

[54] **METHOD OF PYROLYSIS OF COAL IN SITU**

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[22] Filed: **Apr. 23, 1975**

[21] Appl. No.: **570,714**

[52] U.S. Cl. **166/258; 166/259; 166/295; 166/302**

[51] Int. Cl.².....**E21B 33/138; E21B 43/24; E21B 43/26**

[58] Field of Search **166/256, 258, 259, 272, 166/288, 295, 302; 299/3, 6, 14**

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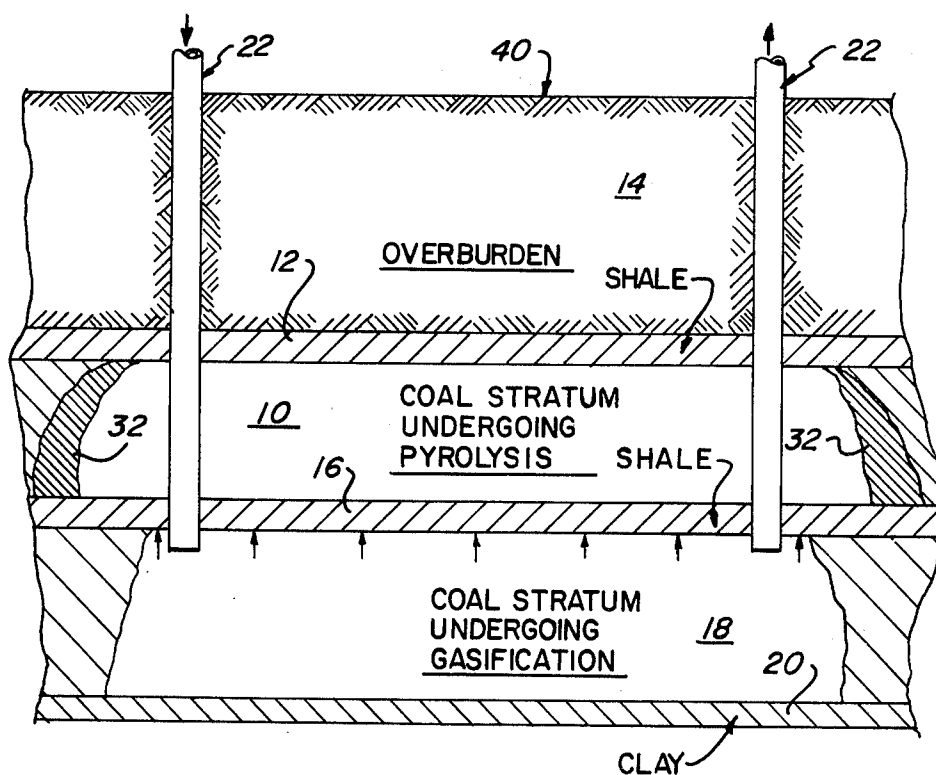
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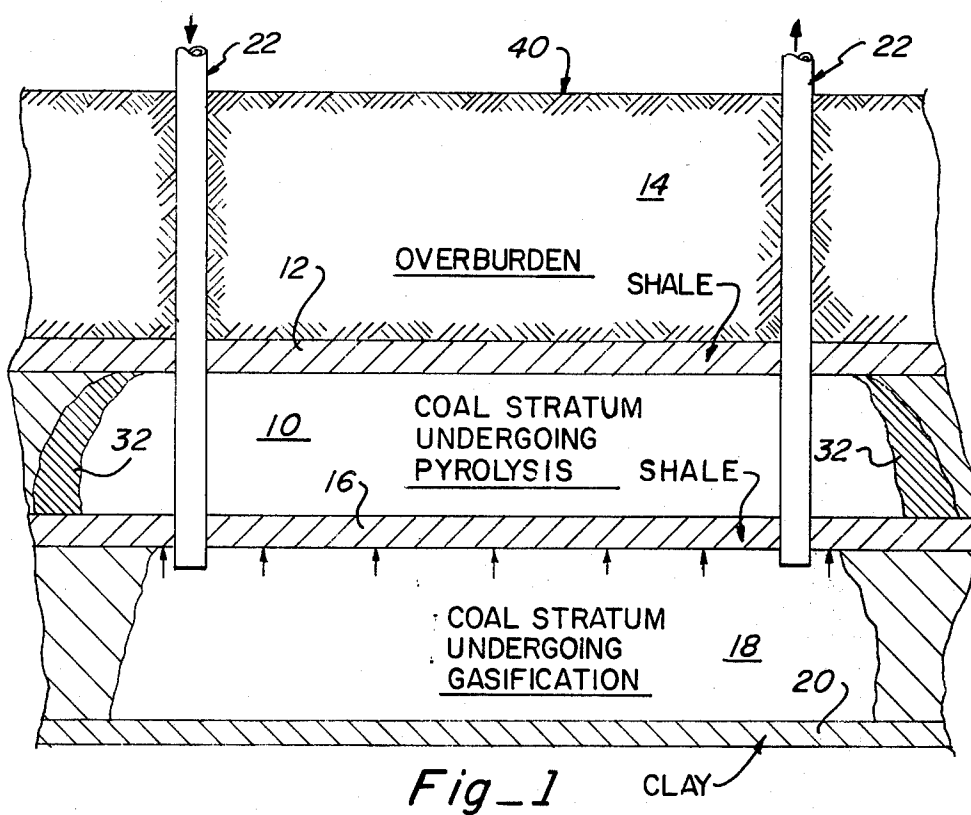
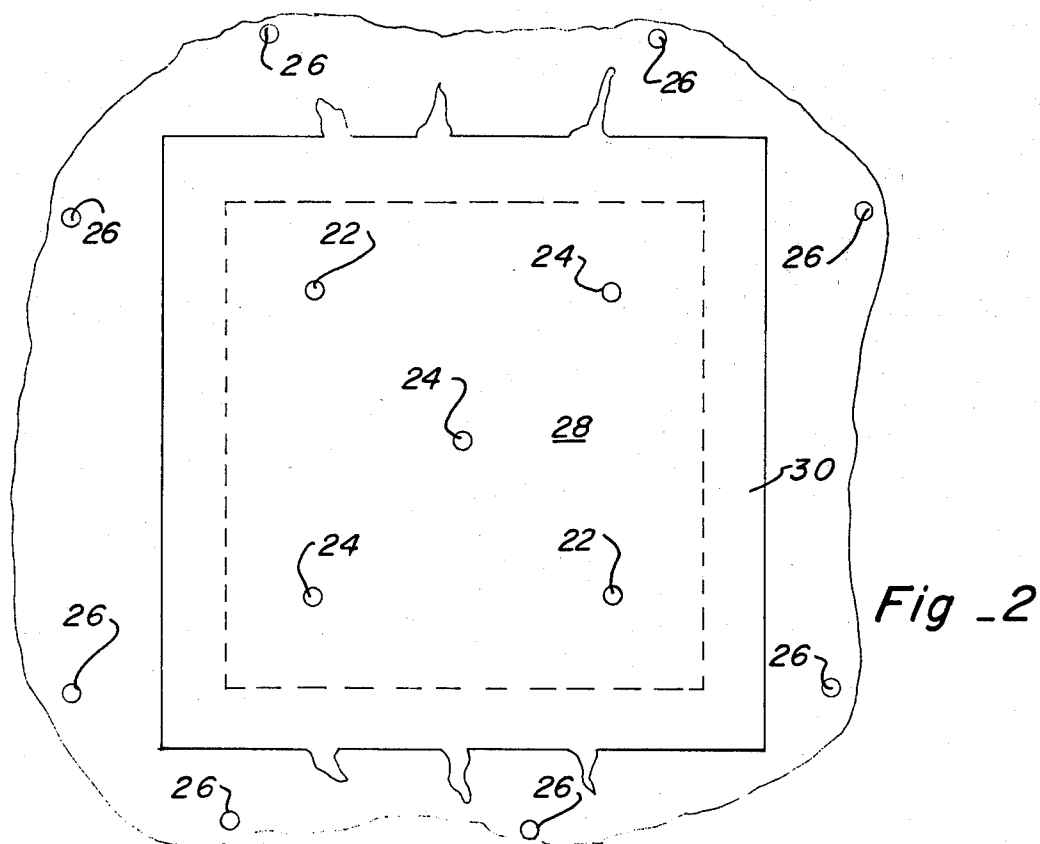
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[57] **ABSTRACT**

