Case Study

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A Patent on Harnessing Helium 3 from Moon

The present invention relates to a method of magnetic processing of particulate extraterrestrial material such as lunar soil for recovery of ***Helium-3***, which is being viewed by fervent researchers and scientists as the key to meeting future energy demands. According to them, this potential gas source, which is rare on the Earth, but more common on the moon's surface, could come in handy as the earth's fossil fuels, such as coal, oil and gas, dry up in the coming decades. The invention also relates to recovery of other valuable components such as anorthite, agglutinates for recovery of native iron, and to a method of beneficiating particulate material such as coal for recovery of low sulfur and low ash clean coal for direct combustion.

This patent was granted by the USPTO on January 5, 1993, to the EXPORTech Company, Inc. (New Kensington, PA).

Background and Prior Art

The lunar soil is known to contain small amounts of the odd isotope of helium, Helium-3, which could be used as a 'clean' burning fuel with deuterium in fusion reactions for generation of electricity on earth or for generation of propulsion power in space.

This is of profound significance for the future of mankind because there is enough of this material in the lunar soil to supply the electrical needs of the U.S. for centuries to come if it can be recovered. Energy calculations suggest that the energy gained from Helium-3 mined on the Moon and shipped back to Earth would be 250 times that used to obtain it.

Helium-3 is a light, non-radioactive isotope of helium. More abundant helium-3 is thought to exist on the Moon (embedded in the upper layer of regolith by the solar wind over billions of years) and the solar system's gas giants. Helium-3 undergoes many reactions, of which the following aneutronic fusion reaction is the one most promising for power generation:

$$D + 3He \rightarrow 4He\ (3.7\ MeV) + p\ (14.7\ MeV)$$

The appeal of helium-3 fusion stems from the nature of its reaction products. Most proposed fusion processes for power generation produce energetic neutrons which render reactor components radioactive with their bombardment, and power generation must occur through thermal means. In contrast, Helium-3 is non-radioactive, and the lone high-energy proton produced can be contained using electric and magnetic fields, which results in direct electricity generation.

Helium-3 could be extremely advantageous as an efficient and economical fuel for nuclear fusion reactors: extremely potent, nonpolluting, with virtually no radioactive by-product. Fusion reactors are still under development and it may be many decades, if ever, before they provide power commercially. However, once these reactors are in place, it is estimated that they will produce far more power and produce much less radioactive waste than the conventional nuclear reactors.

The Helium-3 is known to be concentrated in the mineral ilmenite ($FeTiO_3$) which is found in abundance in lunar mare soils. On the earth's moon there are several types of mineral matter and ores which could function as feedstock for processes that would produce Helium 3 and other matters such as oxygen, iron and silicon. However, no commercial method of beneficiating such materials to concentrate the magnetic elements and compounds exists which would make the separation possible and easy.

Magnetic methods are preferred in the beneficiation of extraterrestrial material because of the unique nature of the lunar regolith and because dry processing is desired, since there is no water on the surface of the moon. Further, there is no atmosphere on the surface of the moon and virtually no free oxygen is present. This, plus the unique presence of solar wind implanted hydrogen, have created unusual components in the lunar soils.

The lunar soil has been finely pulverized by meteorite impact throughout millions of years. The impacts release heat and create glassy components and irregular shaped **agglutinates** containing elemental iron. The agglutinate fractions and "native iron" inclusions are unique to the lunar soil. The agglutinates are a potential source of reduced iron.

At present, there is no single source of information quantifying the distribution of magnetic materials in either terrestrial or extraterrestrial materials. Most magnetic separators known presently are intended for specific applications and the empirical design procedures employed by the manufacturer cannot be extended beyond the present usage.

