfide bearing ores may be processed in accordance with this technique. Because the process of this invention is also useful in reducing non-sulfide copper constituents (ores), for example, copper silicate, copper sulfide bearing ores which contain non-sulfide copper constituents, are contemplated since the copper from these non-sulfide constituents will also be recovered in the process. An example of a non-sulfur bearing copper mineral or constituent often found in copper sulfide bearing ores is chrysocolla ($CuSiO_3 \cdot 2H_2O$). Examples of typical copper sulfide bearing materials useful in this invention, which may or may not contain chrysocolla or other non-sulfur copper constituents, are: chalcocite ($Cu_2S$), chalcopyrite ($CuFeS_2$), and bornite ($Cu_5FeS_4$). In general, however, the ore employed will be a mixture containing one or more of the above.

Copper is usually initially obtained by mining it as a crude ore typically containing about 0.3 to 1% total copper. This crude ore is then ground and processed in known ways to produce a concentrate ore containing about 25–40, and, more typically, 30–35 weight percent of copper in a combined state. In current commercial practices, this material constitutes the feed for a reverberatory furnace whereby the copper is further refined by oxidation techniques. It is this same material which is now advantageously employed in the present process to effect copper beneficiation. This material, in addition to the iron and copper sulfides present, as indicated above, will include impurities such as silicates, antimony, silenium, titanium, cobalt, nickel, gold, silver and other trace elements.

The temperatures and times employed when carrying out the process of this invention will vary over a wide range depending upon many factors which include the type ore or mineral employed, the type process employed, and the degree of conversion (reduction to metallic copper) desired. In most instances, the times employed will be sufficient to achieve an economic metallic copper conversion, usually on the order of greater than about 75%. Of course, it is desirable to remove substantially all the sulfur (present as sulfide) to realize the full benefits of this process. In practical operation, typical times may range from a few minutes to a day or more, depending upon the size of the batch, type of material, etc. Generally speaking, the temperatures employed usually are from about 700° C., preferably 750° C., to the melting point of the ore used, or above the melting point of the ore used. In the usual case, the higher the temperature employed, the faster the reaction rate. To a large extent, the upper limits of the temperature range depend upon the type of process to be employed. If the reduction is to take place upon solid ore, e.g., a fluidized bed process, then, of course, the melting point of the ore is the upper limit of the reaction. Generally speaking, the upper limit for solid systems is about 950° C. and a preferred process temperature is from about 800–925° C. If a molten system is to be employed, the temperatures employed are, of course, above the melting point of the ore, i.e., usually above about 950° C., depending upon the metallurgy of the system. Preferred temperatures for molten systems range from slightly above the melting point of the ore to about 400° C. thereabove.

This invention contemplates within its scope the use of both a batch and a continuous system. This invention further contemplates, as stated above, the use of either a solid-gas contact system, or a molten system wherein the ore is first melted and thereafter reduced by contacting the system with the hydrogen and water vapor. Obviously, in most instances, it is preferred to employ a continuous process rather than a batch process. The choice of whether to use a solid or a liquid (molten) contact system will, of course, depend upon many factors well known to the skilled artisan. For example, if the process is carried out as a solid-gas contact system, the resulting copper will usually be separated in a known fashion by a furnace operation in which the entire reaction mixture is converted to a molten condition and slag and copper values then separated by known methods. One advantage of this solid-gas technique is that it may be incorporated into the now existing and most widely used copper refining processes without any substantial increase in capital cost. Another advantage of the solid-gas contact system is that it can be used to supplement the conventional oxidation copper refining system and thus substantially reduce the amount of $SO_2$ formed. On the other hand, if the entire reduction process is carried out in a molten system, a reactor is provided in which elemental copper is continuously withdrawn from the bottom thereof, and slag is continuously withdrawn from the top, as fresh ore is fed into the system along with the necessary hydrogen and water for the reaction.



As stated hereinabove, hydrogen is one of the basic ingredients for the reduction of the copper bearing ore to metallic copper as contemplated in this invention. The water vapor may be added either as a separate step after the reduction with the hydrogen or, preferably, simultaneously with the hydrogen. Simultaneous introduction of water vapor with the hydrogen is easily accomplished in a known fashion.