A method of pyrolysis of coal in situ includes the steps of establishing a pair of passages between a sub-surface coal formation and the surface with the coal passages being adapted to separately remove liquids and gases from the coal formation, establishing a sump at the bottom of the passages which extends at least partially below the coal formation to receive liquid volatile material released from the formation, and heating the coal formation so that initially tars in the formation will migrate radially until they go beyond the heated area whereupon they will solidify and form a hermetic barrier around the zone to be pyrolyzed to confine gaseous liquid volatile materials released from the coal as a result of the pyrolysis. The released gaseous materials can then flow to the surface through one of the passages and the liquid volatile material can flow into the sump and be pumped to the surface through the other passage.

8 Claims, 3 Drawing Figures





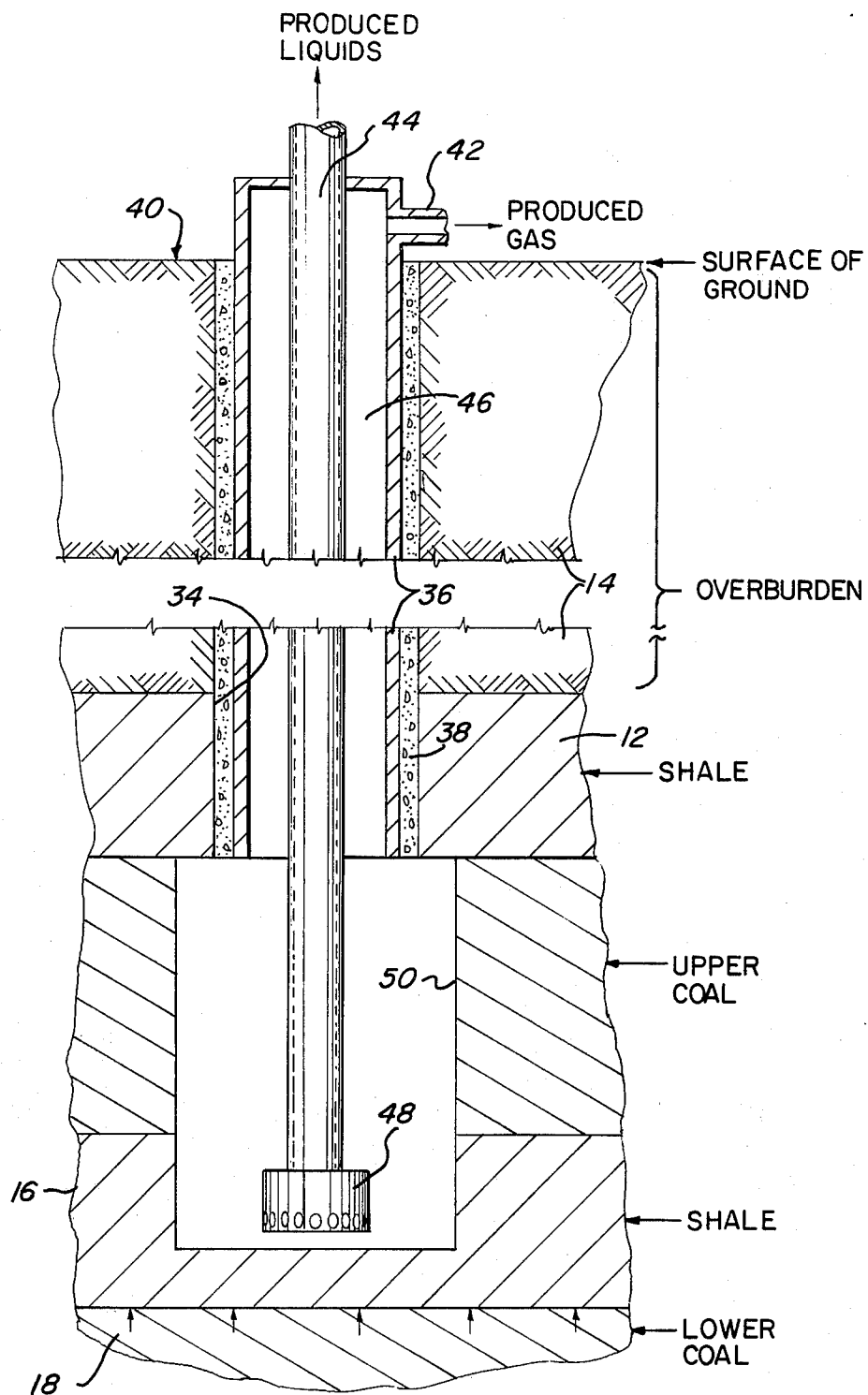


Fig-3

METHOD OF PYROLYSIS OF COAL IN SITU

BACKGROUND OF THE INVENTION

Coal is a complex material made up of hardy residuals from vegetation that grew and died in ancient times. With the multiplicity of vegetation sources, coupled with ensuing variations in physical and chemical environments, coal is far from being a uniform material. In the evolution of coal through geological time, each deposit has been subjected to chemical action, submergence, pressure from the over burden, and heat. As a result, the physical and chemical characteristics show wide variations from deposit to deposit.

Generally the composition and characteristics of coal can be described as relative amounts of moisture, volatiles, fixed carbon and ash. For the most part, the moisture and ash contents are considered to be nuisances while the volatiles and fixed carbons are considered to be useful materials.

Coal has been produced for many centuries for the benefit of mankind. Almost without exception, coal has been removed from its underground site and then transported to various points of use. In the removal process, both nuisance components and useful components are extracted together and are transported together to the points of use. While it is highly desirable to leave moisture and ash contents behind, commercial techniques for doing so are, at best, successful only to a minor degree. Further, extraction techniques beginning with the principle of the primitive pick and shovel have not been improved upon, although significant improvements have been made in mechanization of the pick and shovel concept.

