United States Patent [19]
Rhoades

[11] **3,775,073**
[45] **Nov. 27, 1973**

[54] **IN SITU GASIFICATION OF COAL BY GAS FRACTURING**

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[22] Filed: **Aug. 27, 1971**

[21] Appl. No.: **175,602**

Related U.S. Application Data

[62] Division of Ser. No. 50,790, June 29, 1970, abandoned.

[52] **U.S. Cl.** **48/210,** 48/DIG. 6, 166/256, 166/257, 166/259
[51] **Int. Cl.** **E21b 43/24,** E21b 43/26
[58] **Field of Search** .... 48/210, DIG. 6; 166/256, 257, 259; 299/2

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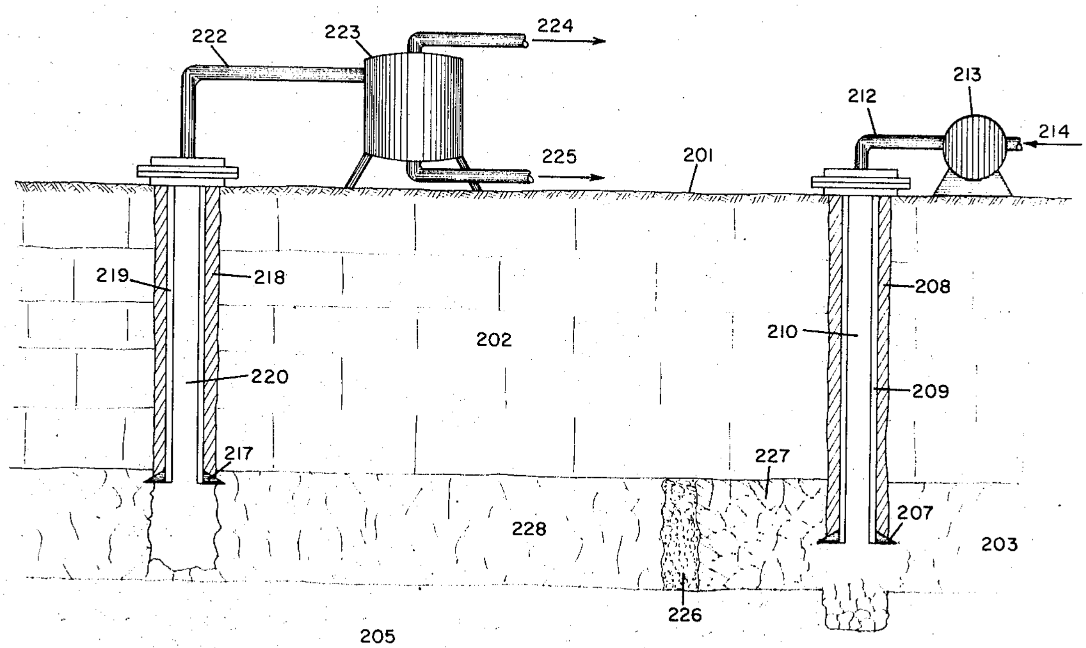
[57] **ABSTRACT**

Two or more wells are drilled into a coal seam. The wells are completed so as to isolate all other strata from the coal seam and a radially extended horizontal fracture is directed by introduction of a first combustion supporting gas under hydraulic pressure so as to connect the wells communitively. A horizontally and vertically directed fracture network is formed within the coal system by ignition of the first combustion supporting gas. A second combustion supporting gas is subsequently injected through at least one well to form a combustion front which may be propagated through the fracture network to produce combustible gases and coal tar liquids.