The amount of hydrogen and water employed will, of course, vary over a wide range, depending upon many factors, including the temperatures employed, the amounts of material to be treated, and the type of ore employed. In addition, since the reaction is dependent upon time and temperature, it is sufficient to state, for purposes of this invention, that a sufficient amount of hydrogen and water vapor will be employed to achieve their functions as indicated by the above reaction formulae for a sufficient period of time in order to achieve the desired yield. The volume ratio of water vapor to hydrogen may conveniently range from about 1:1 to about 20:1. Preferably, this ratio is on the order of about 10:1. In those instances where yields are required to be relatively high, e.g., above 75% of theoretical (either as metallic copper obtained or as sulfur converted to $H_2S$) and preferably above 90%, the amount of $H_2$ will be at least slightly above the stoichiometric amount necessary to achieve the desired conversion.

In a typical continuous process for the economic production of substantially pure copper and the use of the by-products to form elemental sulfur and return hydrogen into the system, a conventional gas reformer is used to obtain hydrogen and water vapor. Such a gas reformer is well known in the art and usually employs a catalyst to bring about the reaction of methane with oxygen and water to produce hydrogen admixed with water and carbon dioxide. (The carbon dioxide is separated by known methods and may be vented or used in other commercial processes.) The hydrogen and water vapor mixture so obtained is adjusted to a desired volume ratio, such as a volume ratio of 10 parts water to one part hydrogen, and this vapor mixture is injected, for example, by means of a pump or blower, through a control valve into the bottom of a continuous reactor heated to a temperature of about 1100–1300° C. Into the top of the reactor is supplied a ground and pulverized ore concentrate by a suitable furnace feed apparatus. The furnace feed apparatus may be used to control the amount of ore concentrate being provided to the reactor relative to the amount of reduction taking place. The product, metallic copper, as well as the various by-products from the reaction, are removed from the reactor in accordance with well known techniques. For example, the metallic copper, formed in the reducing reaction, is withdrawn form the lower portion of the reactor and slag, when iron is present in the ore, is withdrawn from the side of the reactor. From the top of the reactor, excess hydrogen (unreacted hydrogen as well as any hydrogen formed by reaction of water vapor with iron), water vapor, and hydrogen sulfide are removed. These removed gases are then first sent to a conventional hydrogen sulfide separator wherein the hydrogen sulfide is removed from the gas stream and the hydrogen recycled to the reactor system. The hydrogen sulfide, now free of excess hydrogen and water, is then sent to a conventional hydrogen sulfide converter for purposes of converting the hydrogen sulfide into elemental sulfur, which is a valuable by-product.

By the use of the above techniques, and by controlling the flow rates of the various ingredients in accordance with conventional skill in the art, an acceptable economic yield of metallic copper is realized. If the starting ore is substantially pure $CuS_2$ or an iron-bearing copper sulfide, the removed metallic copper product is substantially pure copper metal.

The above described reduction process of this invention may also be advantageously used in conjunction with the

known prior art techniue of oxidizing copper sulfide ores to thereby reduce, and in some instances entirely eliminate, the amount of sulfur dioxide currently being vented to the atmosphere. Generally speaking, this type procedure may be effected in the following manner. A hydrogen-water vapor mixture is initially produced in a known manner, for example by use of a gas reformer. Similarly, as described above, a first reactor is provided and a diverting feeder is provided thereabove. A portion of the ore feed is sent to the first reactor and is treated and contacted with the hydrogen and water vapor mixture in accordance with the subject invention. The remainder of the feed is diverted by the feeder to a conventional reverberatory oxidation reactor where it is oxidized in accordance with the known techniques to produce metallic copper and oxidized products, including sulfur dioxide. The copper bearing mixture, reacted with $H_2$ and $H_2O$ in the first reactor, is then cycled to the oxidizing reverberatory furnace for further purification and thus, the amount of sulfur bearing feed being oxidized is reduced by substantially the amount of feed that was reduced to hydrogen sulfide in accordance with the techniques of this invention. In this respect, the first reactor may be either a solid-gas reactor or a molten ore-gas reactor. Preferably, for economic reasons, the first reactor employed is a solid-gas reactor, for example, a fluidized bed, using reducing temperatures less than about 950° C. As indicated above, the various off-gases from the first reactor may be suitably handled so as to recycle the hydrogen and water vapor. In a preferred embodiment, the hydrogen sulfide formed in the first reactor is separated from the other off-gases and then is reacted with sulfur dioxide formed in the conventional oxidation reactor. As will be readily apparent, by the adjustment of the amount of furnace feed provided to the first reactor, in relation to the amount of furnace feed provided to the oxidation reactor, the amount of sulfur dioxide eventually vented to the atmosphere may be eliminated. That is to say, if the amount of furnace feed presented to the first reactor is such that a stoichiometric amount of hydrogen sulfide is formed (relative to the amount needed to react with the sulfur dioxide) and sent to the reactor wherein hydrogen sulfide is reacted with sulfur dioxide, then no sulfur dioxide is vented to the atmosphere.

