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IN SITU RECOVERY OF EARTH MINERALS AND DERIVATIVE COMPOUNDS BY LASER

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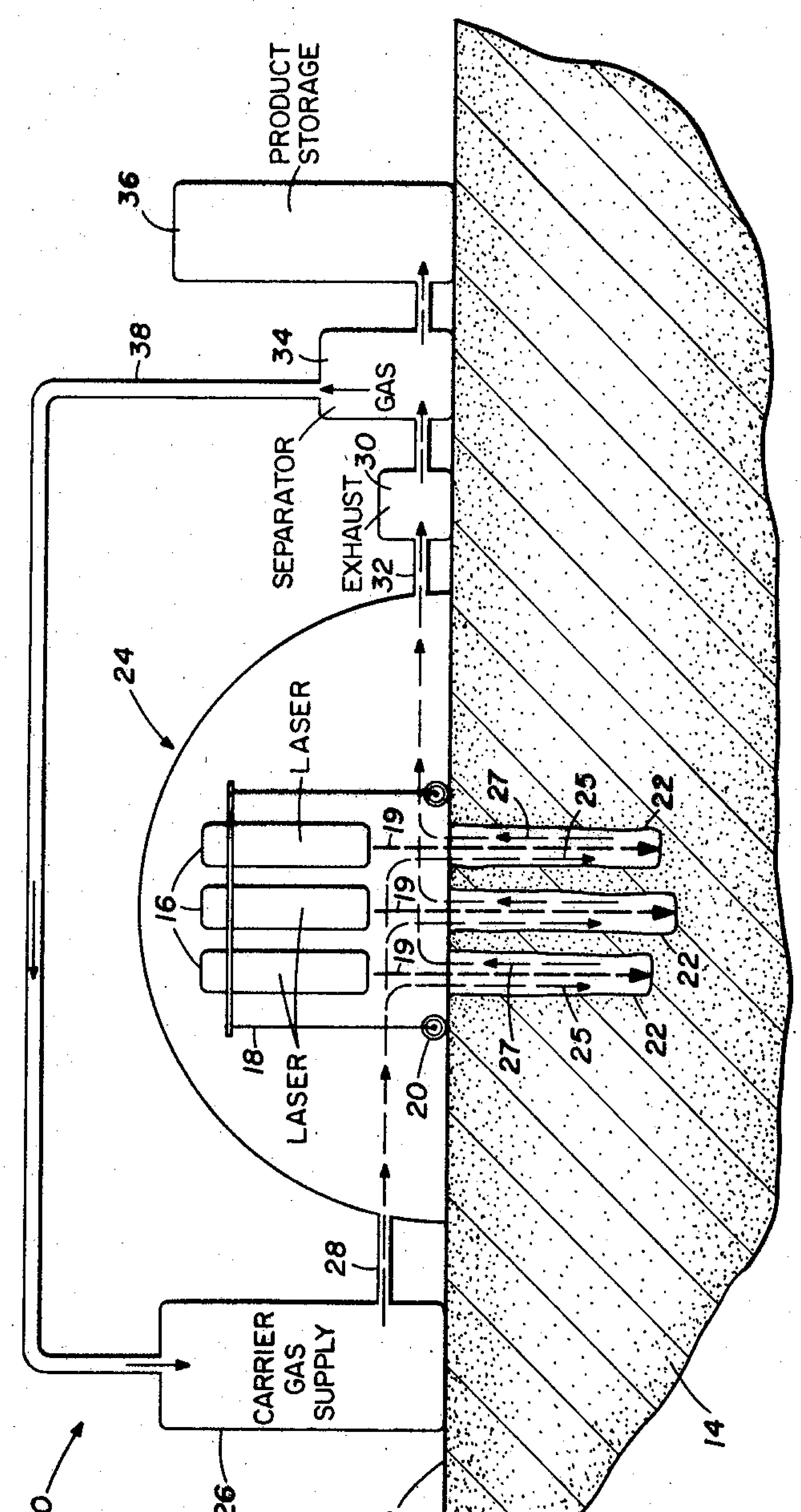