5 Claims, 2 Drawing Figures



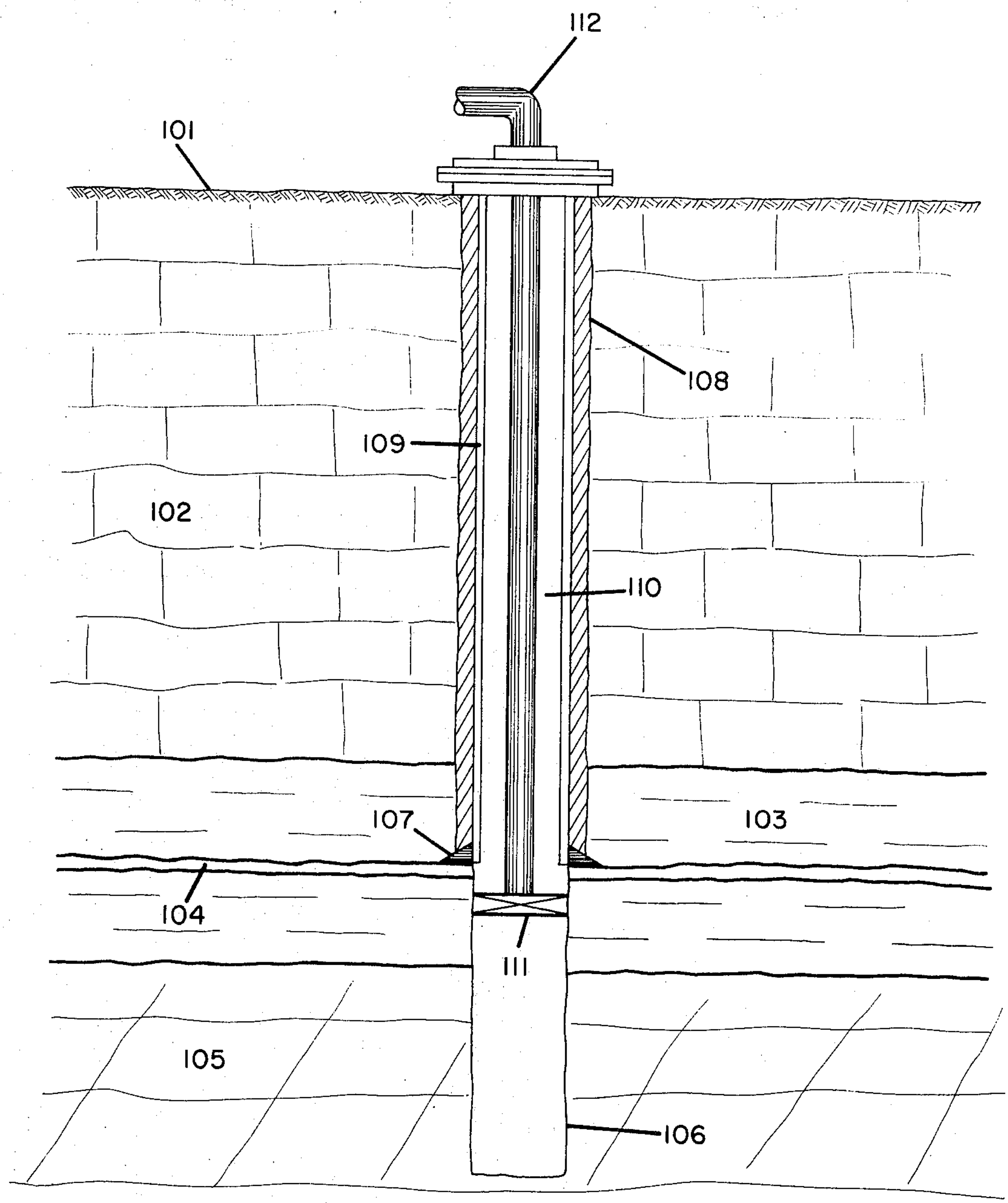


Fig. 1

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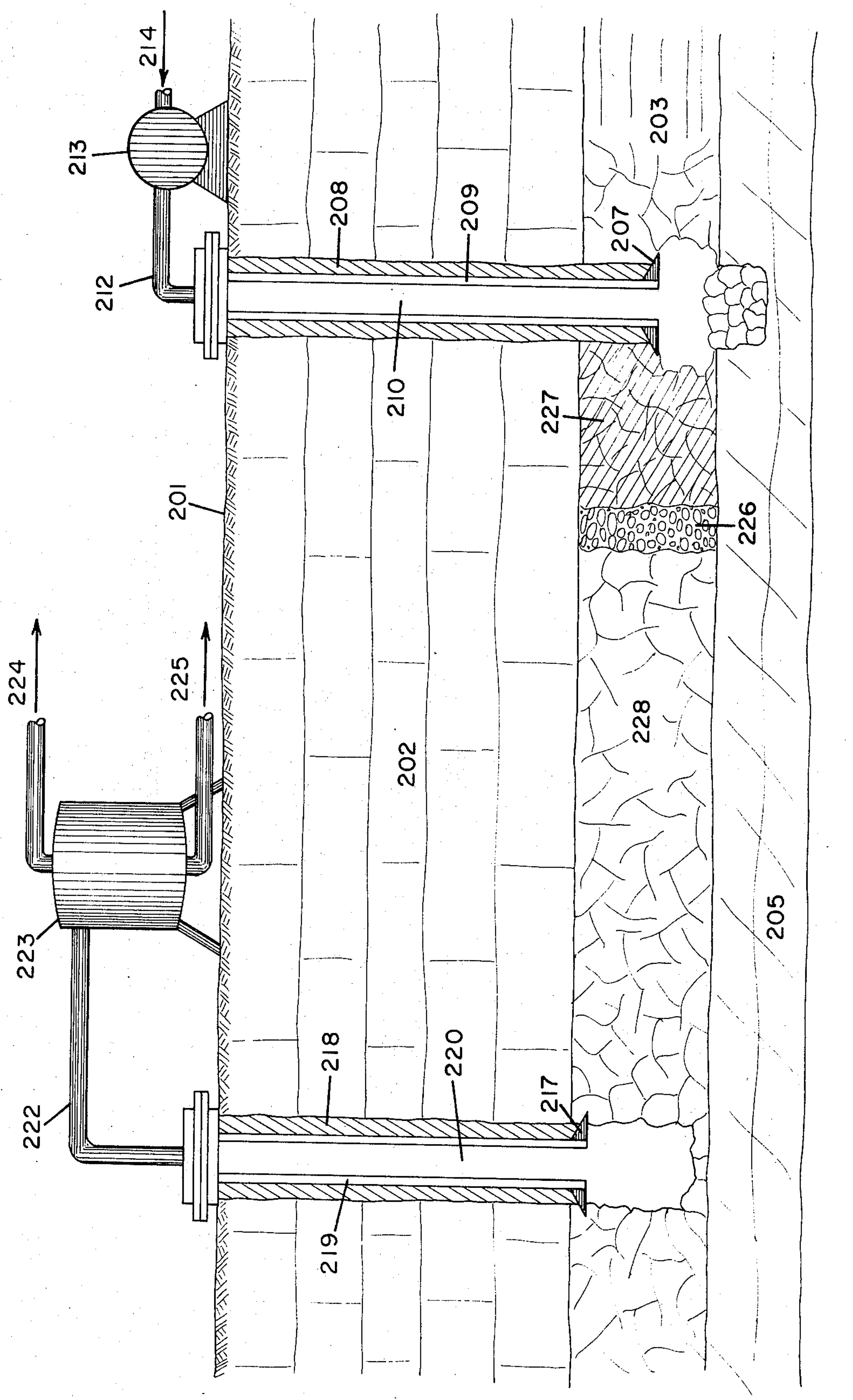

FIG. 2

IN SITU GASIFICATION OF COAL BY GAS FRACTURING

This is a division of application Ser. No. 50,790, filed June 29, 1970, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to the in situ combustion of a coal seam for the recovery of flammable gases and coal tar liquids. More particularly, it relates to a novel method for producing a fracture network through which combustion supporting gas and combustion products may pass during the in situ combustion of a coal seam.

