July 19, 1966 L. H. CONNELL ETAL 3,261,959

APPARATUS FOR TREATMENT OF ORE

Filed Feb. 20, 1962 2 Sheets-Sheet 1

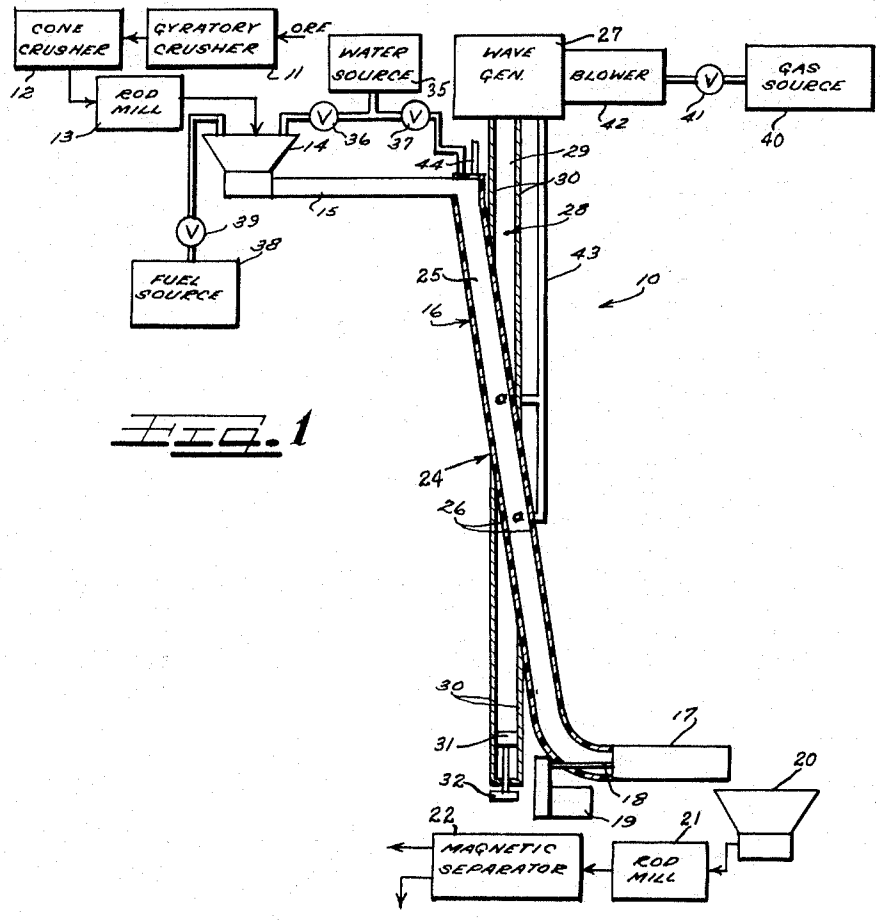


FIG. 1

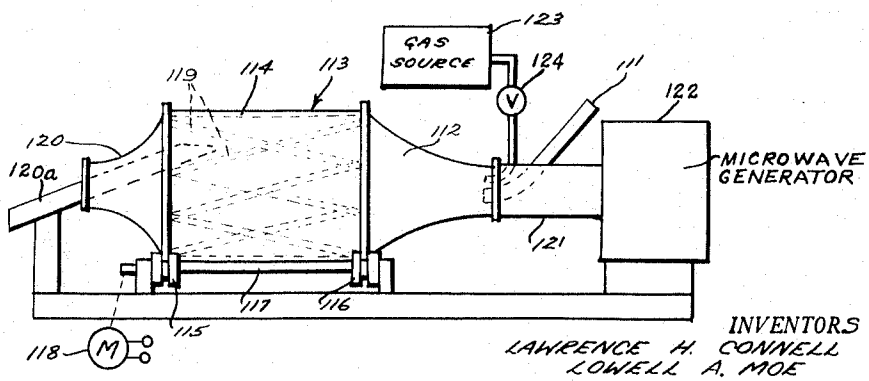


FIG. 2

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FIG. 2

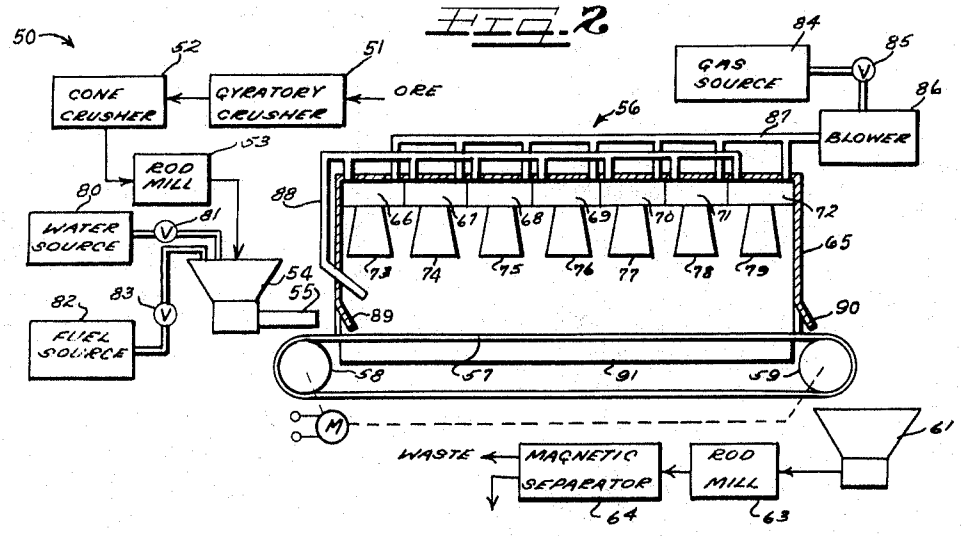


FIG. 3

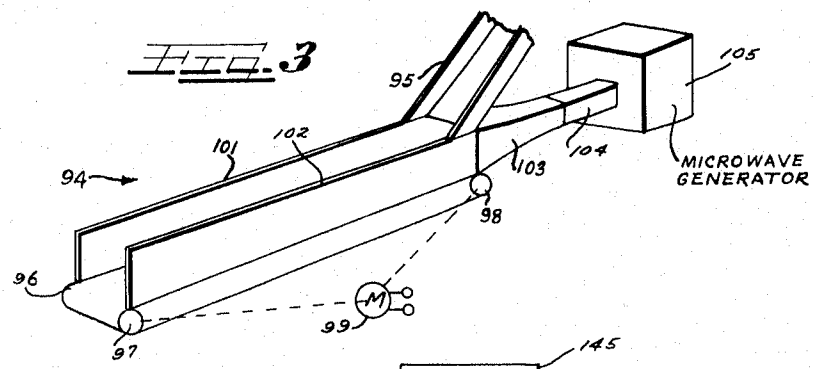
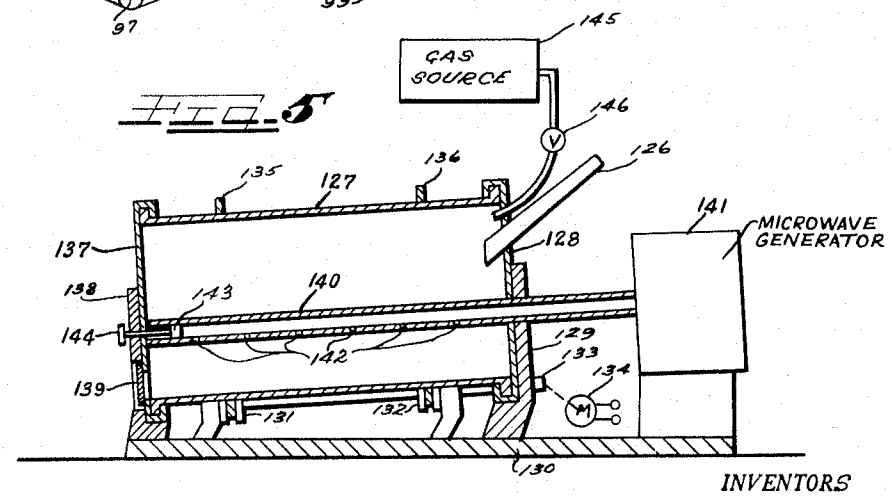


FIG. 5



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APPARATUS FOR TREATMENT OF ORE

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This invention relates to methods and apparatus for treatment of ores and more particularly to methods and apparatus using high frequency electromagnetic fields to cause chemical decomposition of one or more compounds in the ore.

