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# (54) METHOD FOR JOINT-MINING OF COALBED GAS AND COAL

(57) Provided is a method for joint-mining of coalbed gas and coal. The method comprises: a well-drilling step; a fracturing and penetration step; a coalbed gas extraction step; an ignition step; and, an underground gasification step. The method combines an underground coal gasification technology and a coalbed gas extraction technology, not only allows for utilization of the high temperature of underground gasification to heat a coalbed, thus increasing the permeability of a coal seam and increasing the recovery rate of the coalbed gas, but also allows for utilization of the coalbed gas to perform the drilling and fracturing and penetration processes, thus increasing the efficiency of underground coal gasification.

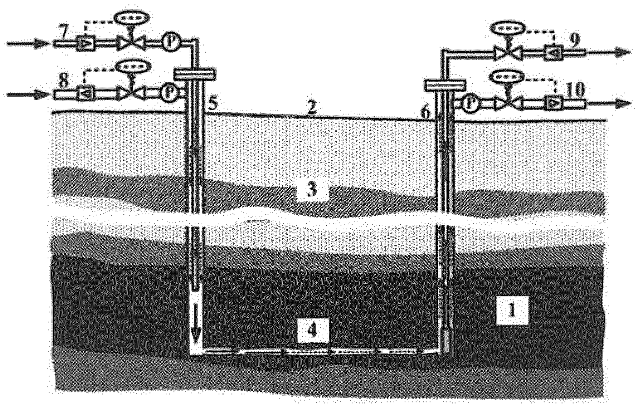



FIG. 2

EP 2 899 363 A1

## Description

### Field of the Invention

**[0001]** The present invention relates to a novel process for mining underground carbon-containing organic mineral reservoir, in particular to a method for joint-mining of coalbed gas and coal.

### Background of the Invention

**[0002]** Coal, as a major source of energy in China, takes up about 70% of primary energy structure and is relatively rich in the total volume. It is predicted that the total volume of coal is about 4.5 trillion tons (within 2000 m), among which the volume of coal accumulated within 600 m is just about 25%. It is estimated from the present coal mining depth (400 m) that there is at least about 80% of the predicted total volume of underground coal in China not yet developed and utilized. The deeper development of coal resource is a long-term task. With the increase of the mining depth, an associated resource, i.e., gas (also referred to as coalbed gas) also increases in content. It is assessed in terms of coalbed gas resource that there is about 36 trillion cubic meters of coalbed gas reserved deeply within 2000 m in China, ranking third in the world, equivalent to the reserves of the onshore conventional natural gas resource.

**[0003]** Although China is rich in coalbed gas resource, reserve conditions of coalbed gas vary a lot among zones of China. Most areas in China show characteristics of low pressure, low permeability and low saturation. Except for the Qinshui basin and the eastern margin of Ordos basin, it is difficult to realize scale and industrial development in other areas at present. Furthermore, as there are many high-gas mines or coal & gas outburst mines, with the increase of the mining depth, both the geostress and the gas pressure further increase and the gas drainage becomes more difficult. Nevertheless, with the increase of the mining depth, the geological environment becomes more complicated that the increased geostress, water influx and ground temperature cause the increase of sudden engineering disasters and serious accidents, for example, rock blast hazards, gas explosion, aggravated strata pressure behaviors, large surrounding rock deformation, rheologic phenomena, increase of ground temperature and the like, which cause great threats to the safe and efficient extraction of deep resources. Hence, from the perspective of either safety during the coal mining or improvement of the utilization of the coal resource to promote the sustainable development of the coal industry, it is necessary to study and solve the problem of difficult extraction and utilization of the coal and coalbed gas.

**[0004]** From the disclosed information, it is shown that the coal seams reserved underground may be burned controllably, by the coal underground gasification technology, to generate gas energy that can be utilized adequately by means of pyrolytic reaction and chemical reaction. In this way, the in-situ gasification mining of coal is realized. This technology has achieved considerable success in the gasification of shallow coal seams and has implemented the commercial operation in the former Soviet Union. Since the oil shock in the twentieth century, some countries in Europe have succeeded in utilizing the coal underground gasification technology to obtain energy from deep coal seams that can not be mined by conventional methods. From 1978 to 1986, Belgium and Germany jointly conducted deep coal seam underground gasification tests (with a depth of coal seams of 860 m) in Thulin of Belgium for the first time; in 1988, six members of the EU established a European underground coal gasification team who conducted medium deep coal underground gasification tests (with a depth of coal seams of 550-650 m) in Teruel mine of Spain, and those tests validated the feasibility of the deep coal seam underground gasification technology in Europe.

**[0005]** The coal underground gasification technology is the most effective technology for the mining of deep coal resources at present. However, the existing coal underground technology only concerns the gasification of coal seams. With the increase of the mining depth of coal, the content of coalbed gas will increase quickly and it is inevitable to have some problems in the extraction of coalbed gas, specifically including: (1) for a coal seam rich in coalbed gas, there may be problems such as safety challenge and waste of resources if gasification is directly implemented to the coal seam; (2) if the conventional coalbed gas mining means is employed without in combination with the underground gasification technology, the subsequent implementation of the underground gasification may cause overlapped functions such as drilling and increased investment cost; (3) injection of $CO_2$ into a coal seam may increase the extraction ratio of $CH_4$ from the coal seam, however, the yield of coalbed gas, which may be increased only in the initial stage of the extraction of coalbed gas, will drop quickly in the later stage as the fracture is likely to close; and (4) as the intermediate of the gasification process and one component of resulting products, $CO_2$, participating in a series of redox reactions, is an important component (about 15-60%) of the output gas and an important factor influencing the calorific value and content of active components of the gas; however, the recycling of $CO_2$ is not taken into consideration in the existing processes.

### Summary of the Invention

**[0006]** The inventor(s) has found that the coalbed gas extraction and the underground coal gasification have some similarities and synergistic effects in drilling, fracturing, fracture expansion and other technological links, so that the collaborative development and utilization of an underground coal resource and a coalbed gas resource may be comprehensively taken into consideration by combining an underground coal technology and a coalbed gas extraction technology. On one hand, a high-temperature medium generated by the underground coal gasification may be used to heat a coal seam. Under the high temperature, the adsorption capacity of $CH_4$ in a coalbed gas is greatly reduced, and the gas is expanded while heated during the process of transferring heat energy to the coal seam, so that it is advantageous for the establishment of a pressure difference, and the seepage rate of the coalbed gas is improved. On the other hand, processes for the coalbed gas in early stage, such as the fracturing stimulation and depressurization by drainage,, improve the permeability of a coal seam, so that it is advantageous for the establishment of a fire zone and the implementation of a subsequent gasification process in the underground coal gasification technology; meanwhile, the permeability of the coal seam after heated may be improved by 2-10 times, so it is more advantageous for the desorption of $CH_4$. In addition, from the perspective of products, the cost of the separation of $CO_2$ from methane is lower than that of $N_2$ from methane, and CO and $H_2$ in the gas may be directly synthesized into methane, so the final product, like the coal gas, is methane. It can be seen that the coalbed gas extraction may be combined with the underground gasification, and the both promote and cooperate with each other, so that the recovery rate of the coalbed gas may be improved, and meanwhile, due to the improvement of the permeability of the coal seam, the reaction surface area is increased, so that it is advantageous for the underground coal gasification reaction.

**[0007]** In view of the difficulties of the extraction of coalbed gas in China, the advantages of the underground coal gasification technology in the coal mining and the above synergistic effects of the both in the process technology, an objective of the present invention is to provide a new method for joint-mining of coalbed gas and coal. The method combines a coalbed gas extraction technology and an underground coal gasification technology, and a medium containing $CO_2$ is used in the joint-mining process.

**[0008]** Hence, the present invention provides a method for joint-mining of coalbed gas and coal, including:

1) a well-drilling step: drilling from the ground to a coal seam such as coal seam to provide at least one injection borehole and at least one production borehole for communicating the coal seam with the ground;
2) a fracturing and penetration step: injecting a fracturing medium containing $CO_2$ into the coal seam from the injection borehole, thereby forcing the fracture medium to flow in the coal seam and to discharge from the production borehole so that the injection borehole is brought to communicate with the production borehole through the communicating fracture in the coal seam;
3) a coalbed gas extraction step: injecting a displacement medium into the coal seam from the injection borehole, displacing coalbed gas in the coal seam, and collecting the coalbed gas from the production borehole;
4) an ignition step: establishing a fire zone in the coal seam at the bottom of the production borehole for igniting the coal seam; and
5) an underground gasification step: injecting a gasification agent containing $CO_2$ into the coal seam from the injection borehole so that a gasification reaction and a pyrolytic reaction occur between the gasification agent and the coal seam to generate heat energy and a gasified gas, transferring the heat energy towards the inside of the coal seam to generate a pyrolyzed gas, synchronously displacing the coalbed gas to generate free methane, discharging and collecting the free methane, together with the gasified gas and the pyrolyzed gas, from the production borehole.

