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[54] **HEATING THROUGH FRACTURES TO EXPAND A SHALE OIL PYROLYZING CAVERN**

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[51] **Int. Cl.²** **E21B 43/24**

[58] **Field of Search** 166/271, 272; 299/4

[56] **References Cited**

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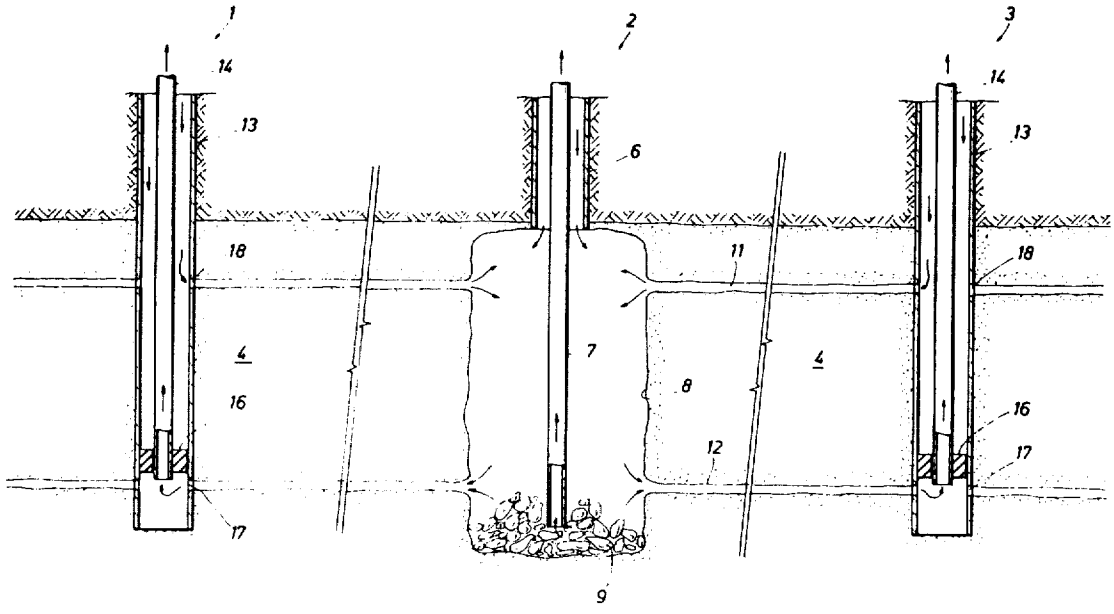
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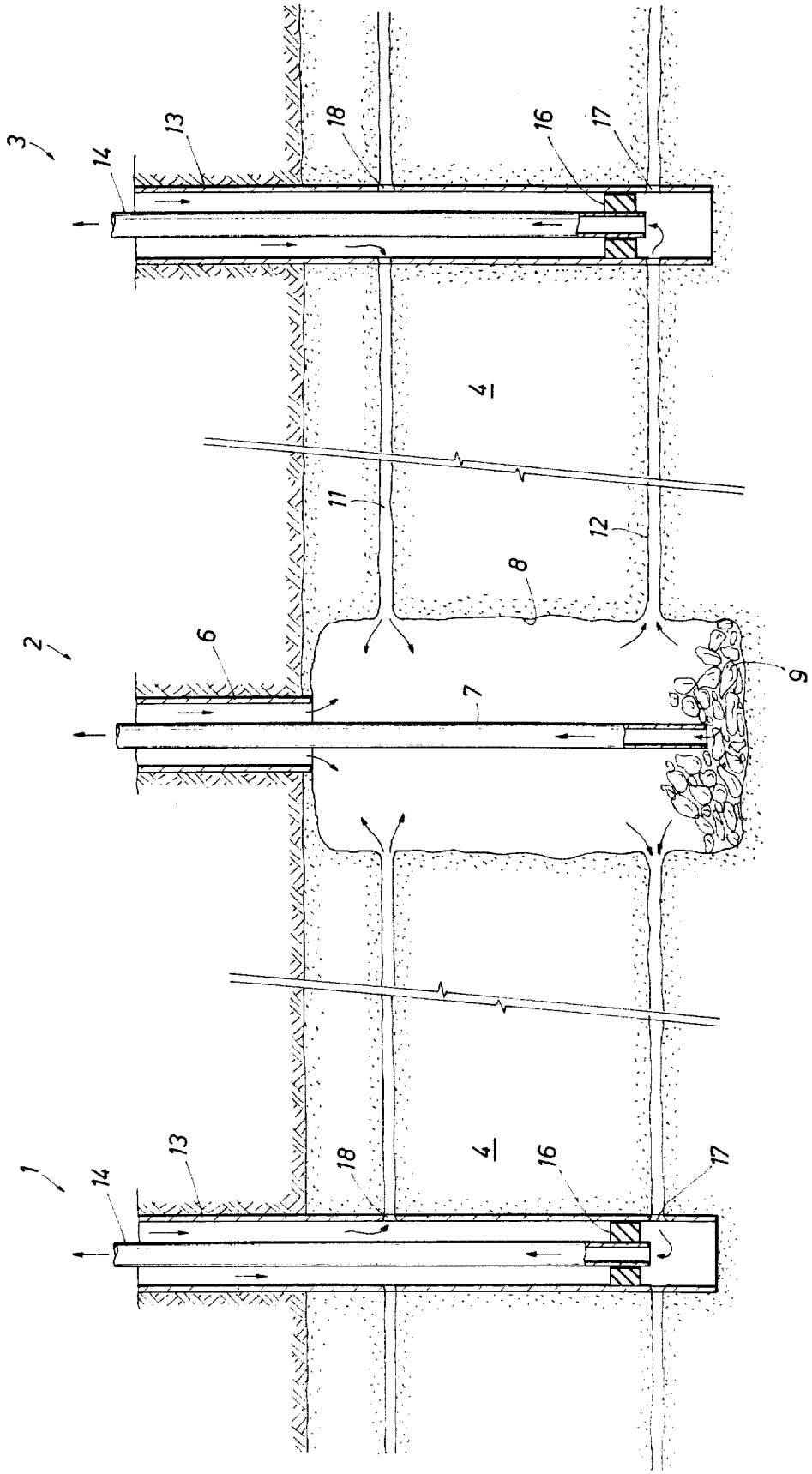
Primary Examiner—James A. Leppink