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IN SITU RECOVERY OF EARTH MINERALS AND DERIVATIVE COMPOUNDS BY LASER

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ABSTRACT OF THE DISCLOSURE

A method and system for recovering minerals from earth formations by directing a laser beam onto the formation to open up a hole in the formation and vaporize and/or pyrolize the minerals locked in the formation. The gaseous atmosphere at the point of contact by the laser beam is controlled and may be either totally inert or substantially nonreactive so as to recover the minerals in elemental or constituent compound form, or may be selectively reactive with the minerals to produce synthetic compounds. The atmospheric gas serves as a carrier gas which is collected and then the vapors fractionally condensed or otherwise separated to recover the minerals or the constituent compounds of the minerals. The atmospheric carrier gas is then reused. The system includes a movable hood for controlling the atmosphere at the face of the formation, a movable support for a gang of lasers, condensation apparatus, and mineral storage facilities.

BACKGROUND OF THE INVENTION

This invention relates generally to the recovery of minerals from earth formations, and more particularly relates to the recovery and simultaneous processing, in situ, of hydrocarbons and other valuable earth minerals.

The shale oil deposits located on the North American continent constitute one of the world's largest reserves of oil. The shale deposits are located relatively close to the surface and have a maximum depth on the order of a few thousand feet. The oil, in a form known as kerogene, is held tightly in a rock called marlstone. The usual drilling technique cannot be used to recover this oil because the marlstone has little or no porosity. Instead, the shale is first mined and crushed, then heated to high temperatures to vaporize the hydrocarbons which are then condensed and recovered. Various thermal techniques for recovering oil locked in tar sands and other low viscosity oil reservoirs have generally been frustrated for various reasons. It has been proposed to combust a portion of the oil in situ to generate the heat required to vaporize the oil, but it is difficult to sustain combustion. It has been proposed to pump heated gases down injection wells, but the heat losses are generally too great either between the surface and the point of application or between the point of application and the formation beyond the well bore. In addition, the tight formation normally associated with this type of reserve makes it very difficult to get the necessary volumetric coverage.

SUMMARY OF INVENTION CLAIMED

This invention is directly concerned with the in situ pyrolysis of hydrocarbons by directing a laser beam onto an earth formation containing hydrocarbons so as to simultaneously open up a hole in the formation and pyrolize the hydrocarbons while controlling the atmosphere at the point the earth formation is being heated so as to prevent combustion. The controlled atmosphere acts as a carrier gas and may be either nonreactive or selectively reactive with the hydrocarbons. The carrier gas may merely envelop the original surface of the formation, or

may be directed into the opening in the formation under pressure. The hydrocarbons are, either in natural form or as synthetic compounds, then fractionally condensed or otherwise separated from the carrier gas. The same process is applicable to the recovery of any earth mineral which can be vaporized in situ by means of a laser, and then selectively separated from the carrier gas by fractional condensation or other suitable process. The laser beam may be directed onto an exposed surface of the mineral bearing formation and then progressively translated so as to obtain maximum volumetric coverage, or may be used to open a hole through overburden before penetrating the mineral bearing formation.

In accordance with the present invention, the system for carrying out the process includes one or more lasers which may be moved so as to progressively vaporize the formation, an enclosure for controlling the atmosphere at the face of the formation onto which the laser beam is directed, means for circulating a carrier gas through the enclosure, means for selectively extracting the vaporized minerals from the carrier gas and means for recirculating the carrier gas through the enclosure.

BRIEF DESCRIPTION OF THE DRAWING

The figure is a schematic illustration of the system of the present invention for carrying out the method of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawing, a system in accordance with the present invention is indicated generally by the reference numeral **10**. The system **10** is disposed on the upper surface **12** of an earth formation **14** which contains the minerals to be recovered. The formation **14** may be an oil bearing shale, low grade coal, metal ore, or substantially any other mineral bearing formation which can be vaporized and the mineral element, compound, or enriched ore condensed or otherwise separated from a carrier gas.