A typical procedure to follow in carrying out a batch-type solid-gas contact system is to provide a heated and enclosed batch reactor containing a preselected amount of crushed ore concentrate therein. The reactor is then preheated to a desired temperature, as hereinbefore indicated, and the hydrogen-water vapor mixture, for example, in a volume ratio of about 10 parts of water to about one part of hydrogen, is injected in the reactor. Of course, it will be apparent that the more intimate the contact between the ore concentrate and vapor mixure, the higher will be the reaction rate. The hydrogen-water vapor mixture is continuously pumped into the reactor, and the off-gases of the reaction, including excess $H_2$ and $H_2O$, are continuously removed therefrom until the desired amount of conversion is achieved. Generally speaking, and depending upon the amount of the batch processed, as well as the thickness of the batch located within the reactor, anywhere from a few minutes to a day or more may be necessary in order to achieve an economic yield. Suitable purging techniques will, of course, be employed for purposes of safety. The hydrogen sulfide-containing effluent gas stream removed from the reactor during the process, may be handled in any desired manner. For example, the hydrogen sulfide may be absorbed in a suitable medium, such as an ammoniacal zinc sulfate aqueous solution, and the remaining vapors vented to the atmosphere. Other known liquid mediums may also be employed to scrub the hydrogen sulfide from the effluent gas stream as is well known in the arts. This process is also capable of giving acceptable commercial yields. Since the ore in this process is not reduced to its molten state, and impurities in the form of slag never removed, the copper so formed may contain other impurities at this point, for example, $Fe_3O_4$. Further refining of the metallic copper may then be carried out in accordance with well known techniques, no fear of atmospheric contamination by $SO_2$ being present, since substantially all sulfur is removed from the ore. One suitable procedure for final refining is to melt the ore, subsequent to its being reduced in accordance with this invention, whereby the impurities are separated as a slag and pure copper then recovered. Conventional electrolytic refining techniques are, of course, applicable to the final elemental copper recovery.

In order to aid those skilled in the art to make and use the present invention, several examples follow. It, of course, is understood that these examples are merely illustrative of the present invention and are in no way intended as a limitation thereon. Unless otherwise indicated, the reactor for the reduction reaction was an indirectly heated VYCOR tube having a nominal diameter of about 38 mm. More specifically, with appropriate insulation, the reactor tube was electrically heated by wrapping the tube with suitable resistance-heating elements. Hydrogen was obtained from a pressure cylinder and the hydrogen-water vapor mixture was obtained by bubbling hydrogen through distilled water at a temperature of 100° C. Ths hydrogen-water vapor steam was then conducted to the reactor by suitable conduits and the effluent gases removed from the opposite end. Suitable superficial velocities of the hydrogen-water vapor mixture through the reactor are about 800 cm./min. to about 1200 cm./min. with the pressure in the tube generally being about atmospheric to several inches of water. The effluent gas stream was then bubbled through an ammoniacal zinc sulfate solution to absorb the hydrogen sulfide with the remaining effluent gases being suitably vented. Following the general procedure of Kolthoff and Sandell, Textbook of Quantitative Inorganic Analysis, p. 681, The MacMillan Company, 1936, the amount of sulfide in the ore converted to hydrogen sulfide is obtainable by analyzing the solution for sulfur.