With the wide variations in the characteristics of coal from deposit to deposit, it becomes necessary to begin with the planned end use for the coal in order to determine which deposit is a suitable candidate for mining. For example, if the planned end use is to make coke for the smelting of iron ore, then the virgin coal must have desired coking characteristics. That is to say, the virgin coal, when heated to high temperature with air excluded, must give up its moisture content and a substantial amount of its volatile content, and still retain sufficient mechanical strength to withstand the rough handling inherent in the smelting process. Further, a ready market must be available at the coking site for the valuable coal chemicals that are present in the volatiles that are removed in the coking process. The problem of selecting a suitable coal for coking is further complicated by the fact that one of the nuisances, the ash or mineral content of the coal, is retained in the coke which later becomes an additive to waste slag in the blast furnace. It is obvious that the selected coal deposits should be in reasonable proximity of the end use facilities because the cost of transporting the nuisance components can place a significant cost disadvantage against the overall project.

Some coals are unusually rich in volatile content and thus are attractive for the extraction of valuable coal chemicals. After mining the coal and removal to proper facilities, the volatiles can be removed by the application of heat in an environment that excludes air, resulting in extraction of volatiles in liquid and gaseous forms. The residue is coke (or for non-coking coal, char) and the retained ash content. Since the residue is a substantial portion of the original coal, commercial practices dictate that a suitable market be found for the

coke or char. The problem of disposal of the nuisance ash then is passed on to the user of the coke or char. Again, the mine, coal chemical extraction plant, and the market for coke or char must be in reasonable proximity of each other to offset the cost of transportation and disposal of the ash. In this case, the second nuisance, moisture content, is largely extracted at the time the coal chemicals are removed.

