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RECOVERING OIL FROM NUCLEAR CHIMNEYS IN OIL-YIELDING SOLIDS

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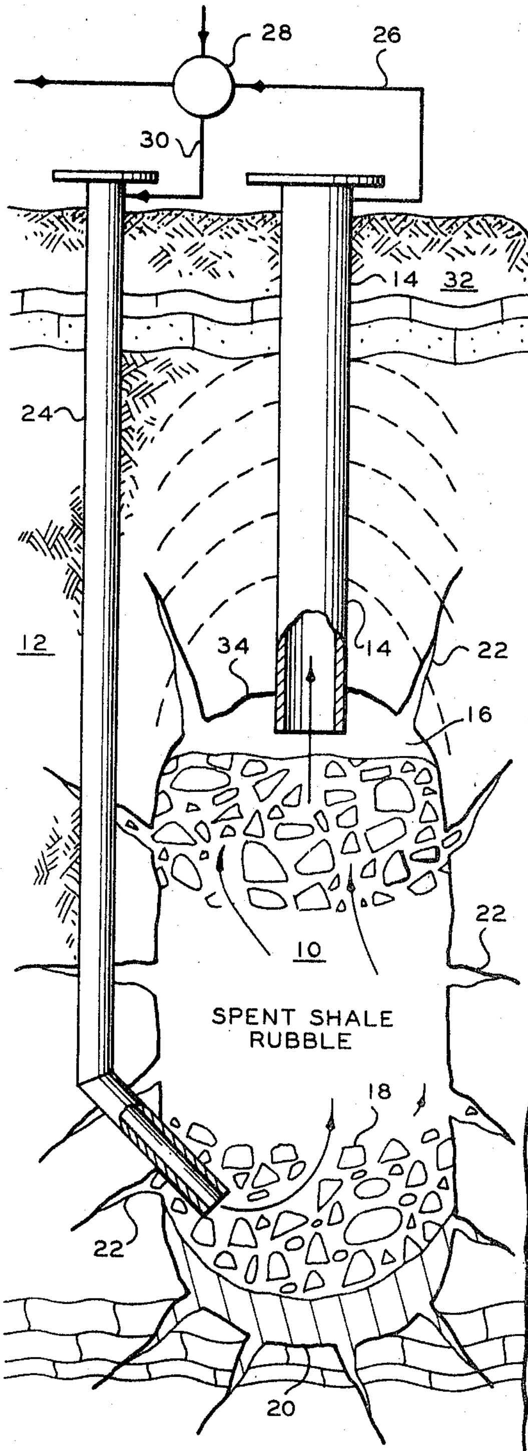

