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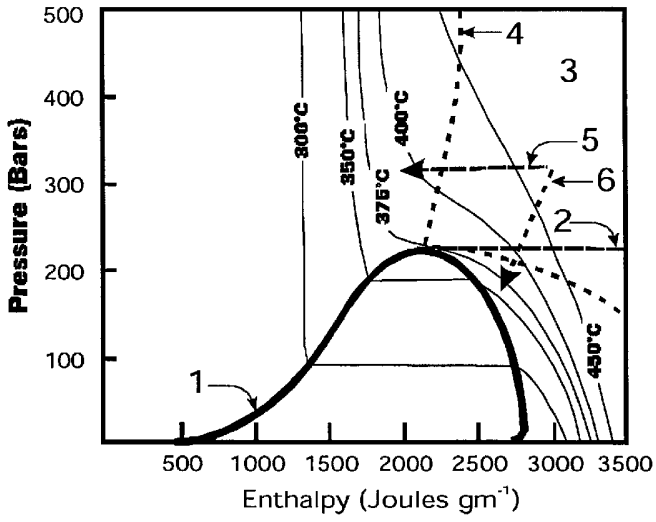
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(54) Title: HYDROTHERMAL MINERAL EXTRACTION



(57) Abstract: Described herein is a system and method for hydrothermal mineral extraction wherein the conditions surrounding hydrothermal systems are used advantageously to extract a mineral-rich brine. Specifically, hydrothermal fluid from ocean based or saline based hydrothermal systems contain a variety of minerals suspended in supercritical water and can be drawn up a well. As long as the water remains a supercritical fluid, the minerals remain largely in solution; however, as the hydrothermal fluid moves away from the this state, the water can cool and exit the supercritical state, causing the depositing or scaling of minerals along the walls of the well pipe. In the instant invention, non-supercritical conditions are rapidly induced onto the hydrothermal fluid such that the brine containing the minerals rapidly precipitates and forms a slurry which is then isolated from the water. Another aspect regards altering the chemistry of the fluid to precipitate the minerals. Another aspect of the invention is related to mineral-rich slurries isolated by this method and to specific minerals isolated therefrom.

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HYDROTHERMAL MINERAL EXTRACTION

FIELD OF THE INVENTION

The present invention relates generally to the field of mineral and energy extraction. More specifically, the present invention relates to a method of hydrothermal mineral and energy extraction.

BACKGROUND OF THE INVENTION

Hydrothermal (hot water) regions within vast water-permeable fractured rock areas form continuous re-circulation zones that can produce supercritical fluids if temperatures and pressures are high enough. These fluids can contain high concentrations of dissolved metals/minerals (such as gold, zinc and copper) and gases (such as hydrogen and methane) [1-5].

These hydrothermal regions exist along the mid-ocean ridge (MOR) spreading centres that circle the globe (e.g. the Pacific Rim of Fire). Other similar geological areas that have near surface magmatic chambers may also be mineable. Much of the interest and research in these areas has so far been focussed on the potential to tap into limitless amounts of geothermal energy [6 –7] . However, the mining potential may surpass the economic benefits of the energy, making the energy a by-product.

The whole concept of a so-called hydrogen economy is predicated on finding or producing large sources of hydrogen efficiently. A large source of geothermal energy, methane, hydrogen and metals/minerals exists in hydrothermal fluids that originate from high temperature reaction zones near magma chambers close to the earth surface [6-7]. Such zones could initially be harnessed from land-based systems using existing technology in the many locations around the world where mid-ocean ridge spreading centres occur on or close to land. Iceland, where the Mid–Atlantic Ridge occurs on land, is such a location [6]. However, many other similar regions exist worldwide (e.g. Azores, African Rift Valley, Red Sea etc.).

SUMMARY OF THE INVENTION

According to a first aspect of the invention, there is provided a method of

hydrothermal mining comprising: withdrawing a quantity of a supercritical hydrothermal fluid from a magma fluid source surrounding a hydrothermal vent, said hydrothermal fluid comprising a brine phase and a supercritical water phase; and rapidly reducing the solubility of the hydrothermal fluid, thereby separating the hydrothermal fluid into water and a slurry.

The method may include air-lift pumping using a hydraulic air compressor or similar device.

The brine phase may comprise dissolved mineral salts.

The hydrothermal fluid may include valuable gases.

The valuable gases may include hydrogen and methane.

The solubility will be reduced by shocking the supercritical fluid out of a supercritical state. This mimics the natural environment that occurs surrounding black smokers at ocean floor vent sites such as the Juan De Fuca Ridge off the West coast of Canada.

The supercritical fluid may be shocked by adding a solubility reducing to lower the temperature of the supercritical fluid or also, to adjust the pH or chloride content of the supercritical fluid.

The temperature may be lowered using a coolant fluid, for example fresh water. Other coolants may include saltwater or water with additives to perform such functions as adjusting the pH. In other embodiments the material introduced may be water or steam or other fluid with characteristics to adjust the pH or chloride content of the hydrothermal fluid while maintaining the temperature and hence buoyancy of the hydrothermal fluid.

The pH may be increased by using alkaline additives in the fluid.

The chloride content may be lowered by adding fluid.

Seeding the flow with particles may help nucleate the sulfides more rapidly.

The temperature may be lowered just below a supercritical temperature of

the fluid.

When a tubing string is provided to withdraw the hydrothermal fluid, solubility of the fluid is preferably reduced adjacent a bottom end of the tubing string.

The method preferably includes reducing the solubility of the hydrothermal fluid by injecting a solubility reducer, as described above, into tubing string above an inlet of the tubing string which receives the hydrothermal fluid.

The tubing string preferably includes a first conduit for withdrawing the hydrothermal fluid and a second conduit for injecting a solubility reducer adjacent the bottom end of the tubing string.