This invention was evolved with the general object of providing improved methods and apparatus for treatment of ore, of the same general type as disclosed in our copending application Serial No. 28,767, filed May 12, 1960, of which this application is a continuation-in-part. As explained in said application, the production of arcs within the ore is highly desirable to obtain efficient operation, particularly in converting hematite ore to magnetite ore and to metallic iron. It has been found that while such arcing does produce highly desirable results, it has a disadvantage in ores having a high content of certain materials, particularly silicon materials, in that the arcs produce sintering of material within the ore and make it more difficult to perform subsequent refining operations.

According to this invention, methods and apparatus are provided for applying a high intensity electromagnetic field to an ore to cause heating of the interior thereof while minimizing arcing within the ore. In particular, it is found that by using a relatively high frequency, in the microwave region, it is possible to minimize the arcing effect and to obtain at the same time, a very high efficiency. The frequency is preferably above about 800 megacycles and up to 3000 megacycles or even higher.

Important specific features of the invention relate to the manner of applying the microwave energy to obtain high efficiency and other advantages.

This invention contemplates other and more specific objects, features and advantages which will become more fully apparent from the following detailed description taken in conjunction with the accompanying drawings which illustrate preferred embodiments and in which:

FIGURE 1 is a diagrammatic illustration of an ore-treating system constructed according to the principles of this invention;

FIGURE 2 is a diagrammatic illustration of a modified ore-treating system constructed according to the invention;

FIGURE 3 is a view illustrating a modified microwave treating apparatus constructed according to this invention;

FIGURE 4 is a view illustrating another modified microwave treating apparatus constructed according to this invention; and

FIGURE 5 is a view illustrating still another modified form of microwave treating apparatus constructed according to the invention.

Reference numeral **10** generally designates one preferred form of ore-treating system constructed according to this invention. In the system **10**, hematite ore is supplied in chunk form to a gyratory crusher **11** which divides the ore into smaller sized chunks which are then fed to a cone crusher **12** which reduces the size still further and feeds into a rod mill **13** used to reduce the ore in comparatively small particles or granules. The rod mill **13** feeds into a hopper **14** from which the ground ore is fed by a screw conveyor **15** into a high frequency field treatment apparatus generally designated by reference numeral **16**.

The ore treated in the apparatus **16** is fed therefrom by a screw conveyor **17**, having a shaft **18** driven from a motor **19**, to fall into a hopper **20** from which it is fed to a rod mill **21** and thence to a magnetic separator **22**. Separator **22** separates the more highly magnetic particles, having a higher iron content, for subsequent treatment and refining.

The treatment apparatus **16** comprises a chute **24** extending downwardly from the conveyor **15** to the conveyor **17**. The chute **24** has a first pair of opposed parallel side walls **25** in a vertical plane (only one of which appears in the sectional view of FIGURE 1) and a second pair of opposed parallel side walls **26** the major portions of the side walls **26** being inclined slightly to the vertical in the illustrated system. The chute **24** is preferably filled or substantially filled with ore and the ore passing therethrough intersects the path of transmission of microwave energy from a microwave generator **27**. The microwave transmission path is defined by a rectangular wave guide **28** having first and second pairs of side walls **29** and **30**. Side walls **29** are coplanar with the side walls **25** of the chute **24** and may preferably be integral therewith in the region of intersection, while side walls **30** have intermediate sections cut out to allow the side walls **26** of the chute **24** to pass therethrough. Side walls **29** and **30** of the wave guide and the side walls **25** of the chute may preferably be of a conductive material, i.e. metal. However, to allow transmission of the microwave energy into the ore, the side walls **26** of the chute **24** are of an insulating dielectric material, at least in the portions thereof which intersect the wave guide transmission path.

To obtain optimum operation, a tuning plug **31** is disposed in the lower end portion of the wave guide **28** and its position may be adjusted by an adjustment control **32**.