[57] **ABSTRACT**

In a process for recovering shale oil by injecting and producing fluid into and out of a rubble-containing cavity in an otherwise substantially non-porous and impermeable subterranean oil shale formation, hot gas is circulated into and out of the cavity through spaced horizontal fractures to preheat the oil shale formation and increase the rate of oil recovery and cavity expansion.

4 Claims, 1 Drawing Figure




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HEATING THROUGH FRACTURES TO EXPAND A SHALE OIL PYROLYZING CAVERN

BACKGROUND OF THE INVENTION

The invention relates to producing shale oil and related mineral materials from a subterranean oil shale formation.

Numerous subterranean oil shale formations contain water-soluble minerals and/or minerals that are thermally converted to water-soluble materials. Such oil shales, in their natural state, are non-porous, impermeable aggregations of solid organic and inorganic materials. As indicated by patents such as the T. N. Beard, A. N. Papadoupolos, R. C. Ueber U.S. Pat. Nos. 3,739,851; 3,741,306; 3,753,594; 3,759,328 and 3,759,574, shale oil can be recovered from such formations by utilizing the water-soluble and/or heat-sensitive materials to form relatively solids-free rubble-containing caverns within which the oil shale is contacted by a circulating hot aqueous fluid that disaggregates the oil shale into fluid-surrounded particles, converts the kerogen to fluid hydrocarbon materials, and dissolves or entrains enough inorganic solid to expand the cavern while producing shale oil. In such prior processes, the transferring of heat from an injected hot fluid such as steam to the oil shale formation is aided by inflowing the fluid into an upper portion of the cavity and withdrawing fluid from the lower portion of the cavity. However, as discussed in the P. J. Closmann and G. O. Suman U.S. Pat. Nos. 3,804,169 and 3,804,172, the processes are subject to a tendency for such "bottom-out" flow paths to become plugged due to the filter-cake-forming tendency of a fluid containing a significant proportion of fines mixed with larger particles. Where, for example, the hot aqueous fluid is the condensate from a top-injected steam, the condensate flows down along the walls of the cavern while rubblizing and disaggregating portions of the oil shale. This entrains or causes the slumping of particles having sizes ranging from only a few microns to several feet in diameter. Such particles, which slump or flow in response to gravity as lumps or a turbidity current moving down the walls of the cavern, tend to pile-up and plug-up around the fluid-withdrawal point near the bottom of the cavern.