## EXAMPLE 1

A sample amount of about 0.158 gram of substantially pure (greater than about 99%) $Cu_2S$ was evenly distributed in a conventional opened-top silica boat and the boat was inserted into the reactor. The oven was first purged for five minutes with nitrogen and thereafter for five minutes with hydrogen gas. The sample generally had particles smaller than 60 mesh with about 50% of the material being retained on a 100 mesh screen, about 25% on a 200 mesh screen, and about 25% on a 300 mesh screen. The reactor was then preheated to a temperature of 950° C. and maintained at that temperature and a mixture of hydrogen and water vapor injected therein at a $H_2$ rate of about 300 standard cc./min. and a $H_2O$ vapor rate (obtained from boiling water) of about 3000 cc./minute (100° C., 1 atm.). The water-hydrogen mixture is continuously pumped into and through the furnace, whereby it contacts the material to be reduced, and the off-gases which include hydrogen sulfide, are continuously removed therefrom for a period of 30 minutes in the manner indicated above. At the end of the 30-minute period, the hydrogen flow is switched away from the boiling water through which it is bubbled and the oven is cooled to a temperature of 500° C., whereafter the oven is purged with nitrogen. The oven is then opened and the boat is cooled to room temperature. The amount of copper remaining in the ore in the boat was measured and found to be 85.08% by weight.

## EXAMPLE 2

The procedure of Example 1, using substantially the same weights of materials, and same flow rates, was conducted except the reaction was allowed to proceed for 60

minutes. The amount of copper remaining in the boat was found to be 86.68% by weight. Another similar run produced about 88.73 weight percent copper.

EXAMPLE 3

A procedure similar to Example 1 was conducted except that the reaction was allowed to proceed for two hours. The copper (substantially pure) was 92.75%. In a similar experiment, run for three hours, the percent of substantially pure copper was 92.1%.

EXAMPLE 4

A procedure similar to Example 1 was conducted using an amount of about 0.1090 gram of $Cu_2S$. The sample was spread as evenly as possible in a silica boat and subjected to the above mentioned reduction treatment for 2½ hours at a temperature of 950° C. using a flow rate of hydrogen of 300 standard cc./min. bubbled through boiling water. The copper content of the reduced ore was found to be 94%.

EXAMPLE 5

Using about 100 milligrams of substantially pure $Cu_2S$ according to the general procedure of Example 1 and injecting the hydrogen-water vapor into the reactor for a period of about 4 hours, 100% of the reduced product was pure metallic copper.

EXAMPLE 6

In order to further point out the unique properties of the subject invention, a commercial ore concentrate was tested by using substantially the same procedure as set forth in Example 2. The amount of material treated was approximately 0.1 gram of the ore in a silica glass boat. The flow rates of the hydrogen and water vapor (hydrogen bubbled through boiling water) were the same as those set forth above. The specific ore employed was an ore concentrate normally supplied to the reverberatory furnace in the conventional oxidation process. This type of ore typically contains combined sulfides of iron and copper, for example, bornite, and chalcopyrite, individual sulfides of iron and copper, for example, $Cu_2S$ and FeS, and copper silicates like chrysocolla. The ore may also contain up to about 20% of impurities of the type mentioned hereinbefore. This ore was passed through a 60 mesh screen before usage but it actually had a general size distribution of about 4–6 percent +150 mesh, about 5–7 percent +200 mesh, about 14–16 percent +325 mesh and about 70–75 percent minus 325 mesh. Before reduction the sample contained about 36 weight percent copper (combined), about 24 percent iron (combined), and about 26 percent sulfur (combined). This ore was then subjected to the reducing process for about 1 hour with the hydrogen sulfide being absorbed in an ammoniacal zinc sulfate solution. An analysis of this solution showed that virtually 100% of the sulfur (present as sulfide) in the pre-reduction sample was converted to hydrogen sulfide by the reducing process. The ore after reduction contained 42 percent copper (total) and about 40 percent of free elemental copper; thus, in the reduced product, slightly in excess of 95% of the total copper therein is present as recoverable elemental copper.

EXAMPLE 7

The procedure of Example 6 was followed, in order to demonstrate the versatility of the present process, by using chrysocolla, a non-sulfur bearing material. The initial material contained no free copper and about 32 percent of combined copper. After reduction, the material contained 49 percent total copper of which 98 percent was free elemental copper.

This example clearly illustrates several important features of this invention, not the least of which is that the present inventive concept is operative on a copper sulfide bearing ore which contains some amount of a non-sulfur copper bearing ore since such an ore may also be reduced by this process to elemental copper.