The microwave generator is preferably operated at a frequency above about 800 megacycles and frequencies up to 3000 megacycles or higher may be used. A frequency of about 2450 megacycles has been found to be highly satisfactory. With such frequencies, arcing can be avoided at microwave energy levels high enough to obtain efficient operation, which is particularly desirable with ores having a high content of sinterable materials such as silica materials. The energy level of operation is of course affected by the rate of feed of the ore through the treatment apparatus. With a reasonably efficient microwave generator (which may be of conventional construction with magnetrons, klystrons or the like) and with the efficiency of transmission of microwave energy possible with the illustrated system, approximately 300 kilowatt hours of energy may be applied to the input of the microwave generator.

It is to be noted that in the system of FIGURE 1, the ore channel should be at a small acute angle to the wave guide to insure a large number of wavelengths in the ore. The effective length of the portion of the waveguide **28** which receives the ore (i.e. the distance between intersections of each wall **26** with the walls **30**) should preferably not be equal to an integer number of half wavelengths. It should also be noted that the dimensions of the wave guide can be increased as desired, using higher modes of propogation of energy.

To increase the moisture content of the ore granules, to thereby increase the conductivity thereof and internal heating by the microwave field, water may be supplied from a source **35** through a valve **36** to the hopper **14** and/or through a valve **37** to the upper end of the chute **24**.

It is also desirable with many ores to add fuel thereto, either solid, liquid or gaseous. Solid fuel such as ground lignite may be supplied into the hopper **14**. Liquid fuel such as kerosene may be supplied from a fuel source

38 through a valve 39 into the hopper. A gaseous fuel or reductant, such as carbon monoxide, may be supplied from a source 40 through a valve 41 into a cooling blower 42 for the magnetron or klystron of the microwave generator 27, to be directed through a duct 43 into spaced points of the chute 24. Such fuels may be used alone or in combination. To prevent the build-up of excessive pressure in the chute 24, a suitable vent 44 is provided in the upper end thereof.

It should be noted that the system of FIGURE 1, and also the other systems disclosed herein, may be used in the conversion of any type of hematite ore to magnetite and may be used, for example, in conjunction with siderite, goethite, limonite and many other types of ores. The ore particle size is preferably in the range between 4 mesh and 40 mesh, although larger or smaller particles may be treated, particularly when the ore is agitated. In general, a liquid fuel such as kerosene is preferred when the particle size is small, while a solid fuel such as lignite is preferred when the particle size is large. However, either reductant works very well when the ore is being constantly agitated. With typical ores, it has been found that 1% or less kerosene fuel, by weight, is satisfactory while 1 to 5% by weight of a solid fuel such as lignite, coal or coke may be used. The intensity of the microwave field should preferably be such as to produce a temperature rise of from 500 to 750° C. within the ore.

FIGURE 2 illustrates a modified system 50 wherein ore is supplied to a gyratory crusher 51, thence to a cone crusher 52, thence to a rod mill 53 and thence to a hopper 54 from which it is fed by a screw conveyor 55 to microwave treatment apparatus 56 including a conveyor belt 57 trained on rolls 58 and 59 which are driven by a suitable motor 60 as diagrammatically illustrated. From the belt 57, the treated ore is fed to a hopper 61 from which it is fed to a rod mill 63 and thence to a magnetic separator 64.

The microwave treatment apparatus 56 comprises a hood 65 over the belt 57 with a plurality of ganged microwave generators 66–72 therein, the generators being provided with horn radiators 73–79 directed at the ore carried on the belt 57. The angles of divergence of the beams from the horns 73–79 are preferably such that the beams extend from one side of the belt to the other and are also preferably such that the edges of adjacent beams coincide or slightly overlap so as to obtain uniform application of the microwave energy to the ore on the belt 57.

The same operating considerations apply as with respect to the system of FIGURE 1, as discussed above. Water may be applied from a source 80 through a valve 81 to the hopper 54. Solid fuel such as lignite may be supplied to the hopper 54, while liquid fuel such as kerosene may be applied from a source 82 through a valve 83 to the hopper 54. A gaseous fuel such as a hydrocarbon gas, or a reductant such as carbon monoxide may be applied from a source 84 through a valve 85 to the intake of a cooling blower 86 connected through duct work 87 to the inlets of the microwave generators 66–72 to pass therethrough and through duct work 88 into the treatment chamber. Flaps 89 and 90 may preferably be provided to minimize flow of gas from the chamber and to maintain pressure therein slightly above atmospheric pressure.