**[0009]** However, it is to be noted that, the method provided by the present invention is not a simple combination of the underground gasification technology and the coalbed gas extraction technology, but respective original processes are improved to adapt to the coupling of the two process technologies. Specifically, at least one of the following improvements is employed.

a. A horizontal well is drilled preferably in a direction vertical to a primary fracture of a coal seam during coalbed gas drilling. The direction of the primary fracture is located in a horizontal plane of the coal seam and may be determined by geostress measurement, directional coring analysis or other means, but the problem on the direction of the horizontal well is not taken into consideration in the existing coalbed gas extraction.
b. The distance of a horizontal section of the coalbed gas horizontal well is determined according to a longitudinal expanded range of an underground gasification fire zone (i.e., the direction of the horizontal well), and the main parameters for determining this expanded range include the distribution and size of the geostress of the coal seam, the original permeability of the coal seam and the permeability of the coal seam at different temperatures, the reactivity of coal, the structure and fault of the coal seam, the mechanical properties of coal rocks at different temperatures and the like. If necessary, it is also required to summarize a proper length in combination with an on-site test. However, the exiting coalbed gas extraction does not consider the length of the horizontal section of the horizontal well according to this standard.
c. The specification (i.e., material, inner and outer diameters, well structure and construction technology) of injection

and production holes of coalbed gas is determined according to the underground gasification technology, specifically including gas inflow/outflow, temperature, operating pressure, service life and so on. However, the specification of the injection and production holes in the coalbed gas extraction is determined by pressure and gas outflow only.

d. In the coalbed gas extraction, it is taken into consideration during drilling a vertical well that the put-down depth of a sleeve and a trajectory of the horizontal section of the horizontal well are located at the lower part of the coal seam and approximate to a bottom plate, thereby ensuring the recovery rate of the coal seam. This point is not taken into consideration in the coalbed gas extraction.

e. A fracturing range (determined according to the distribution of pressure of each hole on site) of the coalbed gas is considered during the design of a gasification furnace for underground gasification to determine an arrangement range of a furnace zone; the arrangement range of the furnace zone is determined only according to the range of thermal state influence (determined by on-site thermometer holes) of the coal seam during the design of the gasification furnace for underground gasification, but the fracturing range of the coalbed gas is obviously larger than the range of thermal state influence.

f. Prior to the ignition and the underground gasification, the content of methane at injection and production holes is monitored, and the content of oxygen in input gas is controlled, so that the nonoccurrence of explosion accidents is ensured. As the coalbed gas extraction is performed at a cold state and no oxygen gets involved, the explosion of methane will not be considered.

**[0010]** In a preferred implementation, the well drilling is drilling a horizontal well on a horizontal plane of the coal seam and in a direction vertical to a primary fracture of the coal seam.

**[0011]** In a preferred implementation, in the coalbed gas extraction, it is taken into consideration during drilling a vertical well that the put-down depth of a sleeve and a trajectory of a horizontal section of the horizontal well are located at a lower part of the coal seam, with 1-3 m away from a bottom plate of the coal seam.

**[0012]** In a preferred implementation, the fracturing medium is a mixture of $CO_2$ and $O_2$, and the volume concentration of $O_2$ is below 20%.

**[0013]** In a preferred implementation, in the coalbed gas extraction step 3), the displacing coalbed gas in the coal seam is injecting $CO_2$ or $N_2$ for displacement.

**[0014]** In a preferred implementation, the method further includes: 6) a $CO_2$ recycling step: recycling $CO_2$ generated during the underground gasification step, and using a part of the recycled $CO_2$ as the gasification agent.

**[0015]** In a preferred implementation, the $CO_2$ recycled in the $CO_2$ recycling step is used as the fracturing medium for the fracturing and penetration step or the displacement medium for the coalbed gas extraction step.

**[0016]** In a preferred implementation, the method further includes: 7) a $CO_2$ storage step: at the end of the underground gasification of the coal seam between the injection borehole and the production borehole, filling a part of the recycled $CO_2$ into a combustion cavity (the combustion cavity is a cavity left after the gasification of the coal seam) for burying and storage.

**[0017]** In a preferred implementation, prior to the ignition step 4), the method further includes a safety detection step for ensuring ignition safety.

**[0018]** In a preferred implementation, the fracturing medium in the fracturing and penetration step is gaseous, liquid or supercritical $CO_2$, or a mixture of $CO_2$ and $O_2$ having a volume concentration of oxygen of below 20%, or a mixed liquid composed of liquid $CO_2$, water collagen (for example, guanidine gum, for improving the denseness of the fracturing medium, reducing the leak-off of the fracturing medium and increasing the width of the fracture) and a chemical additive (for example, potassium chloride, for allowing the fracturing medium to form a stable system).

**[0019]** In a preferred implementation, in the underground gasification step, the volume concentration of $O_2$ in the gasification agent containing $CO_2$ is 20-70% to ensure that ash will not be melted.

**[0020]** In a preferred implementation, in the underground gasification step, the volume concentration of $O_2$ in the gasification agent containing $CO_2$ is 20-50% for establishment of a gasification passage.

**[0021]** In a preferred implementation, in the underground gasification step, the volume concentration of $O_2$ in the gasification agent containing $CO_2$ is 40-70% for gasification of the coal seam at the end of the establishment of the gasification passage.

**[0022]** In a preferred implementation, if the content of water in the coal seam is less than the amount of water required for the gasification of the coal seam at the end of extraction of the coalbed gas, the gasification agent containing $CO_2$ is a mixture of $O_2$, $CO_2$ and water vapor. The addition amount of water vapor should be determined according to a result obtained by dividing a difference between the amount of water required for the gasification and the water content of the coal seam by a decomposition rate of the water vapor.

**[0023]** In a preferred implementation, the establishing a fire zone is performed by electric ignition (for example, placing an electric heater in the coal seam where a fire zone is to be established, controlling the pressure of an ignition hole to be larger than the hydrostatic head to ensure that there is no water in the ignition hole, and then heating and igniting the coal seam to establish the fire zone) or solid fuel ignition (for example, placing hot coke in the coal seam where a fire zone is to be established, feeding oxygen to combust the coke and thus ignite the coal seam so as to establish the fire zone).

**[0024]** In a preferred implementation, in the fracturing and penetration step, when the pressure in the injection borehole drops rapidly (a pressure drop reaches about 5% or more of an initial pressure per day) while the gas outflow of the production borehole is above 100 $Nm^3/h$, communicating fracture has been formed in the coal seam between the injection borehole and the production borehole.

**[0025]** In a preferred implementation, the underground gasification includes forward combustion (a moving direction of flame on a gasification working plane is consistent with an airflow direction), reverse combustion (the moving direction of flame on the gasification working plane is opposite to the airflow direction) or retracting injection point combustion (a set of continuous tubes is inserted into the horizontal well, then the set of continuous tubes is drawn on the ground to allow the continuous tubes to retract in the horizontal well for ignition and gasification at different positions).

**[0026]** In a preferred implementation, the generated gasified gas, pyrolyzed gas and coalbed gas are discharged from the production borehole for synthesis of methane, methane-power generation or production of methane-methanol.

**[0027]** In a preferred implementation, for the conveying of the gasification agent in the underground gasification step, the gasification agent is conveyed from the ground to the fire zone through an annular conveying pipe (i.e., a double-layer sleeve) or directly conveyed from the ground to the fire zone through a borehole.

**[0028]** In a preferred implementation, the $CO_2$ recycled in the $CO_2$ recycling step is used as the fracturing medium for the fracturing and penetration step or the displacement medium for the coalbed gas extraction step.

**[0029]** The method provided by the present invention combines an underground coal gasification technology and a coalbed gas extraction technology, not only allows for utilization of the high temperature of underground gasification to heat a coalbed, thus increasing the permeability of a coal seam and increasing the extraction rate of the coalbed gas, but also allows for realization of the coupling of the drilling technology and the fracturing technology and meanwhile may use directly captured $CO_2$ as a medium for coalbed gas displacement and a gasification agent for the underground gasification, thus adjusting effective compositions of gas. By coupling technologies, the extraction rate of coalbed gas is improved, the effective gas compositions of gas are adjusted, the production cost of gas is reduced, and $CO_2$ capture and resource utilization are realized.