FIG. 1

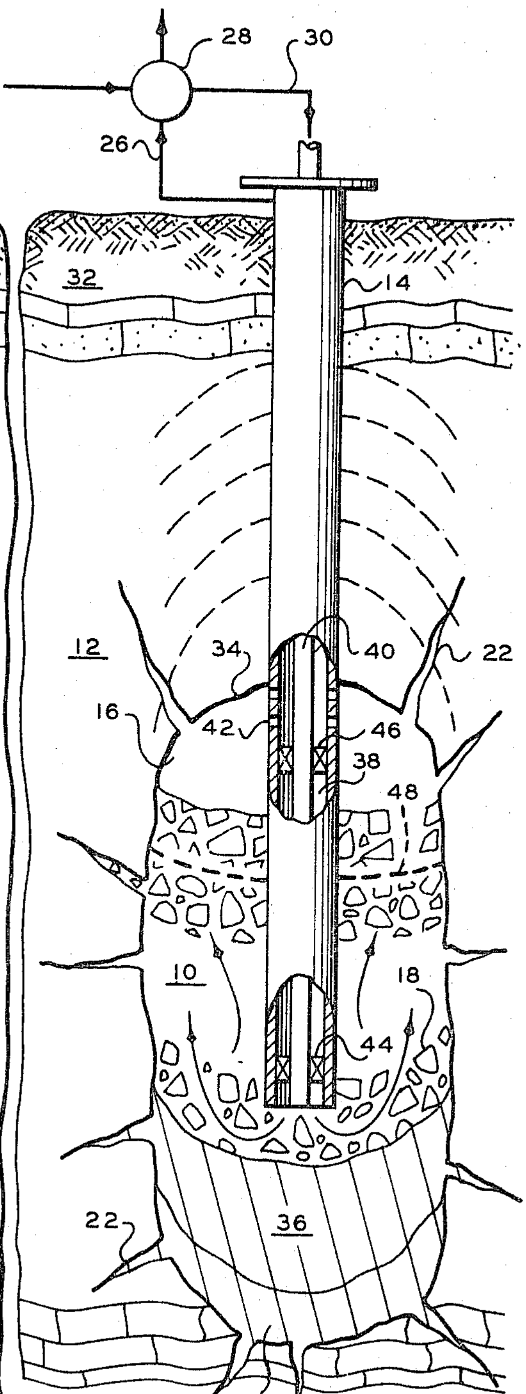

FIG. 2

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RECOVERING OIL FROM NUCLEAR CHIMNEYS IN OIL-YIELDING SOLIDS

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ABSTRACT OF THE DISCLOSURE

Air or other oxygen containing gas is injected into the lower portion of a previously retorted nuclear chimney to burn coke and raise the temperature therein to a level at which the compressive strength of the shale rubble is substantially reduced. Reduction of the compressive strength of the shale results in compaction of the spent shale and consequent loss of support of the roof of the chimney, causing sloughing of raw shale onto the retorted mass where it is then retorted by hot combustion gases rising through the rubble.

This invention relates to a process for the in situ production of hydrocarbons from oil-yielding solids. In one aspect, the invention relates to compacting the rubble contained in a fractured mass produced by an underground nuclear detonation.

The in situ retorting of shattered or broken oil-yielding solids, such as oil shale, in nuclear chimneys resulting from the detonation of a nuclear device in the oil shale is discussed by M. A. Lekas and N. C. Carpenter in an article entitled "Fracturing Oil Shale With Nuclear Explosives for In Situ Retorting" presented in the Quarterly of the Colorado School of Mines, volume 60, No. 3, July 1965, pp. 7–30. The nuclear chimney in an oil shale is a highly permeable mass of broken and displaced shale ranging in size from blocks 2 to 3 feet across to sand sized grains. A 250 kiloton explosive device set off in a thick shale formation is estimated to create a collapsed chimney 400 feet in diameter and 1,000 feet high. The permeability of the chimney shale makes it feasible to produce oil therefrom in situ with hot gases at a temperature of 500 to 1,000° F. or by in situ combustion of a portion of the shale oil or kerogen in the shale and driving out another portion with the resulting heat and hot gases.

The invention provides for additional hydrocarbon recovery in such an in situ retorting process by subjecting the spent or retorted shale to heat so that it is compacted. Compaction results in the loss of support for the roof of the chimney and consequent sloughing off of the raw shale onto the mass of spent shale rubble. The heat necessary for compaction of spent shale and for the destructive distillation of raw shale is obtained by burning the carbonaceous residue of the spent shale. The invention utilizes the sloughing characteristics of unsupported rock to feed raw shale to the retorting chamber or spent shale mass rather than relying upon the more expensive hydraulics or explosives known in the prior art. In addition to oil shale, the invention is applicable to oil-yielding solids including tar sands, oil sands, lignite, coal and other like kerogen-containing materials.

Accordingly it is an object of the invention to provide an improved method for in situ retorting and producing hydrocarbons from oil-yielding solids.

Another object of the invention is to increase the yield of an in situ nuclear chimney retorting method.

Another object of the invention is to reduce the costs of recovering oil from an oil-yielding solid in situ.

These and other objects will be apparent to one skilled in the art upon the consideration of the specification, drawings and appended claims.