The current approach cannot be used in projecting technology needs for processing lunar soils because these materials are not available in sufficient quantity for this testing and because no lunar simulant suitable for magnetic purposes exists. The agglutinate fraction, which is important to **magnetic beneficiation of lunar soils, is unique to the moon because of the presence of the hydrogen reduced iron.**

Description of the invention

The present invention relates to a method of dry magnetic separation of particulate material. It is applicable to dry beneficiation of extraterrestrial ores as a feedstock for the production of Helium-3 and other elements on a large volume basis. The ore is beneficiated using a **magnetic separator**, which is preferably used to remove several fractions of magnetic matter from the product, in one preferred embodiment of the invention, by beginning with the most highly magnetic fraction and proceeding through less magnetic fractions. In another preferred embodiment of the invention, the fractions are separated in a single pass through the magnetic separator, employing a **novel splitter** means.

The magnetic separator can be operated so as to produce a variety of products of differing magnetic susceptibility. The procedure first requires that the electromagnet be calibrated so that magnetic energy gradients can be determined. Next, the separator is operated so as to produce a plurality of sample fractions of differing magnetic susceptibilities. Next, means must be incorporated to measure the magnetic susceptibility ranges and the relevant chemical and physical properties of the separated fractions. These characteristics are then related in a MagnetoGraph. Lastly, means are employed whereby the result of the MagnetoGraph is used to determine the physical and magnetic characteristics of a magnetic separator to process tested materials on a large scale.

Present methods are difficult to apply to studies of weakly magnetic materials such as coal and lunar soils. In the method of calibration described here, the problems associated with the non-linearity of iron based electromagnets have been circumvented by using measured values of the magnetic field to calculate magnetic forces from first principles. With this method, the iron-based Frantz electromagnet can be used conveniently at up to full field strength to carry out analytical separations of feebly magnetic material. No assumptions are required and calibrations employing cumbersome standard materials are avoided.

Fig. 1 illustrates individual steps and components of a preferred method of and apparatus for practicing the present invention. The feed material is air dried and crushed to a suitable size. The material is then screened into multiplicity of screen fractions suitable for subsequent dry magnetic processing.

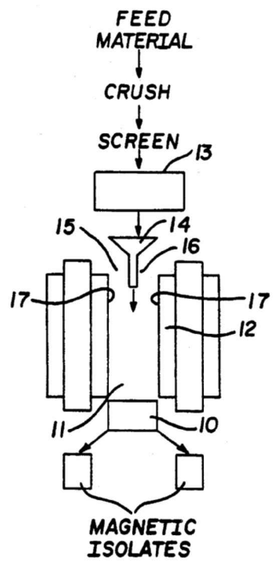

Fig. 1

As the material being separated falls through the magnetized region in the opening between the magnet poles (17), the action of the gradient magnetic field produced by the magnetic separator will cause the paramagnetic particles to move along a line transverse to the direction of fall and the direction of the magnetic field into the regions of higher magnetic field strength and the diamagnetic particles to move into regions of lower magnetic field strength. This tendency to separate is disrupted by the effects of collisions between the particles as they pass through the separator. Collisions between paramagnetic and diamagnetic particles as they move under the action of the gradient magnetic field are particularly bothersome because of their oppositely directed momenta.

The region of space 15 between the magnet poles is enclosed by a splitter apparatus which is made of nonmagnetic material. This apparatus serves to contain the particulate material being processed within the magnetic separation region, to channel the flow of air and particulates, and to provide a means for separation and collection of the many different magnetic fractions as they exit the magnetic separator.

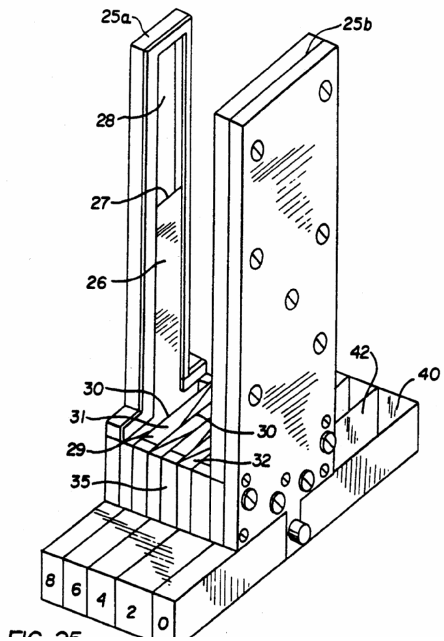

Fig. 2

Fig. 2 is an enlarged perspective view of the splitter apparatus. A unique feature of the apparatus is the ability to separate particle and air flows as they exit the magnetized separation chamber. As particulates fall through the separation chamber, there is a tendency to carry entrained air with the flow. Since the separation chamber is closed on both sides, there would be no place for the air to exit the separation chamber once the particles had fallen into the canisters, if the bottom of the splitter apparatus were not open to the atmosphere. In the present apparatus, both air and particulates fall into the canisters and the air is returned to the atmosphere outside of the separator, through the open cannister tops.