EXAMPLE 8

Following the general procedure of Example 6, a sample of bornite was employed. This sample was crushed and passed through a 60 mesh screen but, in general, its particle size was apparently slightly larger than the material employed in Example 6. An analysis showed that prior to reduction, the bornite material contained about 53 percent of copper (combined), about 10 percent iron (combined) and about 20 percent of sulfur (combined). After the reduction process, the sample was analyzed and showed the presence of about 62 percent copper, of which slightly in excess of 64 percent was free recoverable elemental copper. Additionally, the analysis of the ammoniacal zinc sulfate solution showed that approximately 70 percent of the sulfur present in the form of sulfide in the original sample had been converted to hydrogen sulfide. The final product also contained a substantial amount of $Fe_3O_4$.

EXAMPLE 9

The procedure of Example 8 was generally followed, this time employing chalcopyrite, which had been crushed and passed through a 60 mesh screen. Again, this sample apparently had a slightly larger particle size than did the material employed in Example 6. Prior to reduction, this sample contained about 31 percent of combined copper, about 29 percent of combined iron, and about 33 percent of combined sulfur. Analysis of the ammoniacal zinc sulfate solution, after approximately a one-hour run, showed that about 97 percent of the combined sulfur in the initial sample was converted to hydrogen sulfide. Additionally, the sample subsequent to reduction contained about 36 percent of total copper of which about 68 percent was free, recoverable, elemental copper. $Fe_3O_4$ was likewise present.

EXAMPLE 10

The utility of the process is further illustrated by preparing an ore sample made up of approximately 60 milligrams of the material employed in Example 6 and about 40 milligrams of the material employed in Example 7. This material is then positioned in the reactor and the procedure of Example 1 generally followed, with the exception that the temperature employed is approximately 1100° C. and a reduction time of approximately 1 hour employed. After this one-hour period, the sample is observed and it is noted that a substantial residue in the form of slag is present. Additionally, of the total amount of copper present in the reduced sample, approximately 97 percent is present in the form of recoverable, free, elemental copper.

The foregoing clearly shows that sulfide ores of copper and iron are effectively treated and contacted with hydrogen and water vapor to economically convert sulfur to hydrogen sulfide and results in a high yield of recoverable elemental copper and separable iron. This may economically be done without adding a scavenging agent, like calcium oxide, to the ore.

It will, of course, be apparent that modifications may be made which, pursuant to the patent laws and statutes, do not depart from the spirit and scope of the present invention.

We claim:

1. A non-sulfur dioxide emitting process for copper recovery which comprises injecting a mixture consisting essentially of hydrogen and water vapor into a reactor containing a sulfide ore of copper and iron while said reactor is at a temperature in excess of about 750° C., said ore containing about 25 to 40 percent of copper, such that said mixture reactingly contacts said ore to form hydrogen sulfide, elemental copper and iron oxide, and removing said hydrogen sulfide from said reactor.

2. A process according to claim 1 wherein said ore is at a temperature between about 750° C. and about 950° C.

3. The process of claim 1 wherein substantially simultaneously with the hydrogen sulfide formation there is formed elemental copper and $Fe_3O_4$.

4. A non-sulfur dioxide emitting process for converting a solid particulate sulfide ore of copper and iron to elemental copper and iron oxide separable as a slag, said process comprising continuously injecting a mixture consisting of hydrogen and water vapor into one end of a tubular reactor containing said ore while said reactor is at a temperature in excess of about 700° C. so as to reactingly contact said ore to form hydrogen sulfide, elemental copper and iron oxide, and continuously removing said hydrogen sulfide from the opposite end of said reactor.

5. The process of claim 4 wherein said injecting is done for a time sufficient to convert substantially all said sulfide to hydrogen sulfide.

6. The process of claim 4 wherein said ore is bornite.

7. The process of claim 4 wherein said ore is chalcopyrite.

8. The process of claim 4 wherein the volume ratio of water to hydrogen is about 1:1 to about 20:1.

9. The process of claim 8 wherein the superficial velocity of said mixture through said reactor is between about 800 to about 1200 cm. per minute.



10. A non-sulfur dioxide emitting copper beneficiation process which comprises reducing a copper and iron bearing sulfide ore concentrate containing about 25 to 40 percent copper while said ore is at a temperature in excess of about 700° C. with a mixture of hydrogen and water vapor for a time sufficient to form elemental copper, hydrogen sulfide and iron oxide.

11. A process according to claim 10 wherein said ore is maintained as a particulate solid.

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