The method may include injecting air into the solubility reducer within the second conduit for subsequent injection into the first conduit with the solubility reducer to provide lift to the hydrothermal fluid within the first conduit. In further embodiments, many variations of pump means are conventionally available in place of air injection to provide lift.

When reducing the solubility by either adjusting the pH of the supercritical phase or adjusting the chloride content, temperature of the fluid can be maintained near or just below a supercritical temperature of the fluid.

The method preferably includes locating a well head of the tubing string on land adjacent a body of salt water. Water is preferably isolated from the slurry adjacent a top end of the tubing string.

According to a second aspect of the invention, there is provided a quantity of a mineral isolated by the any of the above-described methods.

According to a third aspect of the invention, there is provided a slurry containing a plurality of minerals isolated according to the any of the above-described methods.

According to a fourth aspect of the invention, there is provided hydrogen and/or methane gas isolated according to any of the above-described methods. Such

gases will evolve from the fluid as the fluid is de-pressurized.

According to a further aspect of the present invention there is provided a hydrothermal mining system comprising:

a tubing string for withdrawing a quantity of a supercritical hydrothermal fluid from a magma fluid source surrounding a hydrothermal system, said hydrothermal fluid comprising a brine phase and a supercritical water phase; and

a solubility reducer for injection into the hydrothermal fluid for rapidly reducing the solubility of the hydrothermal fluid, thereby separating the hydrothermal fluid into water and a slurry.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, which illustrate exemplary embodiments of the present invention:

Figure 1 is a graph of the solubility of supercritical water;

Figure 2 is an elevational view of a well extending into a layer of highly fractured basalt;

Figure 3 is a sectional view of a first embodiment of the well pipe.

Figure 4 is a sectional view of a second embodiment of the well pipe.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the invention belongs. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, the preferred methods and materials are now described. All publications mentioned hereunder are incorporated herein by reference.

DEFINITIONS

As used herein, "magma fluid" refers to fluids that originate from close to or directly from the magma source. This can include juvenile waters (waters that originate

from the magma itself and not seawater or meteoric water sources).

As used herein, "supercritical water" refers to pure water that is above approximately 374°C and 200 bars pressure .

As used herein, "hydrothermal fluid" refers to a multi-component fluid mixture that originates from the hydrothermal convection cell. The fluid when in a supercritical state is composed of a brine phase (salts and dissolved species) and a more purer vapour-like water phase. The supercritical pressure and temperature of these fluids will be higher than that for pure water as defined above.

Described herein is a method of hydrothermal mineral extraction wherein the conditions surrounding hydrothermal vents are used advantageously to extract a mineral-rich brine. Specifically, hydrothermal fluid surrounding the hydrothermal vent and containing a variety of minerals suspended in supercritical water, is drawn up a well pipe. As will be appreciated by one of skill in the art, as long as the water remains a supercritical fluid, the minerals remain largely in solution [3 – 4], however, as the hydrothermal fluid moves away from the vent, the water cools and exits the supercritical state, causing the deposition or scaling of minerals along the walls of the well pipe. In the instant invention, the solubility of the supercritical fluid is rapidly reduced, either by rapidly introducing non-supercritical conditions by lowering the temperature of the hydrothermal fluid, altering the pH of the supercritical fluid or flooding the hydrothermal fluid with fresh water, such that the brine containing the minerals rapidly precipitates and forms a slurry which is then isolated from the water. Another aspect of the invention is related to mineral-rich slurries isolated by this method and to specific minerals isolated therefrom.

In many areas of the world magma from within the earth rises close to or exits onto the seafloor. The enormous thermal energy continuously released creates a unique hydrothermal environment. Hydrothermal vents on the ocean floor release large amounts of fluids at temperatures that can reach above the critical point (approximately 374°C for water) [3]. Because of this they contain large amounts of dissolved minerals

and gases such as hydrogen. Below these vents are vast water-permeable fractured rock areas, a continuous recirculation zone that produces these vents. Further beneath is magma at approximately 1200°C. Drilling into to such environments should allow attaining fluid temperatures as high as currently technically possible (up to 500 - 600°C) [6 – 7]. Saline hydrothermal system areas may be tapped with minimal disturbance to marine ecosystems. These regions are usually highly stable, virtually on a geological time scale and may well be used as an environmentally benign source of power, metals/minerals and gases.

Seawater (Saline) source hydrothermal systems can be harnessed from land by drilling through the land at locations where a mid-ocean ridge spreading centre occurs on the landmass. Hydrothermal regions close to and on the land exist in Japan, Iceland, the Azores, Hawaii, Mid East, African Rift Valley, the Aleutian Islands and New Zealand.

Mining companies have already gone to considerable lengths in the attempt to exploit hydrothermal vents on the seafloor. Success to date has been limited to the recovery of vent chimney material [8 - 9]. This disrupts the ancient marine ecosystem of the vent environment.

What has been overlooked by those in the art seeking to understand hydrothermal vent fluid composition is that supercritical aqueous chloride solutions are highly solvent and hence readily strip metals from the surrounding rock and absorb gases and possibly metals emanated from the magma source fluids themselves. In some locations, valuable metals such as gold are in very significant quantities as dissolved metal ion complexes. In virtually all locations significant quantities of zinc, copper and other valuable metals exist. Many additional metals/minerals exist as well although in lesser quantities. Such metals may include the rare but very valuable Platinum Group Elements PGE' s.