The production of coal energy by the use of wells through underground mining has been a continual subject of interest in the field of energy production. Coal gasification by use of above ground retorting is an old art, one of the better known methods being the Lurgi process developed in Germany prior to World War II. By this method, oxygen and steam are simultaneously injected into a field retort and upon combustion a gas having a calorific value sufficient for commercial usage and coal tar liquids are produced.

The idea of underground gasification then is not new, however, many of the technological advances are. Efforts were mostly confined to the advancement of theory until substantial work and testing was done in Russia. Most of the Russian work involved considerable underground mining and construction in an effort to provide a passageway for air through the coal. Some efforts even involved breaking up the coal underground to provide adequate air passages. The amount of excavation encountered in this process is tremendous. The state of the art then progressed to drilling holes into the coal seam and charging with dynamite. As the burning front progressed through the stratum the charges were automatically set off in an effort to break up and crush the coal and render a segment of the bed more permeable. This resulted in irregularities too great to sustain continued gas flow and the gas produced contained large amounts of air, which considerably lowered the heating value of the produced gas. As this process is far too expensive and limited in scope, shaft and borehole mining combinations were devised which employed steeply sloping seams near outcrops. In addition to being limited exclusively to steeply pitched beds, this process also required a large amount of excavation and mining.

The chief problem, therefore, confronting the spectrum of investigators was the low gasification rate, that is, the rate of air injection which directly affects the amount of gas produced. Although a coal seam contains an appreciable amount of natural cracks and fissures, its overall permeability is quite low. This permeability is considerably below that which is necessary to sustain combustion at rates to be of commercial interest. Consequently, without expensive underground construction, the natural air passageways within the coal bed severely limit air injection. A major effort has been concentrated on methods of increasing air injection rates by shaftless methods. Electrocarbonization utilizing high pressure air injection is one of the methods which has been tested. One of the most promising techniques involves hydraulic fracturing of the coal bed, packing the fractures with sand, backward burning to establish better communication within the bed, then forward combustion to gasify the coal and release the combustible products. All of the tests proved uneconomic and unfeasible by present production standards and have been discontinued before being developed into a commercial process. What is required, then, is a process which may be implemented without utilizing previously used techniques of underground excavation and tunneling. Also required is a method by which air injection rates are not restricted due to low permeability of the coal, the restrictions of fluid flow in the fracture network, and the low permeability of the remaining unburned coal behind the combustion front.

It is an object of our invention, therefore, to provide a novel method for the combustion of underground coal structure.

It is another object of our invention to provide for a method by which a network of fractures created in a coal seam may be used to allow sufficient gas injection volumes to sustain combustion in a coal seam.

It is a further object of our invention to provide a method by which flammable gas and coal tar liquids are afforded a production path by the inducement of a fracture network within a coal seam.

With these and other objects in mind, the present invention will be set forth in further detail with particular reference to the following drawings and description.

SUMMARY OF THE INVENTION

The present invention comprises a method for the combustion of coal in subterranean deposits. In the method, two or more wells are completed within a coal deposit. A radially extended horizontal fracture is induced through the coal deposit so as to interconnect the wells.

The coal deposit is subjected to an excess of a first combustion supporting gas at a pressure greater than the overburden pressure so as to distribute the combustion supporting gas throughout the coal network. Subsequently, the coal deposit and first combustion supporting gas are ignited while simultaneously preventing any fluid or gas production from the coal deposit, so as to form a network of crumbled coal within the coal deposit. Continued injection of a second combustion supporting gas into one or more wells and production of combustible gas and coal tar liquids from one or more of the wells completes the process.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is hereinafter described in further detail with particular reference to the accompanying drawings in which:

FIG. 1 represents an injection well, as utilized in the present invention, completed within a subterranean coal deposit; and

FIG. 2 represents a cross-sectional view of a subterranean coal deposit with the process of the present invention applied thereto.