In the above U.S. Pat. No. 3,804,169, a pattern of fracture-interconnected caverns is equipped with wells arranged so that the hot fluid injected near the top of one cavity is produced through a plurality of surrounding cavities at flow rates arranged so that the flow velocities decrease with radial distance to velocities that are too low to carry the solids to the producing wells. However, where an oil shale formation is thin enough to cause significant amount of heat loss to other formations, the so-arranged flow rates may be uneconomically slow. In the above U.S. Pat. No. 3,804,172, the lower portion of such a rubble-containing cavity is packed with a mass of relatively large rigid solid particles, or boulders, so that the slurried solids are spread out over large surface areas while the fluids are flowing through the relatively large openings that exist between such particles.

In co-pending patent application Ser. No. 489,639, filed July 18, 1974 by P. J. Closmann and M. J. Tham, the tendency for the flow path to become plugged in such a shale oil recovery process is reduced by injecting both a hot solvent-fluid and a hot non-solvent-gas at rates correlated so that the cavern remains substantially free of liquid. However, in using fluids such as steam and nitrogen, this has a tendency to slow the rate of oil production and cavern expansion. Increasing the proportion of steam increases the rate of fines production, and decreasing the proportion of steam decreases the rate of oil production and cavity expansion.

SUMMARY OF THE INVENTION

The present invention relates to an improvement in a process in which shale oil is produced by forming a relatively solids-free rubble-containing cavity or cavern within an otherwise substantially non-porous and impermeable subterranean oil shale that contains water-soluble minerals, injecting fluid into the cavern, withdrawing fluid from the cavern and recovering shale oil from the fluid withdrawn from the cavern. The improvement comprises the following. At least two vertically-separated generally horizontally-oriented fractures are extended between a cavern and at least one laterally displaced well. A hot non-solvent-gas having a relatively insignificant miscibility with any of the organic or inorganic components or pyrolysis products of the oil shale is flowed into the cavern through at least one of the fractures while a hot fluid inclusive of oil shale pyrolysis products is flowed out of the cavern through at least one other horizontal fracture. The rate and temperature of the fluid inflowed through a fracture and the rate of the fluid outflowed through the fracture are adjusted so that the fracture walls are heated and become vertically separated, generally planar heat sources from which heat is transferred to the oil shale formation beyond the walls of the cavity.

DESCRIPTION OF THE DRAWINGS

The drawing schematically illustrates a portion of a subterranean oil shale formation in which the present invention is being practiced.

DESCRIPTION OF THE INVENTION

The present invention is, at least in part, premised on the following. In an oil shale recovery process in which a hot fluid is injected into and produced from a relatively solids-free, rubble-containing cavern with a subterranean oil shale that is otherwise substantially non-porous and impermeable, the heat transferring efficiency is improved by a circulation path in which the point of injection is near the top of the cavity and the point of withdrawal is near the bottom of the cavity. The plugging of such a flow path due to the entraining and screening-out of particles by a hot solvent-fluid that is relatively miscible with one or more of the organic or inorganic solid components or pyrolysis products of the oil shale can be reduced without significantly reducing the rate of oil shale recovery or cavern growth. The kerogen is such an oil shale can be pyrolyzed while forming relatively few fines by contacting the oil shale with a hot non-solvent-gas that is substantially immiscible with any of the organic or inorganic solid components of the oil shale or oil shale pyrolysis products. The rate of non-solvent-gas-induced pyrolysis can be made relatively rapid by using temperatures in the order of 700° to 1000°F. The rate of the heat transfer from the cavity to the surrounding oil shale formation can be materially enhanced by forming vertically-separated generally-horizontal fractures and circulating such a hot non-solvent-gas in through one while