According to the invention, there is provided a method or recovering hydrocarbons from an oil-yielding solid, utilizing a nuclear chimney containing a mass of the solids as rubble which has been previously retorted, the chimney having a first bore hole communicating with its lower portion and a second bore hole communicating with its uppermost portion, comprising injecting an oxygen-containing gas, such as air, through the first bore hole into the lower portion of the chimney to burn the coke and residual hydrocarbons contained therein, the oxygen-containing gas being injected in an amount sufficient to raise the temperature in the lower portion to a level at which the compressive strength of the particular retorted solid is substantially reduced to a value at which the weight of the overlying rubble mass causes compaction of the portion and consequent sloughing of raw shale which is in place above the chimney onto the mass of spent rubble. Hot gases, resulting from the combustion and decomposition of constituents in the solids pass upwardly through the previously retorted or spent solids and then through the newly created (sloughed) raw rubble to educe and distill hydrocarbons therefrom. The hydrocarbons, in vapor and/or liquid state, and the hot gases are recovered through the second bore hole and separated in conventional surface equipment.

Further, in accordance with the invention, as the burned solids compact and the rubble mass settles, the oxygen-containing gas is injected into that portion immediately above the burned compacted zone so as to burn and reduce the compressive strength of the spent rubble located therein, causing compaction of this portion and caving more raw shale from the roof of the chimney which is then retorted. The air injection progresses upwardly in the mass of rubble until there is no longer enough mass above the burn zone to provide the force for compaction of the burned rubble or to a point where the roof of the chimney has been caved to the upper limits of the oil-yielding stratum.

In one embodiment, air or other oxygen-containing gas is injected in a quantity sufficient to melt the solids or a portion thereof so that the mass has practically no compressive strength. When this embodiment is employed in oil shale, temperatures of about 2,200° F. are sufficient for fusion of the shale into a molten slag. When utilizing temperatures of this magnitude, the oxygen-containing gas can be injected above the lowermost portion of the rubble mass so that the molten material can flow downwardly and fill the void spaces of the lowermost portion of the rubble mass.

Burning at these high temperatures results in a loss of weight, consequently mass, in addition to lowering the compressive strength. The rubble mass has void spaces and as the compressive strength is reduced the weight of the overlying mass crushes the burned solids so that they flow into or take up this void space thus the settling is not a result of the loss of compressive strength of the material alone, but is an effect of the combination of decomposition and loss of material to gas flow, the filling of void spaces present in the rubble mass, and the reduction in compressive strength.

The temperature necessary to decompose constituents in the solid material and to reduce compressive strength is of course a function of the composition of the particular solid. These factors can be easily determined by simple laboratory tests, defining the temperature parameters necessary to obtain compaction of an underground rubble mass of the material. One method is to heat cores of the material to various temperatures for various time periods and use a hydraulic compression tester to determine compressive strength.

Referring now to the drawings, wherein like reference numerals will be used to denote like elements in the different figures, the invention will be described in detail.

In FIGURE 1, a previously-retorted nuclear chimney **10** in an oil shale stratum **12** is provided with a central bore hole **14** which communicates with the void space **16** formed by a settling of the shale rubble **18** after detonation of a nuclear device. Previous retorting of the chimney can be accomplished by recovery methods known in the art such as in situ combustion, steam injection or hot gas injection. The nuclear device will generally be detonated in the lower portion of the shale stratum **12** in order to have sufficient cover to prevent surface contamination and venting of radioactive products of the blast. The table below illustrates the characteristics of a typical nuclear chimney.

Chimney characteristics for a 50-kiloton nuclear explosion at 3,000 feet

Radius	ft	133
Height	ft	655
Bulk porsity (fractional)		.267
Void volume	cu. ft	9.85×10^6
Total volume	cu. ft	36.90×10^6
Oil shale rubble volume	cu. ft	27.05×10^6
Oil shale rubble mass	tons	1.86×10^6
Volume shale oil (Kerogen) contained in rubble (assumed 25 gal./ton)	bbls	1.10×10^6

The nuclear blast forming the mass of rubble **18** also creates a solidified melt zone **20** in the bottom of the chimney and fissures or fractures **22** which extend radially outwardly from the chimney.