DETAILED DESCRIPTION OF THE INVENTION

The present invention describes a novel method for the production of combustible gases and coal tar liquids by the in situ combustion of a coal bed. The process comprises the completing of wells in a coal seam, creating a horizontal fracture in the coal seam to establish communication between the wells, igniting a first combustion supporting gas within the horizontal fracture so as to form a horizontal and vertical fractured network between the wells, injecting a second combustion supporting gas, propagating a combustion front through the coal about the injection well and recovering volatile liquids and combustible gases at the production well.

Each production well is completed in a manner so as to be in direct communication with a maximum portion of the coal bed. Casing is barely notched into the coal seam and cemented. The open or uncased hole extends to the bottom of the coal bed. The significant factor in this completion technique is that only the coal bed is left exposed at the producing wellbore. All other strata are cemented and sealed off from the producing wellbore in order that any production from the wells must come through the coal bed itself. Injection wells are cased and cemented to the center of the coal layer to enhance the fracturing operation. Configuration of injection and production wells is not a significant criteria of the present invention and therefore is not treated herein. Essentially, any well pattern combination with which horizontal communication between the wells may be effected may be utilized with the present invention. In addition, the completion technique used may consist of any of the various and sundry well isolation methods as long as the coal seam is left undamaged and remains isolated from the overburdened strata.

Formation of a horizontal fracture within the coal bed is an essential criterion of the invention for success of the entire operation. The fracture should be initiated as close to the center of the coal bed, within the injection well, as feasible and propagated through the bed of the coal seam so as to intersect the surrounding producing wells. The fracture is to provide a passageway through which combustion gas and products may flow. Fracturing out of the coal seam and into another horizon should be avoided where adjacent strata would provide a path through which the gasified products could escape, thereby preventing their recovery. The fracturing of the coal stratum is, therefore, an imperative consideration of the present invention.

The method by which horizontal fracturing of the coal seam is achieved is to introduce a liquid into the coal bed and thereby cause a hydraulic fracture network. To accurately describe the fracture growth wtihin a formation, the mechanism that controls the leak-off rate when the system is pressurized with a liquid must be approximated. Reservoir response to liquid pressure can be grouped to either of three main categories. The first category, which is the dominant factor controlling the leak-off, is the viscosity of the fracturing fluid itself. The compressibility of the fluid within the coal bed should be considered as it is significant when compared to the resistance to flow through a coal formation. The third consideration in predicting leak-off is whether there exists a substance in the fluid which will deposit on the fracture faces and thus create a significant pressure drop between the inside of the fracture and the formation so that most of the fracturing fluid will remain within the fracture. Once these factors are determined, the appropriate fracturing fluid and quantity may be chosen.

After completing the radial extending horizontal fracture, the horizontal and vertical network is created throughout the coal deposit by the introduction of a first combustion supporting gas into the horizontal fracture between the wells and thereafter igniting the coal deposit so as to form a network of crumbled coal within the coal deposit. The method of producing the fracture network within the formation is to subject the coal deposit, after the introduction of a radially extended horizontal fracture, to an excess of a first combustion supporting gas, for example oxygen. The gas forms a highly volatile or combustible combination with the hydrocarbons contained within the coal deposit. Subjecting the coal deposit to a pressure greater than the overburden pressure creates a blanket of the volatile mixture over the entire coal deposit. Ignition of the coal deposit, while simultaneously preventing any production, forms a crumbled network of coal in the coal deposit for propagation of a combustion front through the coal seam by injection of a second combustion supporting gas. The amount of combustion movement is directly proportional to the oxygen injection rate so that the advancement of the combustion front may be controlled as it moves throughout the coal deposit. The requirement of creating the combustion front is alleviated in that the combustion front is already initiated during the fracture network formation and propagated by the subsequent injection of a second combustion front throughout the coal deposit. It is understood that by any of the processes described, a reverse combustion drive may be induced by reversing injection of the combustible gas into the production wells.