circulating a hot gas out through another. This, in effect, surrounds the cavity with a pair of radially-extensive, generally planar, heat sources. It causes the oil shale formation around the cavity to be caught between the jaws of a thermal-pincer and rapidly heated to a temperature at which the gas-pressure-induced spalling of fragments of oil shale into the cavity causes a relatively rapid expansion of the cavity.

As the terms are used herein, "oil shale" refers to a substantially non-porous impermeable aggregation of inorganic solids and a predominately hydrocarbon solvent insoluble inorganic solid material known as kerogen. "Bitumen" refers to the hydrocarbon solvent soluble organic material that may be present in the natural oil shale and is usually the initial thermal conversion or pyrolysis product of kerogen. "Shale oil" refers to gaseous or liquid hydrocarbon materials, which may contain trace amounts of other elements such as nitrogen, sulfur, oxygen or the like, that can be obtained by pyrolyzing and/or extracting organic materials from an oil shale. "Water soluble inorganic minerals" refers to those which are naturally water-soluble solids (having a solubility of at least about 10 grams per 100 grams of solvent in aqueous liquids having pH's of from about 5 to 8) such as the halites or carbonates typified by the alkali metal chlorides, bicarbonates, or carbonates, as well as the heat-sensitive minerals that are either naturally water-soluble or are thermally converted to materials that are water-soluble, such as nahcolite, dawsonite, trona or the like minerals. A "water-soluble-mineral-containing" subterranean oil shale is an oil shale formation that contains, or is mixed with, at least one water-soluble mineral in the form of lenses, layers, dispersed particles or the like.

The present process can be used in substantially any relatively solids-free cavity or cavern or opening in an otherwise substantially non-porous, impermeable subterranean oil shale. Such a cavern is preferably at least as large as the borehole of a well, has a relative high permeability such that the rate of gravity seggregation of fluids is not significantly impaired by a lack of permeability, has a porosity of from about 25 to 95%, and is substantially free of interconnected solids that are ridgidly connected to the matrix of the surrounding earth formations. As indicated in the previously mentioned Beard et al patents, such caverns can be formed by solution and/or mineral mining, nuclear detonation or other explosive fracturing coupled with the mining out of a significant portion of solids. Such caverns are advantageously formed by solution-mining an opening in a water-soluble-mineral-containing subterranean oil shale in which there are vertically separated layers of water-soluble mineral such as halite or nahcolite.

The fractures used in the present process can be substantially any that have generally horizontal and radially extensive permeable channels, such as hydraulically-induced fractures that are propped open with granular propping materials, or fractures having walls that have been etched to provide channels that remain open, or the like. Such fractures can advantageously be formed by locating vertically separated layers of soluble material such as a halite, inducing a fracture along a boundary plane of such a material and etching the material by solution-mining to provide a generally radially extensive self-supporting fracture flow channel. Patterns of cavities and/or wells are preferably arranged so that centrally located wells, such as the center wells in the five-spot pattern of wells and/or well-containing cavities can be used to circulate fluids into and out of fractures that extend into each of a series of surrounding cavities.

A hot solvent-fluid suitable for use in the present process is one which is heated to a temperature of about 500° to 700°F and, at such a temperature, exhibits a significant miscibility with at least one of the organic or inorganic solid or liquid pyrolysis products of a water-soluble-mineral-containing oil shale. Such fluids preferably contain (or consist essentially of) steam at a temperature and pressure causing condensation within the cavern. Such fluids may also include or comprise hydrocarbons such as benzene, toluene, shale oil hydrocarbons, oil-soluble gases such as carbon dioxide, mixtures of such fluids, or the like.