There is also provided a bore hole **24** communicating with the lower portion of the rubble mass **18**. If desired a plurality of bore holes, such as **24**, can be provided in a ring pattern around the chimney for air injection. A product recovery conduit **26** is connected between the well head of bore hole **14** and a heat exchanger **28**. An air injection conduit **30** is connected between the heat exchanger **28** and the well head of bore hole **24**. The overburden stratum **32** contains substantially no oil-yielding solids. For the sake of clarity in the drawing, auxiliary surface equipment such as condensers, separators and compressors have been omitted.

In the embodiment of the invention illustrated in FIGURE 1, an oxygen-containing gas, such as air, preheated by heat exchange with produced gases in heat exchanger **28** is passed via conduit **30** and injected through bore hole **24** into the lower portion of the mass of spent shale rubble in chimney **18**. The spent shale contains coke and a substantial amount of hydrocarbons, since most retorting methods recover only about 70 percent of the Fisher Assay of the oil-yielding solids. The spent shale is at a relatively high temperature for example 400–700° F. because of the previous retorting operation. Upon injection of hot oxygen-containing gas, combustion of the coke and remaining hydrocarbon results. The oxygen-containing gas is injected in an amount sufficient to raise the temperature of the shale rubble to above 1550° F. At this temperature and above there is a significant alteration in the structure of the solids, loss of mass, and loss of compressive strength. For example, when 30 gallon per ton oil shale having a compressive strength of about 12,000 p.s.i. is heated to about 1550° F., its compressive strength is reduced to less than 125 p.s.i. The mass of spent rubble above the burned portion exerts about 1 p.s.i. per foot of depth, therefore when rubble is heated to about 1550° F. at any depth more than 125 feet below the top of the rubble mass, compaction occurs. In addition, as the larger fragments of spent rubble are crushed and compressed, they provide material which is sized to fill a portion of the void spaces in the rubble mass. As shown in the table, these void spaces account for approximately ¼ of the original chimney volume.

By injecting air and raising the temperature of the shale rubble to about 2200° F., there will be formed a molten slag of material which completely utilizes the void spaces for volume reduction and may dissipate to a small extent into the fractures **22** formed by the original nuclear detonation.

In FIGURE 1 the spent nuclear chimney is illustrated in the initial stage of air injection and burning. As the temperature increases, causing compaction and settling of the mass of rubble, the roof **34** and upper portion of the side walls of the chimney are left unsupported and will slough onto the top of rubble **18** filling void space **16**. The hot combustion and decomposition gases which result from the high temperature burning in the lower portion rise upwardly through the rubble mass and rapidly heat the mass of raw shale sloughed from the roof to educe hydrocarbons therefrom. The educed hydrocarbons will be mostly in vapor form because of the high temperature eduction and distillation. The process is especially advantageous because of this rapid high temperature retorting yields large quantities of olefinic and aromatic hydrocarbons which are more valuable than normal shale oil. The hydrocarbons and heating gases are recovered through bore hole **14** at relatively high temperatures, for example 500–900° F., and pass via conduit **26** through heat exchanger **28** to heat the injection air. From heat exchanger **28** the product vapors are passed to various separation and processing steps.

When the burned portion in the lower levels of the chimney has been maintained at the desired temperature level (from about 1550 to over 2200° F.) for a time sufficient to compact the solids air is injected into the rubble above the burned compacted portion by directionally drilling another well or by perforating and fracturing a zone at the desired level so that communication is established with the fractures **22** allowing air to be injected therethrough.

The air injection and burning are established progressively vertically through the spent shale mass, creating more compaction and extending the roof of the chimney upwardly (as shown by the broken lines) through the stratum until all the shale which was in place over the original spent chimney has been retorted. Upon completion of the process and recovery of all available hydrocarbons, there exists a large body of hot or molten shale, into which fluids such as water can be injected to recover the heat.

Referring to FIGURE 2, another embodiment is illustrated and the process of the invention is shown in a more advanced stage. Bore hole **14** extends into chimney **10** penetrating rubble **18** to just above melt zone **36**, which forms from the burned molten shale. Bore hole **14** is provided with a casing **38** and a tubing string **40**. The casing **38** has a perforated section **42** at the level of void space **16** and has packers **44** and **46** to seal the annular space between the casing and the tubing.