Drilling to temperatures of 450°C or greater and depths of 3.5 to 5 km

presents unique technical challenges. Specifically, the prior art teaches that when drilling a well at this depth, water is applied to the drill bit to cool the drill bit. Once drilling is complete, the water-cooling of the drill bit is discontinued and the drill bit is removed. Hydrothermal fluid, comprised of supercritical water, and dissolved metals, minerals and gasses is then brought to the surface via the well pipe. However, as the hydrothermal fluid travels up the well pipe, the fluid cools and the water exits the supercritical state. As a consequence, the solubility of the metals and minerals in the water decreases, and minerals precipitate on the inner surface of the well pipe. This mineral scaling can be a serious problem during geothermal energy development and exploitation, as flow up the well pipe becomes restricted and may eventually plug. This happened at Reykanes Well #9 in Iceland. [10].

As shown in Figure 2, the present invention makes use of a production tubing string including a well pipe 25, to be described in further detail later herein, which communicates with a land based well head 24 of the tubing string which is supported above ground. The well pipe 25 is located to extend down into the ground from the well head to terminate within a layer of highly fractured rock usually mostly basalt 22 which is located directly above a layer of magma 21. The highly fractured rockt 22 is directly adjacent a body of salt-water such as the ocean 23. In this configuration, with the well pipe directly adjacent a body of water while remaining land based, salt water circulated through the highly fractured basalt from the ocean is drawn up through the well pipe 25 as a hydrothermal fluid as described herein. The well pipe 25 may be directionally drilled or drilled perpendicular to the ground.

Turning now to Figure 1, the properties of the hydrothermal fluid are demonstrated in further detail. Figure 1 is a pressure vs. enthalpy diagram for pure water with selected isotherms being illustrated. The saturation curve is illustrated by reference character 1 and is a boundary of the conditions under which steam and water co-exist in a two phase fluid. The dotted line illustrated by reference character 4 is the high solubility

line while the dotted line indicated by reference character 2 is the supercritical line which together form the boundaries of the high solubility region 3.

As long as the fluid state of a hydrothermal fluid remains within this high solubility region 3, it will transport minerals and metals dissolved in solution and suspended or dissolved in the brine phase. Moving outside of the high solubility region will cause the metals and minerals to precipitate out of solution. The faster this fluid is brought out of this region, the more rapid the precipitation. Shock precipitation is the most rapid in which the thermodynamic properties of the solution are driven along the path indicated by reference character 5 to cross over the high solubility line while remaining above the supercritical line. Shock precipitation occurs very rapidly across this path as solubility can vary by orders of magnitude across the pseudocritical or high solubility line [4].

The temperatures and pressures over which the solubility varies are intended to only be shown qualitatively in Figure 1. Figure 1 is a representative diagram of a two phase system for pure water. Actual temperature and pressure may vary considerably, for example the critical temperature increases with increasing salt, metal or mineral concentration, etc. Solubility variation when crossing the pseudocritical temperature line 4 happens extremely rapidly such as that which occurs at the exit of a black smoker vent. Solubility variation within the superheated region below the super critical line to and to the right of the saturation curve 1, results in precipitation occurring very slowly. This is what occurs in a normal well such as Reykanes well #9 [10], when the fluid cools slowly over the length of the pipe to produce scaling and plugs in the pipe.

In the diagram of Figure 1 the fluid acts as a two phase mixture of a more pure water phase and a highly saline brine phase in the highly soluble region 3. The brine phase is mostly responsible for the transport of the metals, minerals and the salts. The brine can precipitate as sticky salts even within the highly soluble region. These salts may become anhydrous and form a solid coating. Since the brine will carry the metals,

minerals and the like, some one these will likely precipitate along with it. Injecting a boundary layer of cold water will prevent this. As the fluid passes outside of the highly soluble region across the pseudocritical temperature line 4, the salts become redissolved in the water and hence may no longer carry the metals as dissolved ion complexes although this chemistry is poorly understood at present. Precipitation occurs much faster here. In general solubility is a function of both pressure and temperature in all regions. As pressure increases, solubility increase. Also as temperature increases, solubility increases.

The instant invention represents an improvement over the prior art and is based on the understanding from natural systems such as seafloor vents that hydrothermal fluid exists as a supercritical fluid before exiting any hydrothermal vent. The hydrothermal fluid contains valuable gases, for example, hydrogen, methane and the like, supercritical vapour-like water and a brine of dissolved minerals and/or metals. Shifting the hydrothermal fluid away from being a supercritical fluid causes the minerals to precipitate out of solution. Thus, as long as the hydrothermal fluid is within the very high solubility region (see Figure 1), it will transport the minerals and metals dissolved in solution and suspended or dissolved in the brine phase. Moving outside of this region or otherwise reducing the solubility of the water, for example, by altering pH, will cause the minerals and metals to precipitate out of solution. As discussed above, in the prior art methods, precipitation occurs gradually as the brine travels up the pipe. In the instant invention, the supercritical fluid is shocked, for example, by rapidly or dramatically reducing the temperature of the fluid, thereby causing the minerals and metals to precipitate out of solution. This is identical to that which occurs at the exit of a black smoker vent on the ocean floor causing the metal sulfides to precipitate as fine (micrometer sized) particles [5]. The resulting slurry is then brought to the surface with minimal scaling of the pipe. In fact, the metal sulfide particles should continuously scrub the pipe walls and keep them clean of any other deposition problems. On land, the individual metals and/or minerals

may then be separated and/or isolated using means known in the art. Similarly, valuable gases will exit the solution as the fluid de-pressurizes and hence, will also be brought to the surface by this method and stored or incorporated into fuel cells, as described below. As can be seen in Figure's 3 – 4, in some embodiments, cold water is used to dramatically reduce the temperature, and thereby the solubility of the fluid, although other suitable means may also be used. A further aspect of the invention is directed to slurries, gases and minerals recovered by the instant method.