A hot non-solvent-gas suitable for use in accordance with this invention can comprise substantially any gas having a temperature of at least about 500°F and, at that temperature, has a relatively insignificant miscibility with any of the organic or inorganic solid or liquid pyrolysis products of a water-soluble-mineral-containing oil shale (e.g. having a solubility of less than about 1 part per thousand in such solid or liquid pyrolysis products). Suitable non-solvent-gases include nitrogen, natural gas, combustion gases, methane that is substantially free of higher hydrocarbons, mixtures of such gases, and the like. Particularly where steam is used as (or as a component of) the hot solvent-fluid, the hot non-solvent-gas can be injected at temperatures higher than about 700°F, for example, to enhance the rate of revaporizing the steam condendate and the drying out of the cavern.

As shown in the drawing, a series of wells, **1**, **2**, and **3**, are completed into a subterranean water-soluble mineral-containing oil shale formation **4**. In well **2**, an outer conduit **6** is terminated near the upper portion of the oil shale formation, while an inner conduit **7** extends to a significantly lower depth. A relatively solids-free cavity **8**, containing a rubble of oil shale particles **9**, is formed, for example, by solution mining techniques. Generally horizontally oriented fractures **11** and **12** are formed along layers of a water-soluble mineral such as halite or nahcolite contained with the oil shale formation. The fractures can be formed by conventional hydraulic fracturing techniques and propped or etched to maintain a permeable channel between their walls. The fractures can be formed prior to or after the expanding of a borehole to the size of the cavity **8** (which expanding can be accomplished by, for example, installing conduits **6** and **7** as shown and circulating in a hot aqueous solvent through conduit **6** while circulating out through conduit **7** a solution of water-soluble minerals).

Wells **3** and **4** are completed in locations into which the fractures **11** and **12** can be extended. They are preferably completed with an outer conduit **13** and an inner conduit **14** with a packer **16** positioned near but above the depth of the depth of the fracture **12** and the end of the conduit **14**. The outer conduits **13** are preferably perforated with perforations such as **17** and **18** near the depths of the fractures **11** and **12**.

In a preferred operating procedure, the fractures **11** and **12** are extended between the wells **1**, **2**, and **3** prior to any solution mining or cavity expanding around well **2** to extend the bore hole beyong a diameter at which packers can be utilized to facilitate fracturing at at least

a pair of selected depths. An aqueous liquid is circulated through the fractures **11** and **12** (sequentially or simultaneously and/or by means of flow patterns that are periodically reversed) to cause the growth and extension of the etched portions of the fracture walls. The cavity **8** is then advantageously formed by a solution-mining procedure, for example, such as the one described in the L. H. Towell, J. R. Brew U.S. Pat. No. 3,792,902. When the cavern has dimensions in the order of a 100 to 200 foot diameter and 300 to 500 foot height, the hot-gas-aided process of the present invention is preferably initiated.

A hot-non-solvent-gas, such as nitrogen, is circulated in through wells **1** and **3** to flow into the cavern **8** through fractures **11** while a hot generally gaseous fluid is outflowed through fracture **12.** In the initial stages, it is advantageous to heat up all of the cavern relatively rapidly by concurrently circulating a similar hot gas into cavern **8** through conduit **6,** while fluid (which is initially apt to be liquid or include liquid) is circulated out through conduit **7.**

The inflowing hot gas can be substantially any non-solvent gas heated to a temperature in the order of 700° to 1000°F by means of surface and/or downhole located heating devices. The outflow conduit **7** in cavity **8** is advantageously extended to a depth below that of the lowermost horizontal fracture **12.** This ensures that most of any liquid that outflows from the cavern will be withdrawn from the conduit **7** and will tend to reduce the plugging of fracture **12** by solids that may be entrained in an overflowing liquid (which would have a velocity that would decrease with radial distance away from the cavity **8**).