Heretofore, most pyrolysis of coal has required mining the coal, using strip mining or underground mining techniques. The coal is then processed above ground to remove as much debris as practical and to crush the coal to appropriate sizes. The coal is then transported to and placed in a suitable retorting vessel so that heat may be applied in the absence of air to drive off the volatile matter in gaseous and liquid form. After the volatiles are substantially removed, the retort chamber and the residual coke or char is removed. Since the residual coke or char is well above the ignition temperature, care must be taken to cool the residual coke or char rapidly to keep it from bursting into flame upon being exposed to air. Such a process of necessity, is composed of many costly steps of handling, requires many different items of equipment and facilities, and requires substantial numbers of employees (some of whom are located underground) to conduct and control operations. Each of the steps in the process, tend to be a batch operation in itself, resulting in numerous start-stop operations. It is for these reasons that coal chemicals have had difficulties in competing with chemicals from petroleum because chemicals from petroleum can be produced in a series of continuous processes from the crude oil reservoir to finished products.

As will be appreciated from the description of the invention hereinafter, the processes for producing chemicals from coal in accordance with the present invention are continuous in principle, are competitive with chemicals from petroleum, require no man power underground, and require substantially less costly equipment at the surface than is required for conventional pyrolysis of coal. Chemicals to be recovered from coal in situ in accordance with the invention include Benzene (C_6H_6), Toluene (C_7H_8), Xylene (C_8H_{10}), Naphthalene ($C_{10}H_8$), Anthracene ($C_{14}H_{10}$), Phenol (C_6H_5OH), Cresols (C_7H_7OH), Pyridene (C_5H_5N), Methanol (CH_3OH), and others.

The processes to be described hereinafter result in the production of coal somewhat analogous to the primary production of petroleum. If the coal to be produced contains 30 percent volatile matter, for example, than approximately 20 percent of the coal in place will be produced as a fluid using the processes of the invention. Such production compares favorably with normal primary production of crude oil. Upon completion of production using the processes described herein, the residual carbonized coal can be further produced using one or more of the processes taught in my copending patent applications Ser. Nos. 510,409 and 531,453.

OBJECTS OF THE INVENTION

It is an object of the present invention to provide a new and improved process for removing coal chemicals from coal in situ, thereby eliminating mining of the coal itself in the conventional sense and eliminating costly surface facilities for the handling of coal through a pyrolysis process.

It is another object of the present invention to provide a new and improved process for removing coal chemicals from coal in situ whereby the coke or char as well as the ash is left in situ.

It is another object of the present invention to provide a new and improved process for pyrolyzing coal in situ which includes the step of defining an underground pyrolyzing zone with a barrier of fluid impervious material.

SUMMARY OF THE INVENTION

All coal has some degree of permeability and thus will permit the passage of fluids along channels of permeability. If the fluid is a gas, the fluid can be made to migrate under the influence of differential pressure within the coal. Such a gas will move from a higher pressure zone to a lower pressure zone and if the lower pressure zone is connected to a conduit to the surface, the gas can be delivered to the surface for processing. If the fluid is a liquid, likewise the liquid can be made to migrate under the influence of differential pressure or by gravity or by a lower pressure zone or lower gravitational zone. If the zone of lower pressure or lower gravitation, such as a sump, is connected to a conduit to the surface, the liquid can be delivered to the surface by differential pressure, gas lift or by pumps for further processing or use.

Pyrolyzing or applying heat to coal results in the separation of the volatile matter from the carbonized coal. Beginning at ambient temperature, and with the application of heat in the absence of air, the coal begins to expand, and entrained gases are expelled, and at a temperature range above 100°C (212°F), the coal gives up its entrained moisture content by evaporation or by flashing to steam, resulting in the build up of formation pressure. A conduit or conduits to the surface can relieve this pressure and deliver steam to the surface. Initially the steam will encounter cooler zones in the coal stratum and will condense into water. When the total coal stratum is heated to a temperature above the boiling point of water, released moisture may be removed to the surface as steam.