**Brief Description of the Drawings**

**[0030]**

Fig. 1 is a flowchart of a method for joint-mining of coalbed gas and coal according to the present invention;

Fig. 2 is a schematic diagram of the method for joint-mining of coalbed gas and coal according to an implementation of the present invention, wherein a coal seam between boreholes is injected with $CO_2$, i.e. by cold state fracturing, for extraction of coalbed gas;

Fig. 3 is a schematic diagram of the method for joint-mining of coalbed gas and coal according to an implementation of the present invention, wherein a fire zone is established to heat a fracture and then expand it to form a gasification passage for synchronous displacement of coalbed gas;

Fig. 4 is a schematic diagram of the method for joint-mining of coalbed gas and coal according to another implementation of the present invention, wherein the extraction of coalbed gas is performed by pinnate branch horizontal drilling technology;

Fig. 5 is a schematic diagram of the method for joint-mining of coalbed gas and coal according to another implementation of the present invention, wherein the ignition is performed, and a passage is thermally performed and then expanded to form a gasification passage for synchronous displacement of coalbed gas;

Fig. 6 is a schematic diagram of the method for joint-mining of coalbed gas and coal according to another implementation of the present invention, wherein the extraction of coalbed gas is performed by directionally horizontal drilling; and

Fig. 7 is a schematic diagram of the method for joint-mining of coalbed gas and coal according to another implementation of the present invention, wherein the ignition is performed, and a passage is heated and then expanded to form a gasification passage for synchronous displacement of coalbed gas;

in which:

1: Coal seam
2: Ground
3: Overlying strata
4: Communicating fracture
5: Injection borehole
6: Production borehole

7: $O_2$ pipeline
8: $CO_2$ pipeline
9: Drainage pipeline
10: Coalbed gas pipeline
11: Initial fire zone
12: Gasification passage
13: Gas pipeline
14: Pinnate branch horizontal well
15: Horizontal well

## Detailed Description of the Preferred Embodiments

**[0031]** In view of the difficult extraction of coalbed gas in China and the advantages of an underground coal gasification technology in coal mining, the present invention provides a new method for joint-mining of coalbed gas and coal.

**[0032]** In view of those aspects, the method provided by the present invention combines a coalbed gas extraction technology and an underground coal gasification technology. As both the underground gasification and the ground coalbed gas extraction are implemented in virtue of boreholes, an underground gasification unit is generally required to at least have a injection borehole, a production borehole and a gasification passage connected between the two boreholes, where the gasification passage is realized generally by fracturing, fire penetration or other means. While a coalbed gas extraction unit is generally required to have at least one blind hole, for example, a vertical hole or a multilateral horizontal well, and it is required to perform fraction expansion by fracturing. Also, the coalbed gas extraction unit may include a gas injection well and a plurality of production wells. Therefore, the underground gasification and the ground coalbed gas extraction have some similarities in technology to a certain extent. The combination of the underground coal gasification technology and the coalbed gas extraction technology not only allows for utilization of the high temperature of underground gasification to heat a coal seam, thus increasing the permeability of a coal seam and increasing the extraction rate of the coalbed gas, but also allows for realization of the coupling of the drilling technology and the fracturing technology and meanwhile may use directly captured $CO_2$ as a medium for coalbed gas displacement and a gasification agent for the underground gasification, thus adjusting effective compositions of gas. By coupling technologies, the extraction rate of coalbed gas is improved, the effective gas compositions of gas are adjusted, the production cost of gas is reduced, and $CO_2$ capture and resource utilization are realized.

**[0033]** As shown in Fig. 1, the method provided by the present invention include well drilling, fracturing and penetration, coalbed gas extraction, ignition of a coal seam, underground gasification, recycling of $CO_2$, storage of $CO_2$ and other steps.

**[0034]** More specifically, the method for joint-mining of coalbed gas and coal provided by the present invention includes the following steps.

**[0035]** Step a1: At least two boreholes are drilled from the ground to a coal seam, and the direction of the connection line between the bottoms of the two boreholes is consistent with the direction of a primary fracture of the coal seam, wherein one of the two boreholes is used as an injection borehole while the other one thereof is used as an production borehole. A high pressure (higher than a fracturing pressure of the coal seam) fracturing medium containing $CO_2$ as a fracturing medium is injected from the injection borehole, and $CO_2$ is forced to move along the bores and fractures in the coal seam and to discharge from the production borehole, so that a communicating fracture is established in the coal seam between the boreholes.

**[0036]** Step a2: The production borehole is closed, and $CO_2$ is continuously injected into the coal seam from the injection borehole. Then, $CO_2$ is stopped to be injected, and both the injection borehole and the production borehole are closed for soaking, so that $CO_2$ is allowed to displace $CH_4$ in the coal seam. Subsequently, the production borehole is opened again for extraction of the coalbed gas.

**[0037]** Step a3: Step a2 is repeated according to the desorption states of the coalbed gas. After the content of $CH_4$ in the gas from the production borehole drops significantly (for example, the volume concentration of methane is less than 5%), the coal seam at the bottom of the production borehole is ignited, and then a certain concentration of $CO_2$ oxygen-rich gas (called oxygen-rich $CO_2$) prepared from $CO_2$ and pure oxygen is continuously conveyed to a fire zone from the injection borehole through the communicating fracture formed in the coal seam between the boreholes, so that a fire source is allowed to move to the injection borehole in a direction opposite to the airflow direction of the oxygen-rich $CO_2$. As a result, a gasification reaction and a pyrolytic reaction occur between the oxygen-rich $CO_2$ and the coal seam; the communicating fracture is processed to form a gasification passage and continuously gasified to generate gasified gas and pyrolyzed gas:

$$C + O_2 \rightarrow CO_2 \text{ -394kJ/mol}$$

$$C + \frac{1}{2}O_2 \rightarrow CO - 111\text{kJ/mol}$$

$$C + CO_2 \rightarrow 2CO + 173\text{kJ/mol}$$

$$C + H_2O \rightarrow H_2 + CO + 131\text{kJ/mol}$$

$$\text{coal} \rightarrow H_2 + CH_4 + CO_2 + \text{tar} + \text{semicoke} + ...$$

**[0038]** Meanwhile, the released heat is transferred to the coal seam to facilitate desorption of $CH_4$ and dry the coal seam, thus increasing the permeability of the coal seam. The desorbed methane, together with the gasified gas and the pyrolyzed gas, is discharged from the production borehole.

**[0039]** Step a4: After a difference between the injection pressure of the oxygen-rich $CO_2$ and the production pressure of the gas drops significantly (generally about 0.3 MPa), the flow of the oxygen-rich $CO_2$ is increased or the oxygen concentration of the oxygen-rich $CO_2$ is increased, so that the temperature of a reaction zone is further improved, the desorption of $CH_4$ is enhanced, and the fire source is allowed to move to the production borehole in a direction opposite to the airflow direction of the oxygen-rich $CO_2$. Accordingly, the full contact reaction of $CO_2$ with the hot coal seam is ensured, and the in-situ gasification mining of the coal seam between the boreholes is realized.

**[0040]** Further, in those steps, the $CO_2$ may be gaseous, liquid or supercritical $CO_2$, or a mixture of $CO_2$ and $O_2$ having a volume concentration of oxygen of below 20%, or a mixed liquid composed of liquid $CO_2$, water collagen (for example, guanidine gum, for improving the denseness of the fracturing medium, reducing the leak-off of the fracturing medium and increasing the width of the fracture) and a chemical additive (for example, potassium chloride, for allowing the fracturing medium to form a stable system).

**[0041]** Further, in the fracturing operation, the pressure change of $CO_2$ injected into the borehole(s) is monitored. When the pressure at the borehole(s) drops rapidly (that is, a pressure drop reaches 5% or more of the original pressure per day) while the gas outflow is not less than 100 $Nm^3/h$, it is indicated that a communicating fracture has been formed in the coal seam between the boreholes.

**[0042]** Further, for the oxygen-rich $CO_2$, the volume concentration of oxygen in step a3 is required to be 20-50%, and the oxygen concentration in step a4 is required to be 40-70%, to ensure that ash will not be melted. If the content of water in the coal seam is not sufficient for the gasification of the coal, the gasification agent needs to be added with water vapor. The addition amount of the water vapor is determined according to the foregoing description.

**[0043]** Further, for the conveying of the oxygen-rich $CO_2$, the oxygen-rich $CO_2$ may be conveyed from the ground to a fire zone through an annular conveying pipe, or may be directly conveyed from the ground to the fire zone through a borehole.

**[0044]** The method may further include a step a5 of recycling $CO_2$: recycling the $CO_2$ generated during the underground coal gasification, and using a part of $CO_2$ as a gasification agent for underground coal gasification to adjust compositions and a calorific value of the gas.

**[0045]** The method may further include a step a6 of $CO_2$ storage: at the end of the gasification of the coal seam between the two boreholes, a part of the recycled $CO_2$ is filled into a combustion cavity formed after the gasification of the coal seam for burying and storage.