To more fully understand the application of the present process, referral to FIG. 1 is suggested. In FIG. 1, an injection well **110** is completed from the earth's surface **101**, through overburden **102**, through coal bed **103** and is spudded into underlaying formation **105**. The well **110** is sealed by a wellbore liner **109** and casing **108** to a point midway in the coal bed **103**. The lower portion of the coal bed **103** and underlaying formation **105** being left as an open hole **106**. A wellhead **112** is connected to the wellbore liner **109** so that fluids may be introduced into well **110**. Retrievable isolation means, for example a packer **111**, are placed in the well **110** at a point slightly below the mid-section of the coal bed **103** by shoe **107** such that the subsequent introduction of a hydraulic fluid at pressures higher than the overburden pressure create a radially extending horizontal fracture **104** through the coal bed **103** to subsequent offsetting wells.

FIG. 2 typifies the resultant crumbled coal bed **228** produced by the process for forming a fracture network as described previously. The injection well **210** and offset production well **220** are completed in similar fashion with respective cement **208** and **218** and casing **209** and **219** as described for FIG. 1. It is noted, however, that production well **220** is completed to the top of the coal bed **203**. Compressor **213**, having inlet **214**, through which a combustible gas is supplied, is connected to wellhead **212** such that combustible gas is introduced into the formation and propagates a combustion front **226** through the crumbled coal bed **228** leaving behind charred residual **227**. Combustible gas and coal tar liquids are produced from wellhead **222** and thereby introduced into scrubber-separator **223** from which dry combustible gas **224** is produced overhead as liquid coal tar products **225** are produced from the bottom.

It is conceivable that pure oxygen may be utilized in the fracturing process, whereas it is generally not thought to be safe or economic, in that the depth of most coal seams subjected to this method is generally not more than several hundred feet, thereby requiring very little safety equipment and a lesser tendency for pre-ignition of materials within the wellbore while oxygen is being loaded into the formation.

A preferred method for controlling the temperature of the flame front, but more particularly to adjust the calorific value of the produced gas, is by the simultaneous injection of water with the combustion supporting gas. A water-gas shift reaction is then obtained at the site of the combustion front which yields a considerably enhanced calorific content produced gas and lowers the temperature of the combustion front. This temperature lowering results in a decreased loss of heat to the surrounding strata and a decrease in the destructive degradation of coal tar liquids. The particular reaction of the water-gas shift reaction is presented below:

$$C + H_2O \overset{heat}{\rightleftarrows} H_2 + CO$$

The increased hydrogen content of the produced gas yields a high energy content energy source gas.

When the present invention is applied to the art of in situ combustion of coal seams it provides an effective means for the combustion and reclamation of coal tar liquids and produced gas in order that a greater area extent of the coal seam may be contacted. The invention enhances the art of in situ combustion of subterranean coal deposits by allowing an economic and facile method for the combustion and reclamation of energy from these deposits.

The present invention has been described herein with respect to the particular embodiments thereof, it will be appreciated by those skilled in the art, however, that various changes and modifications can be made without departing from the scope of the invention as presented.

I claim:

1. A process for the combustion of coal in subterranean deposits which comprises:

a. completing two or more wells within the coal deposit;

b. inducing a radially extended horizontal fracture in the coal deposit so as to inter-connect the wells;

c. subjecting the coal deposit to an excess of a first combustion supporting gas at a pressure greater than the overburden pressure;

d. igniting the coal deposit while simultaneously preventing any production therefrom so as to form a network of crumbled coal within the coal deposit;

e. injecting a second combustion supporting gas into one or more wells to form a combustion front; and

f. producing combustible gas and coal tar liquids from one or more wells.

2. The process of claim **1** in which:

a. the first combustion supporting gas is oxygen; and

b. the second combustion supporting gas is air.

3. The process of claim **2** in which the radially extended horizontal fracture is induced by hydraulic fracturing.

4. The process of claim **1** further comprising the simultaneous injection of water with the combustion supporting gas so that a water-gas shift reaction is provided to increase the calorific content of the produced gas.

5. The process of claim **1** further comprising introducing a combustion supporting gas into at least one production well subsequent to the injection of the second combustion supporting gas into the ignited wells to cause a reverse combustion and flow of injected gas, produced gas, and coal tar liquids to the previously ignited wells.

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