Further application of heat to the coal stratum, for example up to 200°C (392°F) will result in the oozing of tars from the coal which initially are quite viscous and for all practical purposes, immobile. As more heat is added to the coal stratum, the oozing tars become less and less viscous and will flow under the influence of gravity and differential mine pressure. Further applications of heat, for example up to 300°C (572°F) cause some of the volatiles to vaporize into condensable gases. Still further applications of heat will induce thermal cracking of the volatiles resulting in both condensable and noncondensable gases as measured at normal atmospheric temperatures. Without relief, considerable internal pressure will be generated in the coal strata. A suitable conduit to the surface, of course, can release the pressure in the pyrolysis zone to the desired pressure level and serve as a passage for the flow of produced fluids.

In order to facilitate a better understanding of the present invention, it will be described in connection with a multilayered coal deposit, such as commonly found in the western part of the United States. These deposits are a series of coal strata separated from each other by relatively thin sections of shale. The stratum of coal affected by the present invention is immediately above a thin shale stratum which overlies another coal

stratum that is being gasified. The gasification may be carried out in accordance with one or more of the processes set forth in my copending applications, Ser. Nos. 510,409 and 531,453. Waste heat from the lower stratum being gasified is slowly released through the overlying shale to the upper coal stratum resting on the shale. Much of the waste heat lost from the gasification project is captured in the processes described herein for further useful work.

In a commercial project employing the processes described herein, the areal extent of the coal stratum affected can encompass several acres, for example 20 acres, that generally correspond to the areal extent of the heat source which can be an underlying coal formation subjected to in situ gasification. On the periphery of the coal stratum to be subject to pyrolysis, there is a transition zone between the coal that has been heated and the outlying coal that is at ambient temperature. In the initial stages of pyrolysis, released fluids will escape from the affected zone into the outlying stratum of coal. Hot tars migrating radially will enter the transition zone, become cooled and immobile, will plug the natural permeability of the coal that is being invaded, and will form a pressure tight barrier in the transition zone. If there are insufficient tars to provide a good seal, then a hot thermosetting sealant can be injected from the surface into the coal stratum to establish the barrier. This barrier seals an area of several acres that may now be subjected to further pyrolysis, with production efficiencies approaching, and sometimes exceeding, that of retorts above ground. Attributes that are particularly advantageous to production efficiencies include use of waste heat and the substantially lower capital investment required.

Two factors are of particular importance in the early stages of a pyrolysis project underground. These are the water content and the permeability patterns of the underground coal stratum. If the coal stratum is an aquifer it may be highly desirable to provide facilities to dewater the coal and to control the ingress of additional water. Upon application of heat to the formation, the change of water to steam through the latent heat of vaporization is highly endothermic, and thus will absorb enormous quantities of heat for no useful purpose other than to make steam. The problem of water encroachment is eliminated when the transition zone barrier is established.

It is advantageous to know the patterns of underground permeability in order to locate a pattern of conduits to the surface for efficient production. Patterns of permeability can be determined satisfactorily by taking a series of oriented cores through the coal stratum. In cases where permeability is poor, additional permeability can be obtained using fracturing techniques well known in the petroleum industry.

Another method of increasing permeability is the technique of electrolinking. Coal is a reasonably good conductor of electricity with a resistance on the order of 1 ohm for each 10 lineal feet. By placing two electrodes in the coal stratum, some distance apart, for example 200 feet, and passing an electric current between the two electrodes, electrolinking will occur. The electric current will flow along the path of least resistance between the two electrodes. This path will be something other than a straight line and a continuing flow of an electrical current will increase the temperature of the coal along this path. When the temperature in the path reaches a sufficient level, for example

750°F, the coal begins to release gases and a permeable channel is established for the flow of fluids. Repetition of this technique between numerous points in the coal deposit can open a significant number of permeable fluid channels.

