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[54] **METHOD FOR RECOVERY OF COAL ENERGY**
9 Claims, No Drawings

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ABSTRACT: Two or more wells are drilled into a coal seam. Each well is completed to isolate all other strata from the coal seam. A radial horizontally directed fracture is induced so as to connect the wells communicatively. The coal seam is ignited through at least one injection well and the combustion front propagated from one or more injection wells through the horizontal fractures to subsequent production wells by injection of a combustion supporting gas. Injection pressures utilized are sufficiently high to raise the overburden at the fractured surfaces and permit continued air injection during the combustion process. Regulation of the width of the fracture network and corresponding gas and liquid flow is achieved by the control of the injection pressure. The continued production of a flammable gas and coal tar liquids is thereby afforded.

METHOD FOR RECOVERY OF COAL ENERGY

BACKGROUND OF THE INVENTION

This invention relates to the insitu combustion of a coal seam for the recovery of flammable gases and coal tar liquids. More particularly it relates to a novel method for self-regulating or controlling the width of a fracture network through which combustion supporting gas and combustion products may pass during the forward 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 of air through the coal. Some efforts even involved breaking up the coal underground to provide adequate air passage. 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 to expensive and limited in scope, shaft and bore hole mining combinations were devised and employed steeply sloping seams near outcrops. In addition to being limited exclusively to deeply 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 seems to have been concentrated on methods of increasing air injection rates by shaftless methods. Electrocarbonization utilizing high pressure air injection was among many of the methods previously tested. One of the most promising techniques was tested by the Bureau of Mines and involved 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 combustible products. These tests also proved uneconomic and unfeasible by present production standards and were discontinued and never 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 structures.

It is another object of our invention to provide for a method by which one or more horizontal fractures, created in a coal seam may be used in conjunction with the gas injection pressures to sustain combustion in a coal seam.

Another object of our invention is to provide for a method of combustion of coal within subterranean strata through horizontal fracture networks by self-regulating injection of combustion supporting gas.

It is a further object of our invention to provide for a method by which flammable gas and coal tar liquids are afforded a production path by the self-regulation of the width of a horizontal fracture network utilizing controlled gas injection.

With these and other objects in mind, the invention will be apparent from the description which follows.

SUMMARY OF THE INVENTION

The present invention comprises a method of producing a flammable gas and coal tar liquids by the forward combustion of a coal seam. Two or more wells are completed into the coal seam and all sections therewith are segregated from the wellbore by isolation means so that only the coal seam is left exposed and in direct contact with the wellbore. A horizontal fracture is created through the coal seam so as to connect the respective wellbores of the completed wells. The coal seam is ignited through one or more of the wells and the combustion front propagated from one or more of these injection wells to the production wells by injection of a combustion supporting gas into the ignited wells. Injection pressures are maintained at a level such that the overburden rock is lifted from the coal seam at the horizontal fractured surface.

Sufficient injection pressures are maintained to allow a desired amount of gas to be introduced into the coal seam to burn a desired amount of coal per unit time. The overburden is lifted to allow the desired amount of combustion supporting gas to reach the combustion front to produce the product liquid and gas at the desired rate. The process is then self-regulating in that the overburden can be lifted or lowered even to the point of closure if necessary to provide the liquid coal tar, flammable gas and injection gas flow rates.

DETAILED DESCRIPTION OF THE INVENTION

The present invention describes a novel method for the production of flammable gas and coal tar liquids by the insitu combustion of a coal bed. The process consists of completing wells in the coal seam, creating a horizontal fracture in the coal seam to establish communication in the wells, igniting the coal about the injection well, injecting a combustion supporting gas, and recovering volatile liquids at the production well.

Each production well is completed in such 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 divorced 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 and into another horizon should be avoided where adjacent strata would provide a path through which the gasified products could escape and thereby prevent their recovery. The fracturing of the coal stratum is, therefore, an imperative consideration of the present invention.

One method by which horizontal fracturing of the coal seam may be achieved is to introduce a liquid into the coal bed and thereby cause a hydraulic fracture network. To accurately describe the fracture growth within a formation, the mechanism that controls the leak-off rate when the system is pressurized with a liquid the fracturing be approximated. Reservoir response to liquid pressure can be grouped to either of fracturing 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, however, it is normally insignificant 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.

Upon creation of the radially extending horizontal fracture ignition of the coal seam is initiated by one of several techniques. A downhole burner or heater may be introduced accompanied by a sufficient quantity of oxygen to support combustion of both the burner and the coal bed. The coal seam is then ignited by the flame or extreme temperature respectively. The combustion front formed is propagated through the coal seam by continued injection of a 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 reservoir.

It is common practice to separate a fractured network by the use of propping agents. In the combustion of a coal seam, however, it has been found that air injection into the coal bed, which has been hydraulically fractured and heated, results in the production of hot coal tar products which flow into the fracture and when cooled ahead of the combustion front become highly viscous or solid and plug the fracture. Any propping agent contained with this fracture will tend to coagulate the viscous fluid and further block the fracture thereby preventing further has injection. We have found that by injecting air or other combustion supporting gas mixtures at a pressure sufficient to raise the overburden strata this problem is overcome. The unobstructed path of flow afforded the injected gas as the overburden is raised allows a greater amount of gas to be introduced into the coal seam and greater quantities of coal to be contacted and consumed.