In accordance with this embodiment of the invention, preheated air is injected through tubing string **40** into rubble mass **18** thus burning the mass to produce the molten or semimolten zone **36** and cause settling of the rubble. The top of the original spent rubble mass in chimney **10** is shown by line **48**. The raw shale rubble created by sloughing of roof **34** shown above line **48** is retorted by the hot gases rising through the mass. The use of high temperature gases in retorting the shale has the additional advantage of heating roof **34**. The raw shale has a temperature of approximately 140° F. in place and when subjected to hot vapors at from 500–900° F., the raw shale expands thus assisting in sloughing material from roof **34**.

The produced hydrocarbons and gases are recovered through perforated section **42** of casing **38**, flowing up the annulus and via conduit **26** to heat exchanger **28**. Packer **46** prevents the backflow of produced gases into the burn zone.

The high temperature burn zone is progressed upwardly through rubble **18** by raising of packer **44** and perforating casing **38** at the level desired for air injection. As roof **34** sloughs in filling void space **16** packer **46** is raised and new perforations are made to allow for ingress of gases from the newly formed void space.

The temperature range of 1550 to 2200° F., as set forth in this specification, is applicable to oil shales. Other oil-yielding solids, to which the invention is applicable, will show the necessary loss in compressive strengths at different temperatures depending upon their particular composition. These temperatures can be determined by simple laboratory testing of the solids at various temperatures.

Reasonable modification and variation are within the scope of the invention which sets forth a novel in situ method of recovering hydrocarbons from oil-yielding solids.

That which is claimed is:

1. A process for recovering additional hydrocarbons from rubble contained in, and oil-yielding shale surrounding, a previously retorted nuclear chimney formed in a mass of oil-yielding shale, said rubble having been previously retorted under conditions to leave a spent shale having a coke and carbonaceous residue therein, which process comprises, in combination, the steps of:

injecting a free oxygen-containing gas into the lower portion of said previously retorted chimney to initiate and maintain a combustion zone burning coke and residual hydrocarbons in the carbonaceous residue contained in said previously retorted rubble therein, said oxygen-containing gas injection being in an amount and for a period of time sufficient to increase the temperature in said lower portion of the chimney to at least about 1550° F. at which there is a significant alteration in the structure of, loss of mass from, and loss of compressive strength of said rubble in said chimney, the compressive strength of said heated rubble being substantially reduced to the point at which the weight of the rubble mass above said heated lower portion causes compaction of said lower portion of rubble and consequent sloughing of raw oil-yielding solids which are in place above said chimney onto said mass of rubble originally remaining in said chimney subsequent to said previous retorting;

passing combustion and decomposition gases resulting from said burning of said previously retorted rubble upwardly through said sloughed solids to heat and reduce hydrocarbons from said sloughed solids; and

recovering said hydrocarbons and gases from the uppermost portion of said chimney.

2. The process of claim **1** wherein said nuclear chimney has a first bore hole communicating with its lower portion and a second bore hole communicating with its uppermost portion, said oxygen-containing gas being injected through said first bore hole and said hydrocarbons and gas being recovered through said second bore hole.

3. The process of claim **1** wherein:

said nuclear chimney has an axial bore hole extending into the lower portion thereof, said bore hole having a casing and tubing string contained within the casing, said casing being perforated above the rubble mass in said chimney and having a packer below said perforations sealing the annular space between said casing and said tubing;

said oxygen-containing gas being injected through said tubing string; and

said hydrocarbons and gases being recovered through said perforations and the annulus of said casing.

4. The process of claim **1** wherein said combustion zone is progressed upwardly in said nuclear chimney after compacting said lower portion by injecting oxygen-containing gas at successively higher levels in said rubble mass.

5. The process of claim **1** wherein said temperature is within the range of 1550 to 2200° F.

6. The process of claim **1** wherein said temperature is above 1550° F.

7. The process of claim **1** wherein said recovered hydrocarbons and gases are passed in heat exchange with said oxygen-containing gas prior to injection.

No references cited.

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166—272; 176—39