The system **10** includes a plurality of lasers **16** which are supported on a frame **18** that may be moved over the surface **12** of the formation **14** by a suitable means represented by rollers **20**. The beams **19** of lasers **16** are directed downwardly onto the surface **12** of the formation **14**. The laser beams **19** may be progressively moved over the surface **12** so as to progressively vaporize the formation and produce holes **22** of substantially larger diameter than the diameter of the laser beams by either moving the lasers **16** relative to the frame **18**, or the frame **18** relative to the surface of the formation.

An enclosure **24** envelopes the surface **12** of the formation **14** around the area where the laser beams are directed so as to control the atmosphere within and above the holes **22**. If necessary, the gas of the controlled atmosphere can be led into the holes being opened by suitable conduits, not illustrated, as indicated by arrows **25**. The carrier gas and entrained vapors then exit up the holes as indicated by arrows **27**. The enclosure **24** is also movable over the surface **12** by a suitable means, not illustrated, so that the holes may be progressively enlarged to achieve good volumetric coverage of the formation and also enhance vapor flow to clear the hole and enhance penetration of the laser beam.

The enclosure **24** may be constructed of any suitable conventional material, or may comprise a flexible plastic dome supported by gas pressure greater than atmospheric. Where it is desired to maintain the vapors at high temperatures, the lasers may be located within the enclosure so that the heat dissipated by the laser will heat the gas in the enclosure, and the enclosure may include suitable insulation. If a lower temperature is required, then the lasers may be disposed outside the enclosure and the enclosure may include a flexible plastic covered fabric inflated by the gas pressure within the enclosure. The frame **18** and enclosure **24** may be moved together over the surface **12**, or the enclosure **24** may be moved in steps, and the frame **18** moved progressively over the surface within the enclosure **24**.

A receptacle **26** for a carrier gas is in fluid communication with the enclosure **24** by way of conduit **28**. The carrier gas may be a wholly inert gas, such as helium, nitrogen, argon, neon or krypton, may be a substantially nonreactive gas, such as carbon dioxide, or may be an active gas, such as ammonia, bromine, iodine, chlorine, nitrous oxide or nitric oxide, depending upon the mineral being recovered and the type of synthetic compound it is desired to produce, as will hereafter be described in greater detail.

The carrier gas is cycled through the system by a suitable means, represented by exhaust pump **30**, which communicates with the envelope **24** through conduit **32**. The gaseous mixture taken from the envelope **24** is then passed through a suitable conventional separator **34** where the mineral products are extracted from the stream and passed into a suitable storage tank **36**. The carrier gas is then recycled through conduit **38** to the carrier gas supply container **26**.

The separator **34** may be any conventional type used to separate vapors of one element or compound, or group of elements or compounds, from the carrier gas. The separator **34** will customarily be a selective condenser which may fractionally condense hydrocarbon vapors, for example, at different stages to also separate the various hydrocarbon fractions produced by pyrolysis of natural hydrocarbon.

In accordance with the method of the present invention, the beams **19** of the lasers **16** are progessively moved over the surface of the formation containing the minerals to be recovered so as to produce a hole of progressing depth and size. As a result, the minerals to be recovered, together with a portion of the material of the formation, are vaporized. The hot vapors expand and flow upwardly through the hole or holes formed in the formation and combine with the carrier gas flowing through the enclosure **24**. The carrier gas and vapors are then conducted through the separator **34** where the desired constituents of the vapor are separated from the carrier gas and stored. The carrier gas is then recirculated through the system.

When the mineral to be recovered is a ntaural hydrocarbon, which may be in the form of kerogen, coal, or petroleum deposits, for example, the carrier gas may be either a totally inert gas, such as for example, nitrogen, argon, neon, krypton or helium, or may be a nonreactive gas, such a carbon dioxide. In that case, the compounds produced would be natural compounds produced by pyrolysis of the hydrocarbons. The carrier gas may also be a gas which will react with the hydrocarbon vapors at the elevated temperatures produced by the laser to form useful compounds. For example, ammonia, bromine, chlorine, iodine, nitrous oxide or nitrous dioxide may form useful hydrocarbon compounds at the high temperature produced by the laser beam.