**[0046]** For the boreholes, two of boreholes may ensure the implementation of the gasification process, and one of the boreholes is used for gas inflow while the other one thereof is used for gas discharge. Meanwhile, during the coalbed gas extraction, one of the boreholes may be used for injecting gas to displace coalbed gas, while the other one thereof is used for collecting the coalbed gas displaced from the coal seam.

**[0047]** The fracturing of the coal seam in the method at least includes: gas fracturing, hydraulic fracturing or foam fracturing, or mechanical drilling.

**[0048]** In the method, step a1 may use $O_2$ and $CO_2$ to perform fracturing. The concentration of $O_2$ is within 20% and specifically determined according to the content of methane in the coal seam and the expansion limit of methane.

**[0049]** The establishing of a fire zone in the method may be that the mixture of $CO_2$ and $O_2$ is conveyed to the bottom of the borehole, wherein the temperature is determined according to the convention of the $O_2$, ignition point of the coal seam, the exposed area of the coal seam, heat waste of pipes and the like, and the pressure is determined according to the hydrostatic head.

**[0050]** The establishing of a fire zone in the method further includes: electric ignition, solid fuel ignition, or using an original fire zone within an operation zone or a high pressure coal seam in the combustion cavity.

**[0051]** The underground gasification mode in the method at least includes: forward combustion, reverse combustion or retracting injection point combustion. The forward combustion refers that the moving direction of flame on a working plane is consistent with an airflow direction, the reverse combustion refers that the moving direction of flame on the working plane is opposite to the airflow direction, and the retracting injection point combustion refers that a set of continuous tubes is inserted into a horizontal well and then drawn on the ground to allow the continuous tubes to retract in the horizontal well for ignition and gasification at different positions.

**[0052]** The recycling of $CO_2$ in the method may be performed in various ways and mainly depends on the application and quality of gas. For example, if the gas is used for power generation, $CO_2$ in the fume generated after gas power generation may be recycled. For example, if the gas is used for chemical synthesis, $CO_2$ in the gas may be separated and recycled in a decarbonization section during gas purification, and the fume generated by directly combusting gas or coalbed gas may also be used.

**[0053]** In the method, the gasified gas, the pyrilyzed gas and the coalbed gas, which are discharged from the production borehole, may be used for synthesis of methane, or poly-generation production, for example, methane-power generation, methane-methanol, or production of multiple energy chemical products.

**[0054]** The present invention further produces a preferred method for joint-mining of coalbed gas and coal. The whole flow focuses on the utilization of $CO_2$ as a resource. The method specifically has the following advantages.

**[0055]** Compared with other coalbed gas extraction technologies, the present invention combines coalbed gas extraction and underground gasification, greatly improves the extraction rate of coalbed gas, reduces cost, and meanwhile realizes the recycling and utilization of $CO_2$, so that the present invention is particularly suitable for low-permeability coal seams. The coalbed gas extraction and the underground gasification have strong synergistic effects, specifically:

the boreholes bored in step 1 not only may be used for coalbed gas fracturing and coalbed gas extraction in step 2, but also may be used as injection and production boreholes for ignition in step 3 and pyrolysis and gasification in step 4, so that the coalbed gas drilling and the underground gasification drilling are coupled with each other, and it is advantageous for the reduction of well drilling investment and cost saving, particular for the mining of resources in deep coal seams;

**[0056]** $CO_2$ fracturing in step 1 may improve the desorption of methane in the coalbed gas extraction process in step 2, and a large amount of $CO_2$ adsorbed in the coal seam not only may control the temperature of the coal seam during the ignition in step 3 and the pyrolysis and gasification in step 4, thereby avoiding the occurrence of problems of spontaneous combustion or melting of the gasification passage, which are disadvantageous for ignition and gasification, due to partial overheat of the coal seam, but also may improve the yield of pyrolyzed gas of the coal seam in step 4; in addition, the fracturing process in step 1 greatly improves the permeability of the coal seam, provides advantageous conditions for heat transfer and mass transfer for the pyrolysis and gasification in step 4, increases an expanded range of a working plane of gasification, and improves the recovery rate of the gasification of the coal seam; if the mixture of $CO_2$ and $O_2$ is added as a fracturing medium in step 1, the oxygen remained in the coal seam is advantageous for ignition and may react with a combustible gas during the gasification process in step 4, so that the temperature of the coal seam is further improved, the fracture of the coal seam may be prevented from being closed at the end of the $CO_2$ fracturing, the desorption of methane in the coalbed gas and the pyrolysis of coal may be quickened, the content of methane in the generated gas is improved, and the quality of the gas may also be promoted obviously; however, it is required to control the content of oxygen in the mixed gas to be beyond the explosion limit of methane, the specific process may be implemented by controlling the oxygen concentration;
as a large amount of methane is separated out during the coalbed gas extraction process in step 2 and the coal seam is subjected to pressurization and depressurization repeatedly, the permeability of the coal seam is improved greatly, so that it is advantageous for the expansion of the gasification working plane in step 4, and the methane enriched around the production well is also advantageous for ignition;
the high temperature generated by the underground gasification reaction in step 4 facilitates the formation of the fracture of the coal seam (i.e., hot fracture expansion), so the cold fracturing the coal seam and the hot fracture expansion are complemented with each other to generate synergistic effects, so that the seepage capacity of the coalbed gas is improved, the temperature rise of the coal seam greatly facilitates the desorption of methane, and the fracture of the coal seam may be prevented from being closed at the end of the $CO_2$ fracturing in step 1; by combining physical desorption and chemical reaction, the yield of the coalbed gas may be greatly increased; $CO_2$ may quicken the generation rate of CO, suppresses water-gas shift reaction, effectively adjusts the content of the effective compositions in the gas, and allows a hydrogen-carbon ratio to be fit for the synthesis of methane; meanwhile, using $CO_2$ to displace $CH_4$ improves the recovery rate of the coalbed gas, realizes $CO_2$ capture and resource utilization, and achieves $CO_2$ emission reduction.

**[0057]** The present invention will be further described as below in details with reference to the drawings by specific embodiments. However, it should be understood that the present invention is not limited to these embodiments.

**Embodiment 1**

**[0058]** This embodiment will be described with reference to Fig. 2 and Fig. 3. Fig. 2 is a schematic diagram of a method for joint-mining of coalbed gas and coal according to the present invention, wherein a coal seam between boreholes is injected with $CO_2$, i.e. by cold state fracturing, for extraction of coalbed gas. Fig. 3 is a schematic diagram of the method for joint-mining of coalbed gas and coal, wherein a fire zone is established to heat a fracture and then expanded it to form a gasification passage for synchronous displacement of coalbed gas. As shown in Fig. 2 and Fig. 3, boreholes are arranged according to the range of a coal seam to be gasified in this embodiment. The number of the boreholes is determined according to the reserves of the coal seam and the production scale of gas. However, to implement the present invention, at least one injection borehole and one production borehole should be included. The specific implementation is as below.

**[0059]** Referring to Fig. 2 and Fig. 3, a vertical borehole as an injection borehole 5 is constructed from the ground 2 to the coal seam 1 through overlying strata 3. A vertical borehole as an production borehole 6 is constructed at a certain distance away from the injection borehole 5 (generally within 200 m to 600 m; the distance may be specifically determined according to the type of coal by the those skilled in the art; for example, the deeper the degree of metamorphism is, and the larger the length of the borehole is; for lignite, the depth is generally about 200 m, while for bitumite, the depth is generally about 500 m). The bottoms of both the injection and production boreholes are located in the coal seam 1, and are 2 m away from a bottom plate 2 of the coal seam. The direction of a connection line of the bottoms of the injection borehole 5 and the production borehole 6 is consistent with the direction of a primary fracture of the coal seam. The space between the injection and production borehole may be determined according to the coal seam, stratum and other conditions by those skilled in the art.

**[0060]** An $O_2$ pipeline and a $CO_2$ pipeline 8 are mounted at the orifice of the injection borehole 5, and a drainage pipeline 9, a coalbed gas 10 and a gas pipeline 13 are arranged at the orifice of the production borehole 6, wherein the $O_2$ pipeline 7 is used for conveying pure oxygen; the $CO_2$ pipeline 8 is used for conveying $CO_2$, and oxygen-rich $CO_2$ is prepared with a certain volume concentration (in this embodiment, the oxygen concentration is about 10%) in the injection borehole 5; the drainage pipeline 9 is used for draining water in the coal seam during fracturing and coalbed gas extraction; the coalbed gas pipeline 10 is used for discharging coalbed gas during the coalbed gas extraction and conveying $CO_2$ at the end of gasification to store $CO_2$ into a combustion cavity formed after the gasification of the coal seam; and, the gas pipeline 13 is used for conveying raw gas generated during gasification process after ignition. The specific process is as below.