It is of note that under certain conditions which depend on the local hydrostatic gradient in the ground, it may be necessary to add some pumping force (or equivalent lift) at the well location to ensure large wellhead pressures and hence, large flow rates. In yet other embodiments, the method includes pump means for drawing the slurry to the surface. The pump means may comprise for example, an air-lift pump wherein air is added to the injected cold water to increase the lift by reducing the density of the mix; or a Venturi pump or Jet Pump, wherein the pumping power of the injected fluid is used to add additional motive (pumping power) at the downhole location where the device is. Another possibility is the use of down-hole pumps similar to that used in geothermal energy systems today.

The point at which the water temperature ceases to be a supercritical fluid is referred to as the pseudo-critical temperature line. As will be appreciated by one of skill in the art, solubility can vary by orders of magnitude across the pseudo-critical line [4]. In one embodiment of the instant invention, shock precipitation occurs while crossing the pseudo-critical temperature line.

It is of note that even in the highly soluble region where water exists as a supercritical fluid, the material exists in two phases – purer vapour-like water and a brine. As the fluid passes outside of the highly soluble region across the pseudo-critical temperature line, salts become re-dissolved in the water and hence can no longer carry the metals as dissolved in ion complexes. As will be appreciated by one of skill in the art,

other suitable means which reduce the solubility of the supercritical fluid may also be used. As discussed above, the minerals precipitating out of solution form a slurry which is then transported up the well pipe.

As will be appreciated by one of skill in the art, the solubility shock or pseudo-critical temperature line may be established anywhere along the length of the well pipe, provided that the water in the hydrothermal fluid is in the supercritical state. That is, the shock zone does not need to be established near the well hole but may be established up the well pipe, as discussed below.

Turning now to Figures 3 and 4, two embodiments of the well pipe 25 of the tubing string are illustrated in further detail. The common features of both will first be described herein. In each instance the well pipe includes a first conduit in the form of an extraction pipe 11 for collecting the hydrothermal fluid at an inlet 14 at a bottom end thereof. Pumps may be provided along the extraction pipe partway along the pipe or above ground at the well head 24. The well pipe 25 also includes a second conduit in the form of an injection pipe 12. The injection pipe 12 acts as a conduit for receiving an injection fluid 16 which acts as a solubility reducer to cause precipitation within the hydrothermal fluid when the injection fluid is injected into the hydrothermal fluid. The pipes 11 and 12 may be concentric with one another or positioned alongside one another so as to both extend the full length of the well pipe 25. At the bottom of the injection pipe 12 a suitable end cap 13 is provided adjacent the inlet 14 of the extraction pipe. Injection hole 15 are provided which communicate between the extraction pipe and the injection pipe near the bottom free end of the well pipe spaced above the inlet 14, downstream therefrom. The injection holes 15 may comprise a series of nozzles directed from the injection pipe into the extraction pipe which are suitably oriented to direct the injection fluid into the direction of flow of the supercritical fluid drawn up through the inlet 14 towards the well head 24. In other variations the injection holes may comprise the holes in a porous wall separating the extraction pipe from the injection pipe. In this arrangement the

injection fluid is forced through the porous wall into the extraction pipe to come into contact with the supercritical fluid to cause precipitation thereof by rapidly reducing solubility. The continuous flow through the porous wall prevents scaling on the porous wall itself or around the injection holes 15.

Turning now more specifically to Figure 3, the extraction pipe 11 is located concentrically within the injection pipe 12 so that the end cap 13 generally comprises an annular plate sealing the annular opening at the bottom end of the injection pipe. Fluid 16 forced down into the injection pipe is thus forced through the injection holes inwardly towards the extraction pipe 11. The inlet 14 of the extraction pipe is centrally located at the bottom free end of the well pipe.

As illustrated in Figure 4 the injection pipe 12 is instead concentrically located within the extraction pipe 11. The inlet 14 thus comprises an annular opening at the bottom free end of the well pipe which surrounds the end cap 13 sealing the bottom end of the injection pipe 12 closed.

In further arrangements, the injection holes 15 may be oriented to produce a cyclone effect when the injector pipe is located externally of the extraction pipe and the injection fluid 16 is accordingly directed inwards to an interior of the centrally located extraction pipe 11. The injection fluid in some instances may include a suspension of particles to help nucleate salt particles and/or continuously scrub the lower pipe entrance. When the injectors are oriented to produce a hydro cyclone, the heavy particles will tend to stay along the walls for scrubbing action. Centrifugal force will keep them along the wall. Absorbent type materials may also be added to the injection fluid to nucleate sulphides and prevent them from sticking to the walls. Fresh cold water may be used as the injection fluid 16 as the solubility of mineral salts in fresh water increase dramatically as you cool through the pseudocritical temperature line, for example when the injected water is fresh water with no salt. Hence the salts attempting to form at the wall would be continuously dissolved.

In further embodiments selective wall coatings may be provided to prevent adhesion of sticky salts in particular. Electrical inductance heating of the inner pipe to raise the adjacent fluid and scale into the high solubility region may be desirable. Further prevention of plugging would likely result. Jet pumps may be provided at the well head 24 to prevent possible flow reversal due to increasing fluid density in the pipe with respect to the surroundings as the mix is cooled. The prevention of sub surface blowouts is also a desirable effect.

In the first embodiment of the invention shown in Figure 3, the well pipe comprises two pipes – a first pipe for withdrawing the material and a second pipe containing a coolant, in which the first pipe is within the second pipe. As will be apparent to one of skill in the art, other suitable arrangements may also be used, provided that the shocking agent or coolant is able to rapidly reduce the solubility of the contents of the first pipe, for example by reducing the temperature of the contents of the first pipe, thereby shocking the minerals and metals out of solution. In some embodiments, the coolant is water. Other coolants may include saltwater or water with additives to perform such functions as adjusting the pH. In other embodiments the material introduced may be water or steam or other fluid with characteristics to adjust the pH or chloride content of the hydrothermal fluid while maintaining the temperature and hence buoyancy of the hydrothermal fluid.