In accordance with another aspect of the method, the hydrocarbon compounds, either those naturally resulting from the pyrolysis of the hydrocarbon, or those synthetic compounds resulting from combination of the hydrocarbon vapors with an active carrier gas, is fractionally condensed so as to provide the desired compounds in at least a semirefined condition. This can be achieved in most instances by passing the carrier gas with the entrained vapors through a fractionation column, or by the other conventional petro-chemical processes.

Within its broader aspects, the process of the present invention can also be used to recover metals or substantially any other valuable mineral which can be vaporized and then separated from the carrier gas and other vapors in a usable form by fractional condensation, or other separation technique. As illustrated, the system is shown located directly upon the earth formation containing the minerals to be recovered, as might be the case when the overburden has been mechanically removed from oil shale. However, it is to be understood that the system can be operated on the overburden and the laser beam used to penetrate the overburden and the formation. Thus, the use of the term earth formation as used in the following claims is intended to include all the surface layers which it may be desirable to penetrate before reaching the actual mineral bearing sand or ore.

Although preferred embodiments of the invention have ben described in detail, it is to be understood that various changes, substitutions, and alterations can be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. The method for recovering a selected mineral constituent from an earth formation which comprises:
   - playing a laser beam over the surface of the earth formation to progressively vaporize at least a portion of the earth formation including said mineral constituent and thereby progressively expose more of the formation to the laser beam,
   - controlling the atmosphere at the exposed surface of the earth formation upon which the laser beam is being directed and collecting the vapors, and
   - separating said selected mineral constituent from the collected vapors.

2. The method of claim 1 wherein the minerals are hydrocarbons and the controlled atmosphere is substantially free of oxygen.

3. The method of claim 2 wherein the controlled atmosphere is a gas which is substantially nonreactive with hydrocarbons.

4. The method defined in claim 2 wherein the controlled atmosphere includes at least one constituent that reacts with hydrocarbons at the temperature produced by the laser to produce a compound, and the compound is collected from the controlled atmosphere.

5. The method for producing a predetermined compound including a constituent located in an earth formation and at least one constituent not located in the formation which comprises:
   - controlling the atmosphere at the face of the earth formation, the atmosphere including said constituent of the compound not included in the earth formation,
   - directing a laser beam onto the earth formation to vaporize the earth formation and said constituent located in the earth formation in the presence of the atmosphere and cause the vaporized constituents and the selected constituents in the atmosphere to combine to form the compound, and
   - selectively separating the compound so formed from the atmosphere.

6. The system for recovering a selected mineral constituent from an earth formation which comprises:
   - laser means for directing a highly focused beam of energy sufficient to vaporize and excavate substantially all of the formation constituents,
   - means for supporting the laser means at the face of an earth formation in a position to direct the beam onto the formation whereby the beam will penetrate the formation by vaporizing the mineral constituents thereof.
   - means at the face of the earth formation for collecting the vapors, and
   - means for separating said selected mineral constituent from the collected vapors.

7. The system defined in claim 6 wherein the means for supporting the laser means includes:
   - means for progressively translating the laser beam over the formation to form a vapor cavity within the formation.

8. The system defined in claim 6 wherein the means for collecting the vapors comprises:

a hood disposed over and around the point at which the laser beam first penetrates the surface of the formation.

9. The system defined in claim 6 wherein the means for separating the selected mineral constituents from the collected vapors includes:

selective condensation means for selectively condensing and separating more than one mineral constituent from the collected vapors, and

means for passing the collected vapors through the selective condensation means.

10. The method for recovering a selected mineral constituent from its natural location in an earth formation which comprises:

disposing a laser at the surface of the earth formation,

playing the beam from the laser over the earth formation to penetrate the earth formation by vaporization of the earth formation to thus form a cavity in the formation,

withdrawing the vapors from the cavity while continuing to play the laser beam through the vapors onto the exposed surface of the earth formation whereby the beam continues to heat the vapors, and then

condensing said selected mineral constituent from the vapors.

11. The method for recovering a selected constituent from an earth formation which comprises:

progressively vaporizing substantially all constituents of a region of the formation by means of a laser beam so as to progressively excavate the formation and further expose the formation to the laser beam, and

separating the selected constituents from the vapors of the formation by fractional condensation.

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