**[0061]** The high pressure $CO_2$ conveyed by the $CO_2$ pipeline 8 and the $O_2$ conveyed by the $O_2$ pipeline 7 are continuously injected into the coal seam 1 through the injection borehole 7, where the injection pressure is 1.1 times of the fracturing pressure of the coal seam in order to force the gas medium to move through the natural apertures and fractures of the coal seam and then fracture the coal seam to generate a communicating fracture 4, so that the injection borehole is brought to communicate with the production borehole 6 in the coal seam 1. Accordingly, the gas after fracturing is discharged from the coalbed gas pipeline 10 to the ground through the production borehole 6.

**[0062]** The production borehole 6 is closed, and high pressure $CO_2$ continues to be injected into the coal seam 1 from the injection borehole 5, where the injection pressure is not larger than the fracturing pressure of the coal seam and the injection amount is determined according to the content of saturated gas of the coal seam. After the total injection amount of $CO_2$ meets the requirements, $CO_2$ is stopped to be injected, both the injection borehole 5 and the production borehole are closed for well soaking for 1-15 days to ensure that $CO_2$ fully contacts with the coal seam and displaces $CH_4$ adsorbed in the coal sea. Then, the production borehole is opened again, and the water in the coal seam is drained by the drainage pipeline 9 to dewater the coal seam 1. Meanwhile, the coalbed gas pipeline 10 is opened to reduce the pressure at the production borehole 6 and facilitate the desorption of the coalbed gas, which is collected to a ground pipe network through the coalbed gas pipeline 10. After the extraction is performed for a time and when the pressure at the bottom of the production borehole 6 drops to below 10 kPa, a next cycle of injection and extraction is performed.

**[0063]** When the content of $CH_4$ in the gas from the production borehole 6 drops significantly (that is, the volume concentration is less than 5%), the production borehole 6 is opened, the drainage pipeline 9 is taken away and the gas pipeline 13 is mounted. Then, the communication valve between the production borehole 6 and the gas pipeline 13 is opened, and high pressure $CO_2$ continues to be injected into the coal seam 1 from the injection borehole 5, where the injection pressure is larger than the hydrostatic pressure of the coal sea and the injection amount is determined according to the content of water in the coal seam. Then, the $CO_2$ is discharged from the gas pipeline 13 to take away the water in the coal seam between the boreholes, i.e., to dewater the coal sea, so that the coal seam at the bottom of the production borehole 6 remains dry.

**[0064]** An electric igniter is placed down to a section of coal seam at the bottom of the production borehole 6, the communication valve between the production borehole 6 and the gas pipeline 13 is opened. The pure oxygen conveyed by the $O_2$ pipeline 7 and the $CO_2$ conveyed by the $CO_2$ pipeline 8 are mixed in the injection borehole 5 to obtain oxygen-rich $CO_2$ having an oxygen volume concentration of 20-30% as a gasification agent which is then fed into the coal seam at the bottom of the production borehole 6 through the communicating fracture 4. Then, the content of methane at the production borehole is monitored, and the content of oxygen in the input gas is controlled to ensure that the concentration of $O_2$ at the production borehole is not within the expansion limit of methane. After the $O_2$ concentration or the content of methane meets the requirements, the igniter is started to ignite the coal seam at the bottom of the production borehole 6, so that an original fire zone 11 is established. The raw gas generated by the reaction of the gasification agent and the coal seam 1 is discharged by the gas pipeline 13. The flow of the oxygen-rich $CO_2$ is controlled (about 300-500 $m^3$/h) to allow the temperature of the fire zone to be not less than the temperature of the spontaneous ignition point of the coal seam.

**[0065]** After the temperature of the fire zone exceeds 1000°C and if the pressure drop of the input gas exceeds 10%, the flow of the oxygen-rich $CO_2$ is increased at a rate of 500-1000 $Nm^3$/h until the flow reaches 5000-8000 $Nm^3$/h, so that the fire source is allowed to move to the injection borehole in a direction opposite to the airflow direction of the oxygen-rich $CO_2$. Because a gasification reaction and a pyrolytic reaction occur between the oxygen-rich $CO_2$ and the coal seam:

$$C + O_2 \rightarrow CO_2 \text{ -394kJ/mol}$$

$$C + \frac{1}{2}O_2 \rightarrow CO - 111\text{kJ/mol}$$

$$C + CO_2 \rightarrow 2CO + 173\text{kJ/mol}$$

$$C + H_2O \rightarrow H_2 + CO + 131\text{kJ/mol}$$

$$\text{coal} \rightarrow H_2 + CH_4 + CO_2 + \text{tar} + \text{semicoke} + \ldots$$

a part of coal seam is gasified along the communicating fracture 4, and the communicating fracture is expanded to gradually form a gasification passage 12, which is advantageous for the discharge of gas. Meanwhile, the released heat is transferred to the coal seam to facilitate desorption of $CH_4$ and to dry the coal seam, thereby increasing the permeability of the coal seam. The desorbed methane, together with the gasified gas and the pyrolyzed gas, is discharged through the production borehole 6 and the gas pipeline 13.

**[0066]** Then, the flow and the $O_2$ concentration are remained to perform reverse combustion (that is, the expansion direction of the front edge of flame is opposite to the flow direction of the fed gas), and the pressure at the injection borehole 5 is monitored in real time. When the difference between the pressure of the injection borehole 5 and that of the production borehole 6 is small (the pressure difference is less than about 0.3 MPa), it is indicated that the gasification passage 12 between the lower end of the injection borehole 5 and the lower end of the production borehole 6 is established successfully.

**[0067]** After the gasification passage 12 is established, the concentration of oxygen in the oxygen-rich $CO_2$ fed from the upper end of the injection borehole 5 to the underground is increased up to 40-60% (with an increase of 2-5% per day) to improve the temperature of the reaction zone, and forward gasification is performed (that is, the expansion direction of the front edge of the flame is the same as the flow direction of the fed gas) to ensure that $CO_2$ comes into full contact with the hot coal seam in the gasification passage and thus realize the gasification of the coal seam between the boreholes. Meanwhile, as the gasification space is expanded, the effect of the geostress becomes apparent, so that crushed zones of the coal seam around the gasification passage are generated under the combined action of heat effects, and the release of the coalbed gas is thus quickened. In practices, the flow of the $CO_2$ oxygen-rich gas and/or the oxygen concentration may be adjusted according to the thickness of dirt band of the coal seam, the content of water and the distance between the boreholes. If the content of water in the coal seam is less than the amount of water required for the gasification reaction, oxygen-rich $CO_2$ and water vapor may be injected, and the injection amount of water vapor is a result obtained by dividing a difference between the amount of water required for the gasification reaction and the content of water in the coal seam by a decomposition rate of the water vapor.

**[0068]** The combustion cavity is formed after the gasification of the coal seam, and the space of the combustion cavity is filled with ash, coke slag, dirt band, roof rocks and un-gasified coal seam and may be used as a space for $CO_2$ storage. At the beginning of storage, the production borehole 6 is closed, the $CO_2$ pipeline 7 is opened, and high pressure $CO_2$ is injected, where the pressure of $CO_2$ is generally controlled to be 6-8 MPa and the injection amount of $CO_2$ is generally controlled to be 400-500 $Nm^3/m^3$ (400-500 $m^3$ of $CO_2$ per volume of the combustion cavity may be stored). The pressure and injection amount of $CO_2$ are specifically determined according to the volume of the combustion cavity, the hydrogeological conditions of the coal seam and the like.

**[0069]** In the present invention, the generated gasified gas, pyrolyzed gas and coalbed gas are discharged from the production borehole and then used for synthesis of methane.

## Embodiment 2

**[0070]** In Embodiment 2, the extraction rate of the coalbed gas is quickened by a pinnate branch horizontal drilling technology, and the natural fractures and cleats of the coal seam are communicated by a multilateral well technology, thereby increasing the exposed area of the coal seam and facilitating the implementation of the subsequent gasification. This embodiment will be described with reference to Fig. 4 and Fig. 5. Fig. 4 is a schematic diagram of the method for joint-mining of coalbed gas and coal according to the present invention, wherein the extraction of coalbed gas is performed by pinnate branch horizontal drilling. Fig. 5 is a schematic diagram of the method for joint-mining of coalbed gas and coal. The specific implementation is as below.

**[0071]** A vertical borehole as a production borehole 6 is constructed from the ground 2 to the coal seam 1 through overlying strata 3. A vertical borehole as an injection borehole 5 is constructed at a certain distance away from the production borehole 6 (referring to Embodiment 1), and the borehole 5 is brought to communicate with the borehole 6 in the coal seam. The injection borehole 5 is a pinnate horizontal borehole and includes several groups of pinnate branch horizontal wells 14, and the bottom of the borehole is located in the coal seal 1 to be gasified. For the pinnate branch horizontal wells, the aperture and length of a main horizontal well and each of the branch wells and the number of the branch wells among are determined according to the mining area of the coal seal and the coalbed gas. To prevent the well wall from collapse, sieve tubes may be put into the main horizontal well for supporting.