In other embodiments, the walls of the pipes may be coated with compounds known in the art for preventing or reducing adhesion and/or corrosion.

In yet other embodiments, the first pipe may be arranged to include electric inductance heating for raising the temperature of the material, thereby preventing plugging of the pipe.

In yet other embodiments, the first pipe may be arranged to include electric inductance heating for raising or maintaining temperature of the material and the first pipe may be arranged to have pressure maintained by methods disclosed elsewhere in this

document. This is in order to maintain the hydrothermal fluid in the supercritical state to surface and ensure that metals/minerals and gasses remain in solution to be processed at surface.

Seawater source systems, such as in Iceland, contain dissolved NaCl resulting in hydrothermal fluid rich in chloride (Cl^-). The addition of hydrogen, possibly from gases emanating from the magma chamber. This renders the fluid highly solvent (acidic) and capable of voraciously stripping metals from the surrounding vast water-permeable fractured basaltic regions that overlie the magma chamber.

The most important variable on metal solubility is the dissolved chloride (Cl^-) content. Metal solubility is dependent on Cl^- concentration due to the effect of Cl^- on the formation of aqueous metal complexes, ionic strength and charge balance constraints [3 – 4] This is apparent when hydrothermal fluids derived from seawater (rich in dissolved Cl^- and metals) is compared to hydrothermal fluids derived from meteoric water (poor in dissolved Cl^- and hence, metals). In addition, dissolved Cl^- has a dramatic effect on dissolved H_2 and H_2S causing both dissolved gases to decrease with increased Cl^- (gassing-out effect).

The temperature and the pH of Cl^- bearing hydrothermal fluids have a significant effect on metal solubility. Metal solubility increases with an increase in temperature. For example, copper solubility increases by a factor of four if the temperature increases from 350°C to 400°C. Above 400°C this can increase further by orders of magnitude. Metal solubility increases with a decrease in pH. For example there is a dramatic increase in dissolved Fe and Cu when pH adjusted from 5.0 to 4.8 [11].

The pressure and degree of oxidation of Cl^- bearing hydrothermal fluids have an effect on metal solubility. At subcritical pressures, metal solubility increases with a decrease in pressure and increases with an increase in degree of oxidation. The degree of oxidation has a significant effect on metal ratios in solution. For example, High Fe/Cu ratio of metal content in solution in relatively reducing conditions, Low Fe/Cu ratio in relatively

oxidizing conditions [10].

Water in a supercritical state behaves very differently than ordinary (subcritical) water. Supercritical conditions for pure water is defined as water at pressures and temperatures greater than 200 bars and 374°C respectively whereas supercritical conditions for seawater (3.2% NaCl) occur at pressures and temperatures greater than 300 bars and 405°C.

Supercritical water is highly solvent, particularly if dissolved Cl^- is present. If dissolved Cl^- is present supercritical water will separate into a dissolved Cl^- poor vapour-like water phase and a dissolved Cl^- rich brine phase. The solubility of Cl^- and hence the solubility of metals, is significantly higher in the supercritical brine phase than in sub-supercritical hydrothermal fluids. Large variations of Cl^- concentration in hydrothermal fluids indicate at least some of hydrothermal fluids at mid-ocean ridge spreading centres have intersected the two-phase boundary and unmixed into vapour-like water and brine components [10].

Hence, additives to the injected water circuit may be used that reduce either or both the pH or Cl^- concentration. Pure water alone, for example, will reduce the Cl^- concentration and hence, metal solubility. An alkaline such as lime will increase the pH and hence decrease the metal solubility as well. These factors may make it possible to precipitate metal sulfides while still maintaining the temperature within the supercritical state. This would allow for higher thermal energy extraction and larger wellhead pressures (by maintaining the buoyancy of the fluid – lower density).

The solubility of minerals and metal ions increases dramatically above the critical point in a water/chloride solution. Hence, supercritical aqueous chloride solutions circulating through the bedrock strip metals from the water-permeable rock. Some metal may be derived from the magma. Therefore, water emanating from a vent has very high metal concentrations. The solubility of metals as aqueous chloride complexes in supercritical water can be orders of magnitude greater than in seawater derived

hydrothermal fluids at lower than supercritical conditions. Evidence of the latter can be observed at white smoker vents, which predominantly discharge precipitated sulphates and silica (hence, the white colour), rather than black smokers, which are at high temperature (supercritical) and precipitate metal-sulphides (which results in black rather than white suspended particulates).

Benefits Over Conventional Land Based Geothermal Systems

The surrounding rock is highly porous (water permeable) which is ideal and in fact, far better than conventional land based geothermal systems.

No possible shortage of water.

No possible loss of resource pressure as may occur, over time, as with conventional land-based geothermal power plants.

Much higher temperature, hence, much more energy available per unit mass flow rate than conventional land based systems.

Higher temperature differences mean higher plant thermal efficiencies. This means higher power outputs for a given cycle size (e.g. flow capacity).

Minerals and gases exist in significant quantities and may be extracted.

Since local seawater temperatures are near 0°C, precipitation occurs naturally on the seafloor. The result has been the formation of enormous metal-sulphide deposits at vent sites. Such sulphide deposits are in a continuous flux with the surrounding fluids. Deposition and dissolution into the surrounding seawater occurs continuously. Dissolution occurs since the sulphides are not in chemical equilibrium with the surrounding seawater.

In yet another embodiment of the invention, there is provided a method, which involves drilling to a location where temperature and pressure conditions are supercritical and then bringing the fluids in a quasi-isothermal fashion to the surface, where pressure and temperature conditions are lower. Hence, precipitation can be delayed until the fluid reaches the surface. Such a process will also help dissolve existing

overlying metal-sulfide deposits. Dissolved minerals will be deposited and sent for further processing or possible extraction technologies may be developed to selectively precipitate the metals out of solution at the well location. Unused process water could be returned via re-injection well after the metals and minerals are removed and thus this is essentially an environmentally benign process.