The belt 57 preferably has a metallic surface so as to be highly reflective to the microwaves. In the alternative, it may be of a low loss, low loss tangent, or high power factor material. A member 91 having a reflecting surface may be disposed below the belt.

Referring now to FIGURE 3, reference numeral 94 generally designates a treatment apparatus which may be substituted for the treatment apparatus 16 of FIGURE 1 or the treatment apparatus 56 of FIGURE 2. In this apparatus, ore is supplied to a chute 95, as from the screw conveyor 15 of FIGURE 1 or the screw conveyor 55 of FIGURE 2. The ore may preferably have water and a solid or liquid fuel added thereto.

The ore from the chute 95 drops onto a conveyor belt 96 supported by rollers 97 and 98 which are driven by a suitable motor 99 as diagrammatically illustrated. A pair of metal side walls 101 and 102 are disposed along the sides of the conveyor belt so that the ore passes therebetween. The side walls 101 and 102 form a strip line wave guide which is coupled through an exponential tapered section 103 to a rectangular wave guide 104 coupled to a microwave generator 105.

With this arrangement, it is possible to obtain highly efficient transfer of microwave energy to the ore. As to operational conditions, the same general considerations apply as discussed above in connection with FIGURE 1.

Referring now to FIGURE 4, reference numeral 110 generally designates another treatment apparatus which may be substituted for the treatment apparatus 16 of FIGURE 1 or the treatment apparatus 56 of FIGURE 2. In the apparatus 110, ore is supplied to a pipe or chute 111, as from the conveyor 15 of FIGURE 1 or the conveyor 55 of FIGURE 2. The ore may have water and a solid or liquid fuel added thereto.

The ore is fed from the pipe or chute 111 into a tapered entrance section 112 of a drum 113 having a main section 114. Drum 113 is supported by rollers including rollers 115 and 116 on a shaft 117 driven by a motor 118. The section 114 may preferably have internal blades 119 projecting radially inwardly from the inner surface thereof for elevating and dropping the ore as the drum is rotated to thereby agitate the same. The drum 113 has a tapered exit section 120 into which an inclined chute 120*a* may extend to receive the treated ore and supply it to apparatus such as hopper 20 of the apparatus of FIGURE 1.

To treat the ore in the drum 113, the entrance section 112 is connected through a wave guide 121 to a microwave generator 122. The drum thus acts as a wave guide operating in a higher mode, and a high efficiency is possible.

A gaseous fuel or reductant may be applied from a source 123 through a valve 124 into the entrance section 112, and the exit from the drum is preferably small enough to obtain a build-up of pressure within the drum above atmospheric pressure.

As to operating conditions, the same general considerations apply as discussed above in connection with FIGURE 1.

Referring now to FIGURE 5, reference numeral 125 generally designates another treatment apparatus which may be substituted for the treatment apparatus 16 of FIGURE 1 or the treatmnet apparatus 56 of FIGURE 2. In the apparatus 125, ore is supplied to a pipe or chute 126, as from the conveyor 15 of FIGURE 1 or the conveyor 55 of FIGURE 2. The ore may have water and a solid or liquid fuel added thereto.

The ore is fed from the pipe or chute 126 into a rotating drum 127, through a stationary end wall 128 supported on a member 129 extending upwardly from a base 130. Drum 127 is supported from the base 130 by rollers including rollers 131 and 132 on a shaft 133 driven by a motor 134, the rollers being grooved to receive annular flanges 135 and 136 on the drum 127. As illustrated, the drum is supported with its axis at a slight angle to the horizontal, to cause gravity flow of the ore toward an opposite end wall 137 supported on a member 138 extending upwardly from the base 130. The gate 139 may be opened for release of ore from the drum or for further treatment, such as into a hopper 20 as shown in FIGURE 1.

Microwave energy is applied to the ore by means of an axially extending wave guide 140 coupled to a microwave generator 141. The wave guide 140 has a broad side array of slots 142 therein spaced apart a half wavelength, or any odd number of half wavelengths. The slots are inclined to the E field inside the guide 140 and are ener-

gized in phase producing a directional pattern with maximum radiation broadside to the guide. With this arrangement, it is possible to apply the microwave energy with a high degree of efficiency. The tuning plug **143** in the end portion of the guide **140** may be adjusted by control **144** to obtain optimum operation.