**[0072]** After the pinnate horizontal drilling is finished, a drainage rod pump is put in the production borehole 6, and a drainage pipeline 9 and a coalbed gas pipeline 10 are mounted. An $O_2$ pipeline 7 and a $CO_2$ pipeline 8 are mounted at the orifice of the injection borehole 5. Then, the communication valve between the production borehole 6 and the gas pipeline 10 is closed, and high pressure $N_2$ is continuously injected into the coal seam from the injection borehole 5, where the injection pressure is not larger than the fracturing pressure of the coal seal and the injection amount is determined according to the content of the saturated gas of the coal seam. After the total injection amount of $N_2$ meets the requirements, $N_2$ is stopped to be injected, and both the injection borehole 5 and the production borehole are closed for well soaking for 10-20 days to ensure that $N_2$ comes into full contact with the coal seam and displaces $CH_4$ adsorbed in the coal seam. Then, the production borehole 6 is opened again, and the water in the coal seam is drained by the drainage pipeline 9 to dewater the coal seam 1. Meanwhile, the coalbed gas pipeline 10 is opened to reduce the pressure at the production borehole 6 and to facilitate desorption of the coalbed gas, and the coalbed gas is collected to a ground tube network through the coalbed gas pipeline 10. After the extraction is performed for a time and when the pressure at the bottom of the production borehole 6 drops to below 10 kPa, a next cycle of injection and extraction is performed.

**[0073]** When the content of $CH_4$ in the gas from the production borehole 6 drops significantly (that is, the volume concentration is less than 5%), the production borehole 6 is opened, the drainage pipeline 9 is taken away and the gas pipeline 13 is mounted. Then, the communication valve between the production borehole 6 and the gas pipeline 13 is opened, and high pressure $CO_2$ continues to be injected into the coal seam 1 from the injection borehole 5, where the injection pressure is larger than the hydrostatic pressure of the coal sea and the injection amount is determined according to the content of water in the coal seam. Then, the $CO_2$ is discharged from the gas pipeline 13 to take away the water in the coal seam between the boreholes, i.e., to dewater the coal sea, so that the coal seam at the bottom of the production borehole 6 remains dry.

**[0074]** The pure oxygen conveyed by the $O_2$ pipeline 7 and the $CO_2$ conveyed by the $CO_2$ pipeline 8 are mixed in the injection borehole 5 to obtain oxygen-rich $CO_2$ having an oxygen volume concentration of 20-30% as a gasification agent and then fed into the coal seam at the bottom of the production borehole 6 through the communicating fracture 4. Then, the content of methane at the production borehole is monitored, and the content of oxygen in the input gas is controlled to ensure that the concentration of $O_2$ at the production borehole is not within the expansion limit of methane. After the $O_2$ concentration or the content of methane meets the requirements, the communication valve between the production borehole 6 and the gas pipeline 13 is opened. Hot coke is put onto the bottom of production borehole 13, and the amount of the coke put is determined according to the thickness of the coal seam, size of the sleeve, ignition point of the coal seam and the like, so as to ignite the coal seam at the bottom of production 6 and establish a original fire zone 11. The raw gas generated by the reaction of the gasification agent and the coal seam 1 is discharged by the gas pipeline 13. The flow of the oxygen-rich $CO_2$ is controlled to allow the temperature of the fire zone to be not less than the temperature of the spontaneous ignition point of the coal seam.

**[0075]** After the temperature of the fire zone exceeds 1000°C and if the pressure drop of the input gas exceeds 10%, the flow of the oxygen-rich $CO_2$ is increased at a rate of 300-500 $Nm^3/h$ until the flow reaches 3000-5000 $Nm^3/h$, so that the fire source is allowed to move to the injection borehole in a direction opposite to the airflow direction of the oxygen-rich $CO_2$. Because a gasification reaction and a pyrolytic reaction occur between the oxygen-rich $CO_2$ and the coal seam;

$$C + O_2 \rightarrow CO_2 \text{ -394kJ/mol}$$

$$C + \frac{1}{2}O_2 \rightarrow CO - 111\text{kJ/mol}$$

$$C + CO_2 \rightarrow 2CO + 173\text{kJ/mol}$$

$$C + H_2O \rightarrow H_2 + CO + 131\text{kJ/mol}$$

$$\text{coal} \rightarrow H_2 + CH_4 + CO_2 + \text{tar} + \text{semicoke} + \ldots$$

a part of coal seam is gasified along the communicating fracture 4, and the communicating fracture is expanded to gradually form a gasification passage 12, which is advantageous for the discharge of gas. Meanwhile, the released heat is transferred to the coal seam to facilitate the desorption of $CH_4$ and to dry the coal seam, thereby increasing the permeability of the coal seam. The desorbed methane, together with the gasified gas and the pyrolyzed gas, is discharged through the production borehole 6 and the gas pipeline 13.

**[0076]** Then, the flow is remained to perform reverse combustion (that is, the expansion direction of the front edge of flame is opposite to the flow direction of the fed gas), and the pressure at the injection borehole 5 is monitored in real time. When the pressure shown by a pressure meter connected to the upper end of the injection borehole 5 drops significantly (the pressure drop is generally 10-60% of the original pressure), it is indicated that the original fire zone 11 has been expanded close to the bottom of the injection borehole 5. When a difference between the pressure of the injection borehole 5 and the pressure of the production borehole 6 is small (or the pressure difference is less than about 0.3 MPa), it is indicated that the gasification passage 12 between the lower end of the injection borehole 5 and the lower end of the production borehole 6 is established successfully.

**[0077]** After the gasification passage 12 is established, the concentration of oxygen in the oxygen-rich $CO_2$ fed from the upper end of the injection borehole 5 to the underground is increased up to 50-70% (with an increase of 2-5% per day) to improve the temperature of the reaction zone, and forward gasification is performed (that is, the expansion direction of the front edge of the flame is the same as the flow direction of the fed gas) to ensure that $CO_2$ comes into full contact with the hot coal seam in the gasification passage and thus realize the gasification of the coal seam between the boreholes. Meanwhile, as the gasification space is expanded, the effect of the geostress becomes apparent, so that crushed zones of the coal seam around the gasification passage are generated under the combined action of heat effects, and the release of the coalbed gas is thus quickened. In practices, the flow of the $CO_2$ oxygen-rich gas and/or the oxygen concentration may be adjusted according to the thickness of dirt band of the coal seam, the content of water and the distance between the boreholes.

**[0078]** In the present invention, the generated gasified gas, pyrolyzed gas and coalbed gas are discharged from the production borehole and then used for methane-power generation.

## Embodiment 3

**[0079]** Embodiment 3 is basically the same as Embodiment 2, except for a different that an original passage for drainage and gas extraction is established by directionally horizontal drilling technology and the horizontal well 15 is formed with an arrangement mode of a U-shape structure. The horizontal well is vertical to a direction of a primary fracture of a coal seal, a vertical well, i.e., a production borehole 6, is used for drainage while gas extraction is performed by an injection borehole 5. At the end of the original extraction of coalbed gas, a fire zone is established in the production borehole 6, the passage starts being heated, and the synchronous displacement of coalbed gas is performed to implement the gasification of the coal seam between the boreholes. This embodiment will be described with reference to Fig. 6 and Fig. 7. Fig. 6 is a schematic diagram of a method for joint-mining of coalbed gas and coal according to the present invention, where the extraction of coalbed gas is performed by directionally horizontal drilling technology. Fig. 7 is a schematic diagram of the method for joint-mining of coalbed gas and coal, wherein the ignition is performed, and a passage is heated and then expanded to form a gasification passage for synchronous displacement of coalbed gas. In the present invention, the produced gasified gas, pyrolyzed gas and coalbed gas are discharged from the production borehole and then used for methane-methanol production.

**[0080]** The present invention uses underground gasification to generate a large amount of heat, so that the passage for coalbed gas fracturing is greatly expanded while heating the coal seam and improving the methane desorption capacity of the coal seam, the yield of the coalbed gas may be greatly improved, and the problem of low permeability of coalbed gas reservoirs in China is fundamentally solved. Meanwhile, the underground gasification chemically utilizes the coal seam, in which coalbed gas has been extracted, and the generated gas containing a large amount of methane, CO and $H_2$ is converted by a ground technology to obtain clean methane. The collaborative development and comprehensive utilization of coalbed gas and a coal seam itself in the present invention may greatly reduce the production and development cost, improve the yield of the final product methane, greatly promote the quality of gas and realize the joint-mining of coal and coalbed gas. In addition, the use of fluid containing $CO_2$ as a processing medium for fracturing and gasification improves the methane desorption capacity in the coal seam, the extraction rate of the coalbed gas and the content of effective gas compositions such as methane or other combustible gases in the gasified gas, and the generated $CO_2$ during this process may also be recycled. Therefore, the present invention is a new low-carbon, efficient and clean method.