The continuous sustainable energy obtainable from supercritical hydrothermal fluids is enormous. For example, a 6-inch diameter hydrothermal vent can have the equivalent thermal capacity of a small commercial power stations electrical capacity (around 60 MW). The energy flux from such systems far exceeds that of an equivalent oil or gas stream. Water temperatures can exceed 550°C and by drilling deeper it is likely that one can attain temperature as high as metallurgicaly possible. Supercritical power cycles promise to produce affordable energy.

Current drilling technologies can reach depths in excess of 5 km. Basalt is a volcanic rock that results from the cooling of lava and is highly fractured in such systems. These fractures occur during the thermal cycle of the basalt.

The large amount of dissolved metal and gases present will likely render this enormous amount of energy as a by-product of the metals and gas recovery. Such a high temperature energy source could be used in-situ for many extraction technologies such as; metal extraction methods, thermal catalytic splitting of water into hydrogen and oxygen, liquefying hydrogen cryogenically etc.

Storage methods for hydrogen are being investigated worldwide. One of the most promising to date is carbon fibre nanotubes (adsorption storage), which could probably be used to economically store and ship pure H_2. Fuel cells operating on methanol emit greenhouse gases such as CO_2. Conversely, H_2 cells are environmentally benign and produce only water vapour. An ultimate long-term objective is to evaluate, design and extract hydrothermal resources in a sustainable manner. Fuel cells operating on hydrogen are environmentally benign with water vapour as the only by-product. Currently, barriers to

a hydrogen economy are fuel cell costs, vehicle storage, distribution infrastructure and a sustainable hydrogen source. Transportation fuel cells will be commercial in the next few years. Highly improved storage methods on vehicles such as metal hydrides and carbon nanotubes are at the early research level but offer promise. Larger scale storage and distribution can be rationalized using extensions of existing technologies. However, sustainable large-scale hydrogen sources are problematic as electrolysis and other conversion technologies are relatively inefficient, which is a problem when using power from limited renewable sources, even for off-peak hydro-electric and natural gas reforming. Finding sustainable hydrogen sources would eliminate greenhouse gases and emission problems in general. It would also help solve a large number of associated environmental problems such as resource extraction concerns and land and water pollution.

The whole concept of hydrogen as a clean energy source is predicated on producing hydrogen without damaging the environment. Using conventional fossil energy sources to produce hydrogen could be worse than their direct use, when considering the low conversion efficiency. The need for a clean, large, and relatively benign source of energy is crucial. One such source is land-based geothermal energy. Iceland, for example, has been chosen as a model for a hydrogen based economy in the near future. Iceland is blessed with significant land-based geothermal sources and hence, their use to produce hydrogen makes good environmental and economic sense. Similar saline hydrothermal resources exist worldwide.

According to the present invention hydrothermal mining is accomplished by withdrawing a quantity of hydrothermal fluid from a magma fluid source surrounding a hydrothermal vent adjacent a land based well head. The hydrothermal fluid comprises a brine phase and a supercritical water phase. The solubility of the hydrothermal fluid is rapidly reduced from the high solubility region across the high solubility line or pseudocritical temperature line to cause precipitation which separates the fluid into water

and a slurry of precipitated metals, minerals and salts. In the process valuable gases including hydrogen and methane may be released from the fluid and captured. The solubility may be rapidly reduced by shocking the supercritical fluid into a sub-supercritical state. This may be accomplished by lowering the temperature of the supercritical fluid by injecting a solubility reducer in the form of a coolant. Alternatively the pH of the supercritical fluid may be adjusted by injecting a suitable solubility reducer to affect pH of the fluid and thereby rapidly reduce the solubility by shocking. In a further variation, the solubility reducer which is injected may comprise a chloride content adjuster to thereby affect the solubility in the fluid. Any combination of the solubility reducers may be used. When solubility is adjusted using pH or chloride content as the active means the fluid may be maintained at high temperature as it is brought up the well pipe by providing an insulated pipe to make the best use of captured heat from the fluid. Alternatively the fluid may be cooled just below the supercritical line, for example just below 350°C so as to cause precipitation, and then this high temperature fluid can be maintained isothermally again using an insulated pipe for capturing as much heat as possible. Ideally the injection of the solubility reducer occurs near the bottom end of the well pipe 25 spaced slightly above the inlet just downstream therefrom. The slurry is then brought up to the well head for isolation of the water and precipitated particles above ground. The method may include injecting air into the solubility reducer within the second conduit for subsequent injection into the first conduit with the solubility reducer to provide lift to the hydrothermal fluid within the first conduit.

While the preferred embodiments of the invention have been described above, it will be recognized and understood that various modifications may be made therein, and the appended claims are intended to cover all such modifications which may fall within the spirit and scope of the invention.

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CLAIMS

1. A method of hydrothermal mining comprising:

withdrawing a quantity of a supercritical hydrothermal fluid from a magma fluid source surrounding a hydrothermal vent, said hydrothermal fluid comprising a brine phase and a supercritical water phase; and

rapidly reducing the solubility of the hydrothermal fluid, thereby separating the hydrothermal fluid into water and a slurry.

2. The method according to claim 1 including pumping the hydrothermal fluid to increase flow rates.

3. The method according to claim 1 wherein the brine phase comprises dissolved mineral salts.

4. The method according to claim 1 including extracting valuable gases from the hydrothermal fluid.

5. The method according to claim 4 wherein the valuable gases include hydrogen and methane.

6. The method according to claim 1 wherein the solubility is rapidly reduced by shocking the supercritical fluid into a sub-supercritical state.

7. The method according to claim 6 wherein the supercritical fluid is shocked by lowering the temperature of the supercritical fluid, adjusting the pH of the supercritical fluid, adjusting the chloride content of the supercritical fluid, or a combination thereof.