With regard to operating conditions, the same considerations apply as discussed above in connection with FIGURE 1. A gaseous fuel or a reductant may be applied from a source **145** through a valve **146**, as diagrammatically illustrated.

It will be understood that modifications and variations may be effected without departing from the spirit and scope of the novel concepts of the invention.

We claim as our invention:

1. In apparatus for treating ore, means for supporting ground ore in a treatment region, a microwave generator at one end of said region, and divergently tapered wave guide means for transmitting microwave energy from said generator longitudinally through said region to cause internal heating of ore in said region by maximum absorption of energy within the ore, said wave guide means being coincident with the treatment region over a distance greater than one-half wave length of the microwave energy.

2. In apparatus for treating ore, means for supporting ground ore in a treatment region, a microwave generator at one end of said region, wave guide means for transmitting microwave energy from said generator longitudinally through said region to cause internal heating of ore in said region by maximum absorption of energy within the ore, and means for agitating ore in said region, said wave guide means being coincident with the treatment region over a distance greater than one-half wave length of the microwave energy.

3. In apparatus for treating ore, wall means defining a confined ore-flow path, a microwave generator at one end of said path, and wave guide means coupling said generator to said path to cause transmission of energy longitudinally through a portion of said path and internal heating of ore therein by maximum absorption of energy within the ore, said wave guide means being coincident with the ore-flow path over a distance greater than one-half wave length of the energy.

4. In apparatus for treating ore, wall means defining a confined ore-flow path, a microwave generator at one end of said path, and wave guide means extending from said generator and intersecting said ore-flow path at an acute angle, said wall means being at least partly of a dielectric material to permit transmission of energy longitudinally through a portion of said ore-flow path and internal heating of ore therein by maximum absorption of energy within the ore, said wave guide means being coincident with the ore-flow path over a distance greater than one-half wave length of the energy.

5. In apparatus for treating hematite ore, means for supporting ground ore in a treatment region, a microwave generator, wave guide means for transmitting microwave energy from said generator to said region to cause internal heating or ore in said region, a blower having an inlet and an outlet, means for supplying a gaseous reductant from said outlet to said microwave generator to cool the same, and means for applying the gaseous reductant from said microwave generator into said ore in said treatment region, said wave guide means being coincident with the treatment region over a distance greater than one-half wave length of the microwave energy.

6. In apparatus for treating ore, a conveyor belt for receiving and conveying ore, wall means on opposite sides of said belt defining therewith a confined ore-flow path and also defining a strip line wave guide section, a microwave generator, and means coupling said generator at one end of said wave guide section to cause transmission of energy longitudinally through a portion of said path and internal heating of ore therein by maximum absorption of energy within the ore, said strip line wave guide section having a length greater than one-half wave length of the energy.

7. In apparatus for treating ore, a rotatable drum arranged to receive ground ore, a microwave generator at one end of said drum, and wave guide means for transmitting energy from said generator into the interior of and longitudinally through said drum to cause internal heating or ore therein by maximum absorption of energy within the ore, said wave guide means being coincident with said drum over a distance greater than one-half wave length of the energy.

8. In apparatus for treating ore, a rotatable drum arranged to receive ground ore, a microwave generator at one end of said drum, and wave guide means for transmitting energy from said generator into the interior of and longitudinally through said drum to cause internal heating of ore therein by maximum absorption of energy within the ore, said wave guide means including a divergently tapered section having an outlet coupled to one end of said drum, said wave guide means being coincident with said drum over a distance greater than one-half wave length of the energy.

9. In apparatus for treating ore, a chute defining a confined ore-flow path, means for feeding ore into the upper end of said chute, means for withdrawing ore from the lower end of said chute, a microwave generator, wave guide means extending from said generator and intersecting said chute at an acute angle, said chute having walls of dielectric material to permit transmission of energy longitudially through a portion of said path and internal heating of ore therein, said wave guide means being coincident with said chute over a distance greater than one-half wave length of the energy.

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