**[0081]** Although the present invention has been described in details above, the present invention is not limited to the specific implementations as described herein. It should be understood by those skilled in the art that other modifications and deformations may be made without departing from the scope of the present invention. The scope of the present invention is defined by the appended claims.

## Claims

1. A method for joint-mining of coalbed gas and coal, comprising:

   1) a well-drilling step: drilling from the ground to a coal seam to provide at least one injection borehole and at least one production borehole for communicating the coal seam with the ground;
   2) a fracturing and penetration step: injecting a fracturing medium containing $CO_2$ into the coal seam from the injection borehole, thereby forcing the fracture medium to flow in the coal seam and to discharge from the production borehole so that the injection borehole is brought to communicate with the production borehole in the coal seam;
   3) a coalbed gas extraction step: injecting a displacement medium into the coal seam from the injection borehole, displacing coalbed gas in the coal seam, and collecting the coalbed gas from the production borehole;
   4) an ignition step: establishing a fire zone in the coal seam at the bottom of the production borehole for igniting the coal seam; and
   5) an underground gasification step: injecting a gasification agent containing $CO_2$ into the coal seam from the injection borehole so that a gasification reaction and a pyrolytic reaction occur between the gasification agent and the coal seam to generate heat energy and a gasified gas, transferring the heat energy towards the inside of the coal seam to generate a pyrolyzed gas, synchronously displacing the coalbed gas to generate free methane, discharging and collecting the free methane, together with the gasified gas and the pyrolyzed gas, from the production borehole.

2. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, the fracturing medium is a mixture of $CO_2$ and $O_2$, and the volume concentration of $O_2$ is below 20%.

3. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, further comprising:

   6) a $CO_2$ recycling step: recycling $CO_2$ generated during the underground gasification step, and using a part of the recycled $CO_2$ as the gasification agent.

4. The method for joint-mining of coalbed gas and coal according to claim 3, **characterized in that**, further comprising:

   7) a $CO_2$ storage step: at the end of the underground gasification of the coal seam between the injection borehole and the production borehole, filling a part of the recycled $CO_2$ into a combustion cavity for burying and storage.

5. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, prior to the ignition step 4), further comprising a safety detection step for ensuring ignition safety.

6. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, in the coalbed gas extraction step 3), the displacing coalbed gas in the coal seam is injecting $CO_2$ or $N_2$ for displacement.

7. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, the injection

borehole or the production borehole is composed of a directional borehole and a vertical borehole.

8. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, the injection borehole and the production borehole are composed of vertical boreholes.

9. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, the establishing a fire zone is performed by electric ignition or solid fuel ignition.

10. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, the underground gasification comprises forward combustion, reverse combustion or retracting injection point combustion.

11. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, the well drilling is drilling a horizontal well in a direction vertical to a primary fracture of the coal seam.

12. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, the $CO_2$ used in the fracturing and penetration step is gaseous, liquid or supercritical $CO_2$, or a mixed liquid composed of liquid $CO_2$, water collagen and chemical additive(s).

13. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, in the fracturing and penetration step, when the pressure in the injection borehole drops rapidly while the gas outflow of the production borehole is above 100 $Nm^3/h$, the injection borehole and the production borehole have been communicated with each other in the coal seam.

14. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, in the underground gasification step, the volume concentration of $O_2$ in the gasification agent containing $CO_2$ is 20-70% to ensure that ash will not be melted.

15. The method for joint-mining of coalbed gas and coal according to claim 14, **characterized in that**, in the underground gasification step, the volume concentration of $O_2$ in the gasification agent containing $CO_2$ is 20-50% for establishment of a gasification passage.

16. The method for joint-mining of coalbed gas and coal according to claim 15, **characterized in that**, in the underground gasification step, the volume concentration of $O_2$ in the gasification agent containing $CO_2$ is 40-70% for gasification of the coal seam at the end of the establishment of the gasification passage.

17. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, if the content of water in the coal seam is less than the amount of water required for the gasification of the coal seam at the end of extraction of the coalbed gas, the gasification agent containing $CO_2$ is a mixture of $O_2$, $CO_2$ and water vapor.

18. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, for the conveying of the gasification agent in the underground gasification step, the gasification agent is conveyed from the ground to the fire zone through an annular conveying pipe or a borehole.

19. The method for joint-mining of coalbed gas and coal according to claim 3, **characterized in that**, the $CO_2$ recycled in the $CO_2$ recycling step comes from fume generated during gas power generation or a decarbonization section during gas purification.

20. The method for joint-mining of coalbed gas and coal according to claim 1, **characterized in that**, the generated gasified gas, pyrolyzed gas and coalbed gas are discharged from the production borehole for synthesis of methane, methane power generation or production of methane-methanol.

21. The method for joint-mining of coalbed gas and coal according to claim 3, **characterized in that**, the $CO_2$ recycled in the $CO_2$ recycling step is used as the fracturing medium for the fracturing and penetration step or the displacement medium for the coalbed gas extraction step.

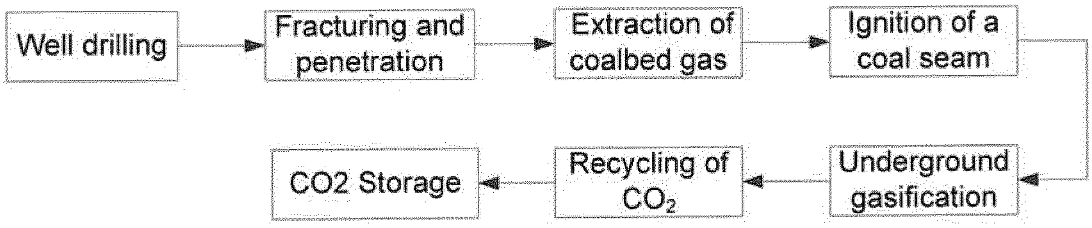
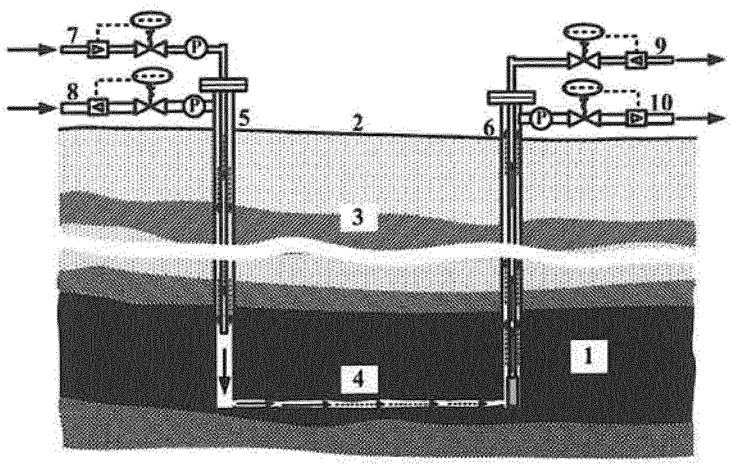

Well drilling
Fracturing and penetration
Extraction of coalbed gas
Ignition of a coal seam
Underground gasification
Recycling of CO2
CO2 Storage