8. The method according to claim 7 wherein the temperature is lowered using cold water.

9. The method according to claim 7 wherein the temperature is lowered just below a supercritical temperature of the fluid.

10. The method according to claim 1 including providing a tubing string to withdraw the hydrothermal fluid and reducing the solubility of the fluid adjacent a bottom

end of the tubing string.

11. The method according to claim 10 including reducing the solubility of the hydrothermal fluid by injecting a solubility reducer into tubing string above an inlet of the tubing string which receives the hydrothermal fluid.

12. The method according to claim 10 including providing a first conduit in the tubing string for withdrawing the hydrothermal fluid and a second conduit in the tubing string for injecting a solubility reducer adjacent the bottom end of the tubing string.

13. The method according to claim 12 including injecting air into the solubility reducer within the second conduit for subsequent injection into the first conduit with the solubility reducer to provide lift to the hydrothermal fluid within the first conduit.

14. The method according to claim 1 including reducing the solubility by either adjusting the pH of the supercritical phase or adjusting the chloride content while maintaining temperature of the fluid near but just below a supercritical temperature of the fluid.

15. The method according to claim 1 including providing a production tubing string for withdrawing the hydrothermal fluid and locating a well head of the tubing string on land adjacent a body of salt water.

16. The method according to claim 1 including providing a production tubing string for withdrawing the hydrothermal fluid, reducing the solubility of the fluid adjacent a bottom end of the tubing string and isolating the slurry from the water adjacent a top end of the tubing string.

17. A hydrothermal mining system comprising:

a tubing string for withdrawing a quantity of a supercritical hydrothermal fluid from a magma fluid source surrounding a hydrothermal vent, said hydrothermal fluid comprising a brine phase and a supercritical water phase; and

a solubility reducer for injection into the hydrothermal fluid for rapidly reducing the solubility of the hydrothermal fluid, thereby separating the hydrothermal fluid

into water and a slurry.

18. Minerals isolated by the method according to any one of claims of 1 to 16.

19. A slurry containing a plurality of minerals isolated according to the method of any one of claims 1 to 16.

20. Hydrogen gas isolated according to the method of claim 4 or 5.

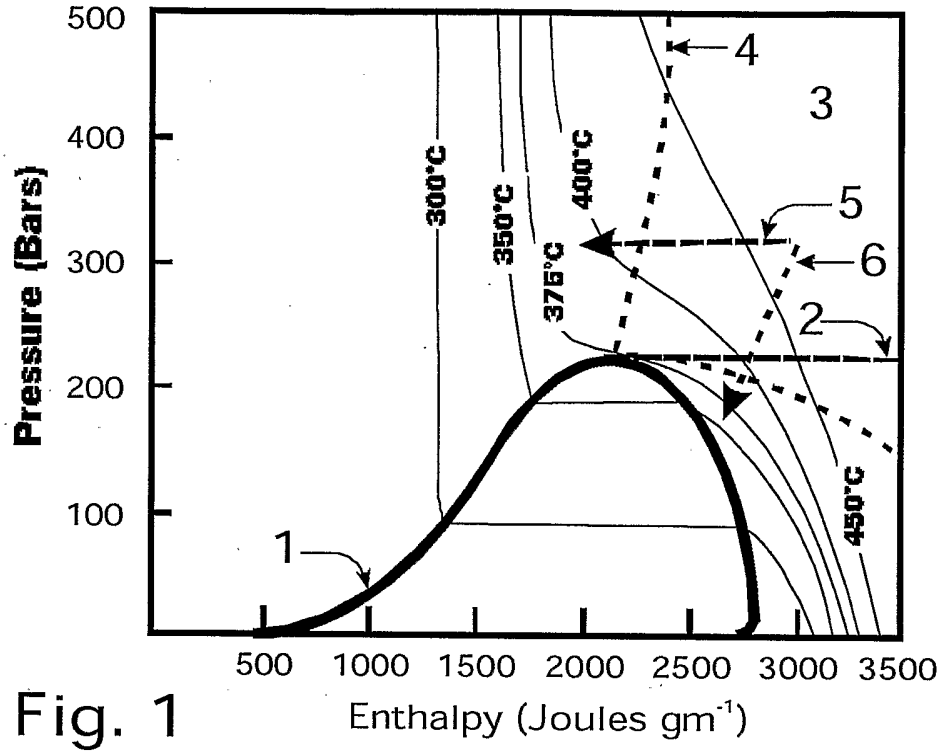

500
400
300
200
100
Pressure (Bars)
300°C
350°C
375°C
400°C
450°C
1
2
3
4
5
6
500 1000 1500 2000 2500 3000 3500
Enthalpy (Joules gm-1)