Without the above feature for removing the air after particle separation, the air which travels with the particles through the separator would return up the separation chamber disrupting the particle flow patterns and destroying the separation efficiency.

A surprising discovery of this work is the fact that paramagnetic material is displaced out of the separator into the regions of low field strength and exits in canisters 0 and 1 and 7 and 8. While this fact is not fully understood at this time, it is believed due to interaction of the paramagnetic and diamagnetic particles in the outer shells of the coal stream as it falls through the separator. Since the diamagnetic coal component is in predominance in the first pass, it can push paramagnetic mineral matter out of the high force region if the minerals are on the wrong side of the stream.

PROCESSES PROPOSED FOR LUNAR MANUFACTURE OF MATERIALS

PRODUCTS	PROCESSES
H. He. N,	Heating lunar soil to release implanted solar C gases wind gases.
Oxygen	Vapor phase pyrolysis of lunar soil
Iron	Collection, melting, and casting of native lunar iron
Iron	Refining and deposition of native iron by gaseous carbonyl process
Iron Refractory Oxides. & Slags	Destructive distillation of lunar soil iron oxide by solar heating, disproportionation of iron oxide
Oxygen	Hydrogen reduction of ilmenite and electrolysis of the water produced
Oxygen Steel	Carbothermal reduction of ilmenite and electrolysis Steel of the water produced
Magnesium	Carbothermal reduction of magnesia

Current thinking calls for mining about 5 million tons of regolith per year to obtain approximately 2.25 million tons of the minus 50 micron size fraction for thermal processing for Helium-3 recovery. It is estimated that this effort will result in 33 kg of Helium-3. One kg of Helium-3 may produce as much as 10 MW-years of electricity on earth when fusion reactors are operational.

It has been estimated that the solar wind has implanted about one million tons of **Helium-3 in the fine particle fraction of the lunar regolith and that it tends to be concentrated with the mineral ilmenite in lunar mare soils**.

Ilmenite is paramagnetic and can be recovered by dry magnetic separation with use of the methods and apparatus of the present invention. Because of this, the method of MagnetoGraphs will be of great utility in establishing the feasibility of magnetic concentration of Helium-3 bearing minerals and rock fragments from the lunar soil and the method and apparatus of the present invention will successfully establish the process for its practical recovery. **The use of the methods of this patent can result in a factor of two to five in the amount of material that must be processed for recovery of Helium-3 from lunar regolith.** This has the potential for making a significant impact on the potential of this new clean fuel.

It is interesting to note that the average temperature in dark areas out of direct sunlight on the surface of the moon is -171º C. or approximately 100º K. This temperature is within the range of new high temperature superconducting materials such as the yttrium-barium-copper oxides currently under study. Because of this, magnetic separators employing advanced high temperature superconducting magnet windings may find application in magnetic beneficiation of lunar soils.

Claims

There are 37 claims in the patent. Only 18 claims are being reproduced here. All claims, except the claim 1, have been renumbered.

1. A method of dry magnetic separation for separating materials of different types and levels of magnetism from a raw sample containing particulate material having a range of magnetic susceptibilities, said sample including a feebly magnetic fraction and a strongly magnetic fraction, comprising the steps of:

a. processing said raw sample through a first dry magnetic separation pass to remove substantially all of said strongly magnetic fraction from said raw sample, thereby separating said strongly magnetic fraction from said feebly magnetic fraction;
b. processing said feebly magnetic fraction through a second dry magnetic separation pass including a magnetic separator means and a splitter means, thereby separating said particulate material into at least three different magnetic susceptibility fractions, each said fraction exhibiting a range of magnetic susceptibilities, which range is different from each other said range of magnetic susceptibilities of each said other fraction, and thereby producing a spectrum of separate refined particle samples comprising each said fraction;
c. collecting said refined particle samples comprising each said fraction;