Fig.1


7
8
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1

FIG. 2

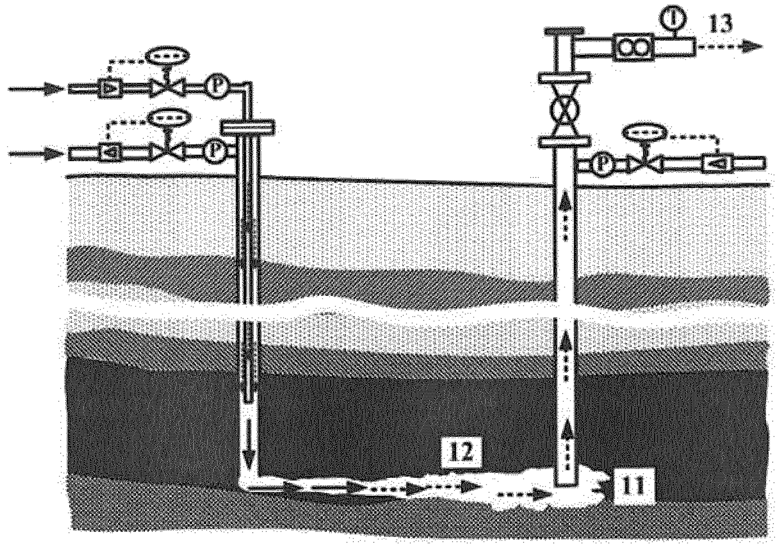


FIG. 3

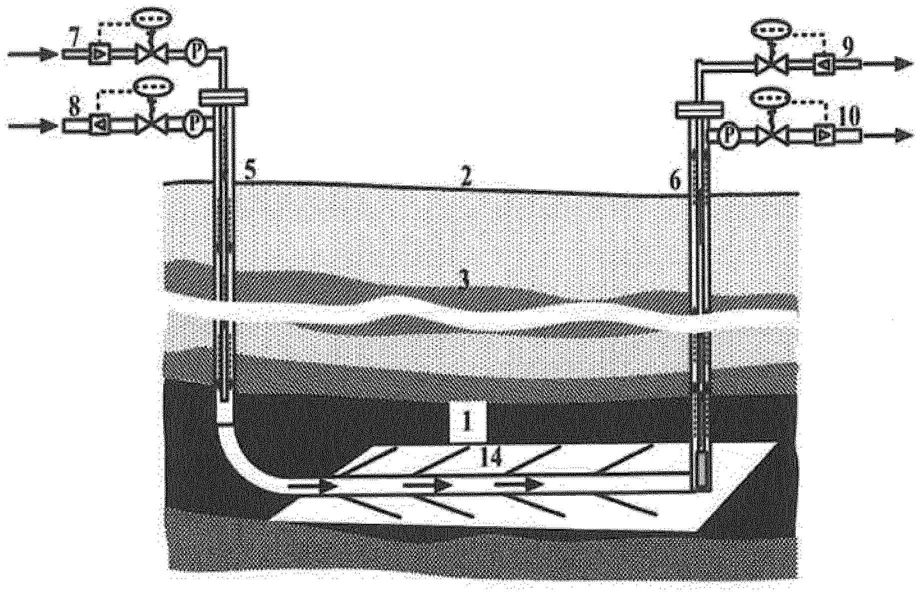


FIG. 4

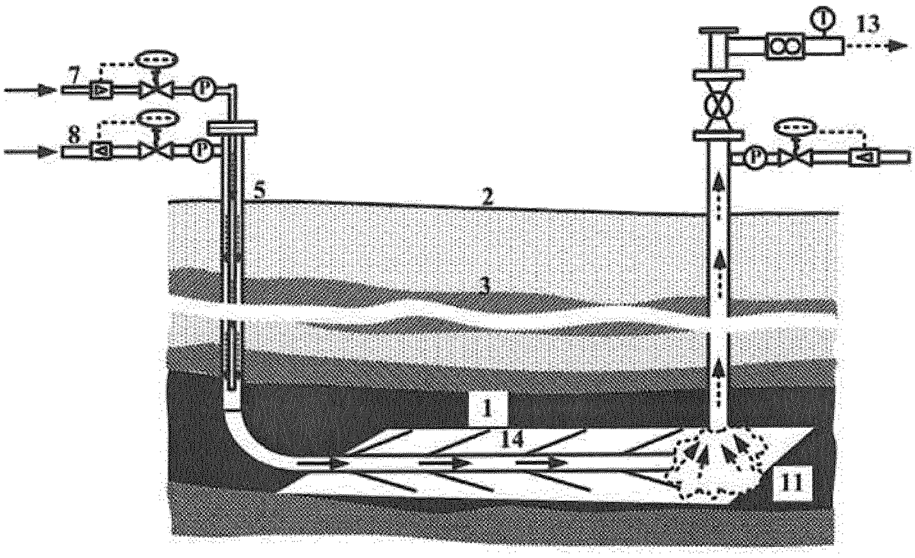


FIG. 5

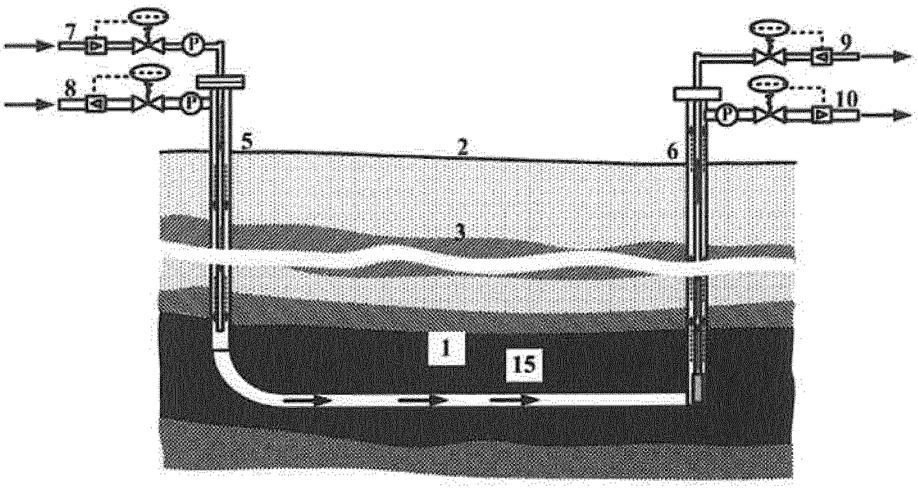


FIG. 6

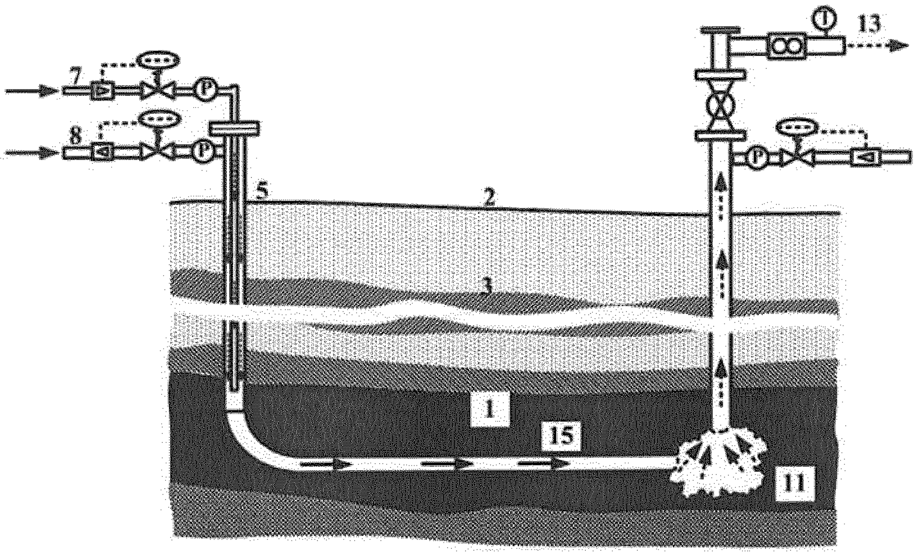


FIG. 7

# INTERNATIONAL SEARCH REPORT

International application No.
**PCT/CN2013/083781**

**A. CLASSIFICATION OF SUBJECT MATTER**

E21B 43/00 (2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC: E21B 43/-, E21B 7/-, E21B 47/-

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, CNPAT, CNKI: co-extraction, drill, fracture, carbon dioxide, gasifying agent, oil gas, oxidation, injection, carbon oxide, methane, coal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | CN 102477857 A (ENN COAL GASIFICATION MINING CO., LTD.), 30 May 2012 (30.05.2012), see claims 1-25 | 1-21 |
| A | CN 102080519 A (ZHONGKUANG RUIJIE (BEIJING) TECHNOLOGY CO., LTD.), 01 June 2011 (01.06.2011), see claims 1-6 | 1-21 |
| A | US 6571874 B1 (RAG AKTIENGESELLSCHAFT), 03 June 2003 (03.06.2003), see claims 1-7 | 1-21 |
| A | EP 0039824 A1 (ZIMPRO-AEC, LTD.), 18 November 1981 (18.11.1981), see claims 1-14 | 1-21 |

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 13 November 2013 (13.11.2013) | **26 December 2013 (26.12.2013)** |

| Name and mailing address of the ISA/CN: | Authorized officer |
|---|---|
| State Intellectual Property Office of the P. R. China<br>No. 6, Xitucheng Road, Jimenqiao<br>Haidian District, Beijing 100088, China<br>Facsimile No.: (86-10) 62019451 | **ZHOU, Wei**<br>Telephone No.: (86-10) **62414371** |

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## INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
**PCT/CN2013/083781**

| Patent Documents referred in the Report | Publication Date | Patent Family | Publication Date |
|---|---|---|---|
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| CN 102080519 A | 01.06.2011 | None | |
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| | | EP 1112437 B1 | 23.07.2003 |
| | | CN 1097136 C | 25.12.2002 |
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| | | DE 59906375 D1 | 28.08.2003 |
| | | CN 1320189 A | 31.10.2001 |
| EP 0039824 A1 | 18.11.1981 | NO 811621 A | 07.12.1981 |
| | | US 4330038 A | 18.05.1982 |
| | | CA 1215316 A1 | 16.12.1986 |

Form PCT/ISA/210 (patent family annex) (July 2009)