After the coal formation to be pyrolyzed has been conditioned as by the removal of water and the preliminary heating of the formation resulting in the establishment of a suitable fluid impervious barrier around the pyrolysis zone, the heat such as may be supplied by an underlying burning coal formation is allowed to separate the volatile materials in the coal from the carbonized coal with the gaseous volatiles being allowed to escape to the surface through a passage provided therefor and the liquid volatiles being allowed to flow into a sump from which a pump can convey the liquid volatiles to the surface.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic vertical section taken through a portion of the earth illustrating the geologic relationship of the coal zone to be pyrolyzed with a lower coal zone being gasified.

FIG. 2 is a diagrammatic plan view illustrating a possible well pattern for use in practicing the method of the present invention.

FIG. 3 is a diagrammatic vertical section taken through a well and surrounding subsurface formation, the well being designed for use in the method of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. 1, a geologic condition ideal for practicing the method of the present invention is illustrated. It will there be seen that the coal stratum or formation 10 to be pyrolyzed is situated beneath a thin shale zone 12 which lies immediately beneath what will be termed the overburden 14 and above a second thin shale zone 16 which overlies a second or lower coal stratum 18. The lower coal stratum 18 overlies a bed of clay 20 or the like defining the lower limit of the lower coal stratum. Also illustrated in FIG. 1 are a pair of wells 22 which establish passages of communication between the surface of the ground and the lower coal formation 18. These wells are used for the injection of gasifying agents and the removal of gases for in situ gasification of the lower coal stratum which may be carried out in accordance with the teachings in my copending United States patent applications Ser. Nos. 510,409 and 531,453.

The heat generated by the burning coal in the lower stratum or formation 18 during the gasification process is transmitted through the shale layer 16 separating the coal strata and supplies the heat for pyrolysis of the upper coal stratum 10.

Prior to the start of production activities, several wells 24 (FIGS. 2 and 3) may be drilled from the surface to the upper coal stratum and oriented cores taken through the coal to determine the permeability pattern. With permeability information thus derived, a proper pattern of production wells can be established to make maximum use of available permeability channels. If greater permeability is desired, it can be obtained by conventional oil field practices such as hydrofracking, explosive fracking, etc. or by electrolinking as described in the Summary of the Invention. Production of volatile liquids and gases through pyrolysis may be

obtained with a single production well 24, such as shown in FIG. 3, or with a multiplicity of wells located, possibly as shown in FIG. 2, on channels of maximum permeability in the coal stratum 10.

A further pre-production step would include testing the coal stratum 10 for its free water content. If the coal stratum 10 is an aquifer, then an outer group of service wells 26 may be drilled outside the pyrolysis zone 28 into the upper coal stratum to remove excess water. The water removal phase can be expedited by installing pumps in the service wells 26 and in the production wells 24 provided in the pyrolysis zone.

Removal of water is continued while the upper coal stratum 10 is heated by the underlying burning coal formation causing the liquid volatiles, such as tars, to migrate radially outwardly until they are slightly beyond the pyrolysis zone 28. Typically, the tars will begin to soften at about 500°F and will begin to migrate at about 800°F. The migration of tars can be effected by raising the formation pressure as occurs normally with the application of heat in the pyrolysis zone and/or lowering the pressure in the surrounding areas in a conventional manner via the service wells 26. Once the tars have migrated beyond the heated pyrolysis zone, the cooler temperatures, approximately 60°F to 80°F in a transition zone 30 allow the tars to solidify and form a fluid impervious barrier 32 around the pyrolysis zone. After the barrier 32 is established, the removal of water can be terminated as the pyrolysis zone will then be sealed off from encroaching water. A fluid impervious barrier could also be formed by injecting a thermo-setting sealant material into the formation and allowing it to radiate outwardly until it sets up in the formation.