A particular feature of the present invention is a self-regulation or control of the rate of combustion which may be achieved. A specific flow rate desired, which will give a resultant rate of combustion, may be initiated by use of a gas flow regulator in control of the gas compression means. The pressure under which gas in injected is automatically increased or decreased as the gas flow regulator demands. By this procedure a specified gas flow rate is continually introduced into the coal bed. As pressure requirements increase, the overburden structure is raised to afford a greater path for gas and liquid coal tar products to flow through. The reciprocal of this procedure occurs as less obstruction is exposed to the gas flow path and a lesser pressure and lesser resultant fracture width is required. Therefore, the gas injection pressure will be increased or decreased as required with the resultant raising or lowering of the overburden strata and widening or narrowing of the fracture width.

The operation of the invention may be more properly understood by illustration of the following example:

EXAMPLE

A four spot pattern consisting of three producing wells surrounding a central injection well at a distance of 20 feet from the injection well and at 120° intervals was used in the experimental study. The wells were completed into a 22 inch coal seam at a depth of approximately 36 feet below the earth's surface. Three thermocouple wells, to monitor the progress of the combustion front, were spaced midway between each production well and the central injection well. The producing and injection wells were drilled to the bottom of the coal bed and cased and cemented from the earth's surface to the top of the coal seam. The completion technique resulted in all the production wells having as much open hole in the coal layer as possible while allowing no communication between the coal and the overburdened and underlying strata.

A horizontal fracture was induced radially from the central injection well to each of the three production wells. The location of the induced fracture was checked in each of the production wells and found to be in the center of the coal seam of each. A constant air rate of 14,000 standard cubic feet per minute at 20 p.s.i.g. was established through the fracture. This pressure was below the pressure required to part the fracture and lift the overburden structure. A propane fired burner, positioned opposite the fracture in the injection well was ignited and burner combustion was sustained at the rate of 50,000 B.t.u.'s per hour. Immediately after lighting the burner the injection air rate began to drop. After several hours of burning the injection rate has decreased to an unmeasurable amount due to sealing of the fracture by the viscous coal tar products. The compressor was then set to deliver a constant rate of combustion supporting gas at an upper limit of 65 p.s.i.g. This pressure was sufficient to raise the overburden and afford a gas flow path through the fractured network.

It was observed that during the initial injection at 20 p.s.i.g. there existed a continued decline in calorific content of the producing gas stream. After the overburden was lifted, during the constant injection portion of the experimental study at 65 p.s.i.g. or less, the calorific content rose to an average value of 130 B.t.u.'s per standard cubic foot. This value was relatively constant and sustained the burning of a production flare for the entire four and one-half days of the experimental study. A continuous flow of coal tar liquid was also produced over this production interval.

It can be readily discerned from the above example that a sustained combustion drive may be conducted through a horizontal fracture in a coal seam by use of the present invention. The self-regulating aspect of the process allows the continued injection of combustion supporting gas at a uniform rate thereby yielding means by which a controlled combustion drive may be conducted. A sustained rate of combustible gas is attained for a source of energy and a path is provided through which coal tar liquids may be produced.

It has been found that approximately 1 p.s.i. per foot of overburden is sufficient to "float" the overburden strata and separate the fracture after the fracture is initially created. Experiments showed that in wells at the aforementioned test depth pressures 20 to 30 p.s.i.g. above the minimum required pressure to obtain fracture separation are adequate to maintain a constant gas injection rate, and flammable gas and liquid coal tar production. Means for gas injection control may be provided by use of gas regulation which will increase or decrease the gas injection pressure as required. An electrically controlled pressure regulator responsive to a flow rate sensitive rotometer is an example of the regulation means which may be applied. Particular mechanics of the gas flow regulation means are not a particular limitation upon the present inventive concept and may consist of any suitable control mechanism.

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:

$$3C + 2H_2O \xrightarrow[\text{air}]{\text{heat}} CH_4 + 2CO$$

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

When the present invention is applied to the art of insitu combustion of coal seams it provides for an effective means for the combustion and reclamation of coal tar liquids and producing gas in order that a greater areal extent of the coal seam may be contacted. The invention enhances the art of insitu 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 as has been described herein with respect to he 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.

Therefore, we claim:

1. In a process for the combustion of coal in subterranean deposits wherein two or more wells are interconnected through a radially extended horizontal fracture through the coal deposit, a combustion front is initiated at one or more wells by connecting the coal seam therein, and the combustion front is propagated through the horizontal fracture and heats the coal deposit by subsequent injection of a combustion supporting gas into the ignited wells, the improvement which comprises injecting the combustion supporting gas at a pressure above that required to separate the coal deposit along a (previously created) horizontal fracture plane previously created by hydraulic fracturing allowing injected gas, produced has, and coal tar liquids to flow freely.

2. The process of claim 1 in which the combustion supporting gas is air.

3. The process of claim 2 in which the injection pressure required to separate the horizontal fracture is at least about 1 p.s.i.g. for each foot of depth from the earth's surface to he horizontal fracture.

4. The process of claim 3 in which excess injection pressure is utilized to insure fracture separation.

5. The process of claim 1 in which the injection pressure is controlled so that a uniform flow of combustion supporting gas may be maintained.

6. The process of claim 5 in which the combustion supporting gas is air.

7. The process of claim 6 in which the injection pressure is varied in response to measurements of the flow of injected gas.

8. 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.

9. The process of claim 1 further comprising introducing a combustion supporting gas into at least one production well subsequent to he injection of the combustion supporting gas into the ignited wells at a pressure above that required to separate the coal deposit 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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