Fig. 1

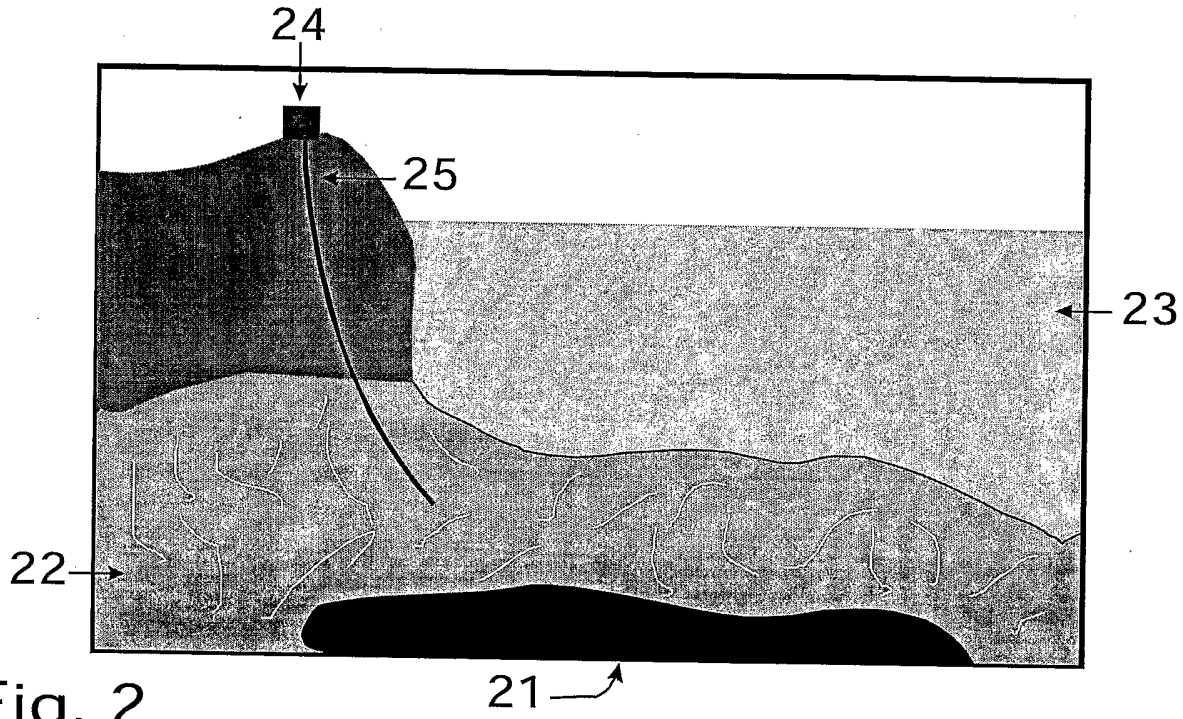


Fig. 2

Fig. 3

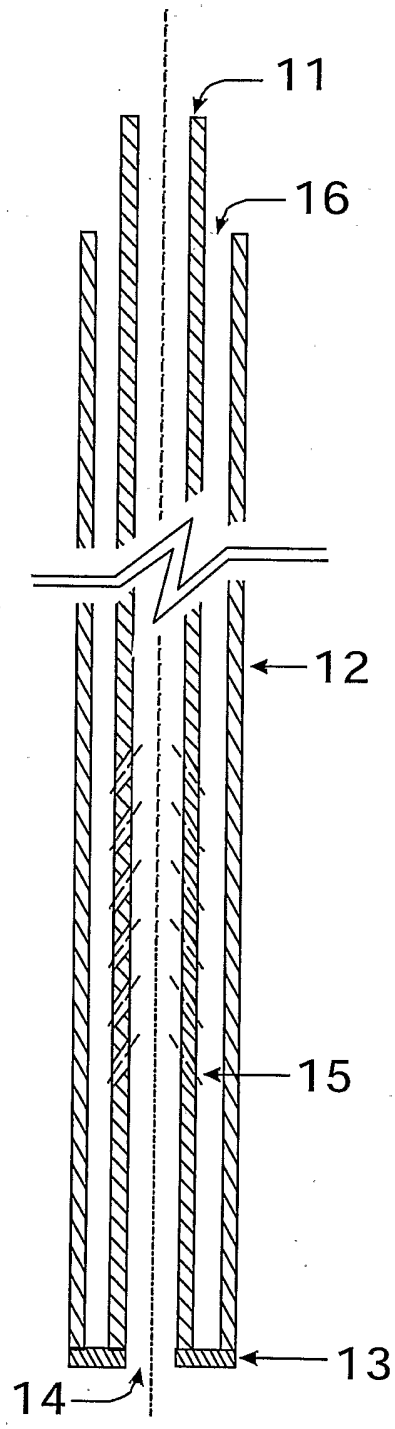
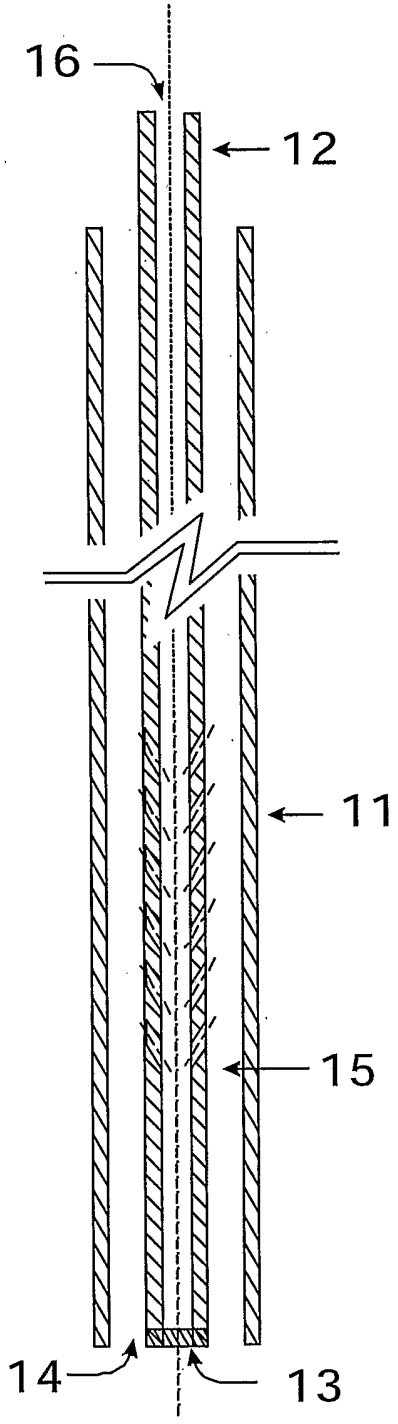


Fig. 4



INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 03/01522

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C22B7/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C22B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
17 March 2004	31/03/2004

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 03/01522

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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