A preferred embodiment of a production well 24 is illustrated in FIG. 3 and is established by drilling a bore 34 through the overburden 14, the upper shale layer 12 and the upper coal stratum 10. An hermetically sealed casing 36 is set in the well bore with the cement 38 from the top of the upper coal formation 10 to the surface 40. At the top of the casing, an exit conduit 42 is provided through which gases produced from pyrolysis can flow and valve means (not shown) are provided to control the flow of gases therethrough. A string of tubing 44 is positioned inside the casing 36 defining an annulus 46 in communication with the exit conduit 42 and a pump 48 is installed at the lower end of the tubing for the production of liquids from the pyrolysis zone. An enlarged cavity 50 is provided at the bottom of the well bore so as to extend at least partially into the shale formation 16 separating the upper and lower coal formation. This cavity may be formed by underreaming the well bore in a manner conventionally practiced in the petroleum industry. The cavity, which may extend for example, one foot into the shale, forms a sump for the collection of liquids. It is important that the sump be located in a hot area so that liquids will be kept hot and fluid for removal by the pump 48.

With the fluid impervious barrier 32 circumscribing the pyrolysis zone 28 and with at least one production well 24 established, the pyrolyzed upper coal formation 10 is ready for production. As more and more heat is applied to the shale stratum 16 by the underlying burning coal formation 18, the coal in the upper coal formation 10 continues to ooze tars which may be referred to as liquid volatiles. The liquid volatiles drain into the sump or cavity 50 where they are pumped to the surface by the pump 48. When the temperature in the sump reaches thermal cracking temperatures, for ex-

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ample 1,800°F., some of the liquid volatiles will be cracked to gases and may be removed through the annulus 46 and be produced with gaseous volatiles released during pyrolysis through the exit conduit 42 provided in the casing 36. Gaseous volatiles, such as methane, are of course released from the coal by the pyrolysis and flow directly through the annulus 46 to the exit conduit 42. The rate at which the gaseous volatiles are released, which is controlled by the valve (not shown) in the exit conduit 42, determines the pressure in the formation, thus allowing the pressure to be maintained at desired levels.

Produced fluids, both liquids and gas, may be processed at the surface after recovery in facilities (not shown) similar to those used conventionally in connection with above ground pyrolysis retorts with the valuable coal chemicals being separated into useful components such as benzene, anthracene, cresol, and the like. Production may be continued as described so long as the volatile matter is released in volumes of commercial value.

Although the present invention has been described with a certain degree of particularity, it is understood that the present disclosure has been made by way of example and that changes in details of structure may be made without departing from the spirit thereof.

What is claimed is:

1. A method of pyrolysis of coal in situ comprising the steps of:

establishing a hermetically sealed passage between a subsurface coal formation and a surface location wherein said passage includes means for removing both liquids and gases from the coal formation, heating at least a portion of the coal formation, driving fluid tars in the coal which are mobilized by the heat outwardly from the heated portion and allowing them to solidify in lower temperature portions of the coal formation to define a fluid impervious barrier around the heated portion, and allowing volatile material released from the heated coal to be removed through said passage and flow to a surface location.

2. The method of claim 1 further including the steps of:

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establishing a cavity in the coal formation in fluid communication with said passage, said cavity extending at least partially below the coal formation, and

pumping liquid volatile material released from the heated coal which has flowed into said cavity out of said cavity to a surface location.

3. The method of claim 2 further including the step of establishing two distinct passages between the coal formation and the surface whereby liquids and gases can be transferred separately from the coal formation to the surface.

4. The method of claim 3 further including the step of establishing fluid permeable channels in the coal formation to facilitate the flow of gaseous and liquid fluids released from the coal during pyrolysis.

5. The method of claim 2 wherein said cavity is established so as to be of a larger cross-sectional area than said passage.

6. The method of claim 1 wherein the coal formation is heated by burning a second coal formation beneath said first mentioned coal formation to supply heat to the first mentioned coal formation.

7. The method of claim 6 wherein the pressure in the coal formation zone defined by said barrier is controlled by relieving the pressure at the surface end of said passage.

8. A method of pyrolysis of coal in situ comprising the steps of:

establishing a hermetically sealed passage between a subsurface coal formation and a surface location wherein said passage includes means for removing both liquids and gases from the coal formation, heating at least a portion of the coal formation, injecting a thermo-setting sealant material into the formation through said passage and allowing the sealant to flow radially from the passage until it sets up to form a barrier around said portion of the formation, and

allowing gaseous volatile material released from the heated coal to be removed through said passage and flow to a surface location.

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