d. measuring the magnetic susceptibility range of magnetic susceptibilities of each said fraction collected;
e. correlating said magnetic susceptibility range of at least one said collected fraction with at least one identifying physical and/or at least one chemical characteristic of said collected fraction in order to determine which fraction or fractions are to be recovered for further processing; and
f. processing said recovered fraction or fractions through at least one additional dry magnetic separation pass including a magnetic separator means and a splitter means, thereby separating said fraction or fractions into at least two different magnetic susceptibility fractions, including a clean fraction and a refuse fraction, said clean fraction having a magnetic susceptibility correlating with said identifying physical and/or chemical characteristics.

2. The method of claim 1 wherein said strongly magnetic fraction has a paramagnetic susceptibility of greater than about $+1 \times 10^{-6}$ cc/gm.

3. The method of claim 1 wherein said raw sample is obtained from earth's ***moon***.

4. The method of claim 3 wherein at least one said fraction contains ilmenite.

5. The method of claim 3 wherein at least one said fraction contains concentrated ***helium***-3.

6. The method of claim 1 wherein said magnetic separator means is capable of producing a magnetic ***energy*** gradient greater than 25 million $Gauss^2$/cm and preferably greater than 100 million $Gauss^2$ /cm.

7. The method of claim 1 wherein said magnetic separator means employs a superconducting magnet to produce a magnetic ***energy*** gradient sufficient to perform said separating.

8. The method of claim 7 wherein said superconducting magnet is adapted for dry magnetic separation of said feebly magnetic fraction during said second dry magnetic separation pass, and said separation is carried out at operating temperatures of at least 100 ° K, achieved by performing said separation in a region out of direct sunlight on the illuminated side of the earth's ***moon*** or on the dark side of earth's ***moon***.

9. The method of claim 8 wherein said superconducting magnet is adapted for dry magnetic separation of said feebly magnetic fraction during said second dry magnetic separation pass, said superconducting magnet including a magnetic coil comprised of a high temperature superconducting material, and said separating is achieved at high temperature superconducting operating temperatures, and high temperature superconducting operating temperature are achieved by performing said separating on earth's ***moon***.

10. The method claim 9 wherein said high temperature superconducting operating temperatures are 100° K or above.

11. The said low temperature superconducting operating temperatures are from 1° to 4.2° K.

12. The method of claim 1 wherein said magnetic separator means employs an electromagnet to produce a magnetic ***energy*** gradient sufficient to perform said separating.

13. The method of claim 12 wherein said electromagnet is adapted for dry magnetic separation of said feebly magnetic fraction during said second dry magnetic separation pass, and said separating is carried out at operating temperatures of at least 100 ° K, achieved by performing said separating in a region out of direct sunlight on the illuminated side of earth's ***moon*** or on the dark side of earth's ***moon***.

14. The method of claim 1 wherein said magnetic separator means employs a permanent magnet to produce a magnetic ***energy*** gradient sufficient to perform said separating.

15. The said permanent magnet is adapted for dry magnetic separation of said feebly magnetic fraction during said second dry magnetic separation pass, and said separation is carried out at operating

temperatures of at least 100 º K, achieved by performing said separation in a region out of direct sunlight on the illuminated side of the earth's ***moon*** or on the dark side of earth's ***moon***.

The present invention deals with the beneficiation of particulate lunar soil for the recovery of Helium-3, which is concentrated in the mineral ilmenite. The invention is novel in the sense that the ore is beneficiated using a magnetic separator; the fractions are further separated in a single pass through the magnetic separator, employing a novel splitter means. Also, lunar stimulants have been used in the present invention, which may have bypassed a major lacuna in previous attempts caused due to limited supply of the test material.

However, possibility also exists that the broad claims made herein may impede future research, as it would come in the way of anyone trying to claim the beneficiation of extraterrestrial soil for the recovery of Helium-3.