Where it is desired to enhance the rate of oil shale-disaggregation and/or solid removal by solution or entrainment of solids in a liquid, the circulation of the hot non-solvent gas in through fracture **11** and out through fracture **12** can be continued while a selected proportion of a solvent-fluid such as steam and/or hot aqueous liquid is concurrently circulated in through conduit **6** and out through conduit **7.** The proportions of the circulating hot non-solvent and solvent fluids are preferably controlled so that the cavern is kept substantially liquid-free at least to an extent that prevents any significant amount of plugging relative to the outflow of fluid through conduit **7.** An inclusion of a suitable, but not excessive, proportion of such a hot solvent-fluid can readily be attained by establishing a selected rate of circulation of hot non-solvent fluid in through conduits **6** and **13** and out through conduits **7** and **14** and then including increasing proportions of solvent fluid in the stream inflowing through conduit **6** while observing any tendency for a significant decrease to occur in the amount of fluid outflowing through column **7.**

The present process is particularly suitable for use in a nahcolite-containing subterannean oil shale. In such a formation, the decomposition of the nahcolite (by heating it to a temperature at which it is converted to CO_2 and a water-soluble carbonate) is an effective mechanism for inducing the rubbling of the oil shale formation. When the walls of a cavity are heated to a sufficient temperature, the pressure which is built up within the rock by the CO_2 being generated by the thermal conversion of the nahcolite (which is commonly present in discontinuous nodules within the oil shale formation), tends to create fractures and to hydraulically displace portions of the oil shale toward the relatively solids-free void space within the cavity. This has been shown to be quite effective in expanding a cavity into which steam is injected while a liquid solution of dissolved inorganic material is being outflowed. The dissolving of the carbonates (into which the nahcolite is thermally converted) increased the pH of the steam condensate and this increases the rate of disaggregation of the oil shale that is contacted by the then alkaline aqueous liquid. This, however, has a disadvantage of increasing the tendency for the plugging of the flow path and for being most effectively conducted at a relatively low temperature, of less than about 700°F. Since an oil shale rock formation is generally a poor conductor of heat, and since the heating or a rock builds up thermal stresses that might inhibit the fracturing of the rocks around a cavity and/or nodules of nahcolite, tests were made and model studies were made, to determine the overall effect of these stresses. In order to fracture the rock and cause the rubbling, the gas pressure must overcome the tensile strength of the rock and both the induced thermal stresses and the in situ horizontal stress within the earth formation at the depth being considered.

By subjecting the oil shale beyond the fracture wall to a more rapid heating, i.e. by subjecting it to the heat being conducted away from a pair of generally planar heat sources (i.e. the hot gas conveying fractures above and below such portion) the rate of cavity growth will be materially increased. In the present process, the spacing of such horizontal fractures is preferably such that there is at least about one pair per each 100 to 200 feet of vertical height of the cavity.

What is claimed is:

1. In a shale oil producing process in which a relatively solids-free, rubble-containing cavity is formed within an otherwise substantially non-porous and impremeable subterranean oil shale, and fluid is injected into and withdrawn from the cavity, the improvement which comprises:

forming at least two vertically-separated, substantially horizontal fractures that extend between the cavity and at least one adjacent well;

inflowing a hot non-solvent-gas into the cavern through at least one of said fractures;

outflowing a hot fluid containing oil shale pyrolysis products from the cavern through at least one other of said fractures; and

adjusting the rate and temperature of the fluid inflowing and outflowing through the fractures so that the fracture walls are heated and become vertically separated, generally planar heat sources from which heat is transferred to portions of the oil shale formation surrounding the walls of the cavity.

2. The process of claim **1** in which said fractures are located along the boundaries of layers of water soluble minerals that are present within said oil shale formation.

3. The process of claim **1** in which said circulation of hot non-solvent gas is continuously or intermittently supplemented by a circulation of a hot solvent fluid into the cavity through a conduit terminating in an upper portion of the cavity and a circulation of fluid out of the cavity from a conduit terminating in a lower portion of the cavity.

4. The process of claim **3** in which the hot non-solvent-gas is nitrogen and the hot solvent-fluid is steam.

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