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(54) UNDERGROUND COAL GASIFICATION AND LINKAGE METHOD

(57) An underground coal gasification and linkage method comprises the following steps: a) establishing a fire region (4; 21) in a bottom coal layer of a first drill hole (1; 11; 22); b) taking another existing drill hole outside the fire region or a newly drilled drill hole as a second drill hole (2; 13, 14, 15; 23, 24, 25), and mechanically and directionally drilling a nearby coal layer near the bottom of the first drill hole near the fire region through the lower end of the second drill hole, so as to link the nearby coal layer, thereby forming, in the nearby coal layer, a directional passage (5; 17; 27) communicating with the fire region; and c) conveying oxygen-containing gas to the fire region through the second drill hole and the directional passage, and performing hot working on the directional passage, so as to expand the directional passage, thereby forming a gasification passage used for an underground coal gasification furnace.

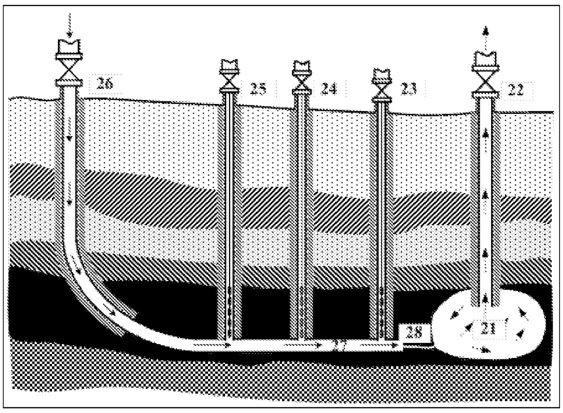

FIGURE 3B

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of CN Application No. 201110388215.1 filed on November 30, 2011, entitled "UNDERGROUND COAL GASIFICATION AND LINKAGE METHOD", which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to a method for underground coal gasification and linkage, which is applicable for the fields of underground coal gasification.

BACKGROUND OF THE INVENTION

[0003] Underground coal gasification technology refers to a process in which a gasifying furnace is directly constructed in an underground coal seam, and a gasification action is controllably performed on the coal by feeding in a gasification agent, so that coal may be converted in situ into a combustible gas in natural state and conveyed to the ground.

[0004] Linkage is one of the key steps in the process of constructing an underground gasifying furnace, which refers to a process in which a highly permeable channel is artificially constructed along the coal seam at the bottom of the gas inlet and outlet drilled wells before the gasification process, so that it may be guaranteed that the gasification agent may be fed to the coal seam swimmingly and the coal gas may be discharged from the coal seam, and a thermal condition essential to the gasification action may be provided.

[0005] In the development course of the underground coal gasification technology, various gasification channel linkage methods have been developed for different coal seam hydrogeological conditions and physicochemical properties by foreign countries, especially, the former USSR, wherein the methods most widely researched and applied so far mainly include: air firepower infiltration, hydraulic pressure fracture and electric power linkage, etc. Although these linkage methods are different in the principles and implementation modes thereof, the processes are similar essentially, and external forces are required to increase the connectivity between natural coal seam pores and fissures, so as to improve the gas permeability of the coal seam. Once a fissure channel is formed, heating process must be performed on the coal seam to enlarge the fissure channel into a gasification channel, because the fissure channel formed in the initial stage cannot meet the technological requirements for large-scale gasification due to the main problems of small channel section, large resistance and small gas throughput. Heating process (generally referred to as combustion linking) refers to a process in which a coal seam is combusted by feeding in the air and the fissure channel section is further enlarged after the coal seam is combusted. Generally, it may be further divided into reverse combustion linking and forward combustion linking according to the relation between the gas admission direction and the flame front moving direction, wherein reverse combustion linking tends to burn a narrow channel with a fixed diameter, while forward combustion linking generally expand forward with a wide flame front. Therefore, reverse combustion linking may form a regular channel, and forward combustion linking may enlarge the ignition source.

[0006] However, as limited by the diversity of geologic conditions and the anisotropy of the coal seam structure, it is indicated by theoretical research and practice result at home and abroad that the above methods has certain defects in specific application, mainly as follows:

1) Great influence of coal seam and stratum conditions: for example, for a coal seam that is deep embedded or has a low permeability, when gasification channels are linked via combustion infiltration, problems due to large stratum pressure or low coal seam permeability may occur, for example, it is difficult to form a fissure and to control the direction of a fissure-expanded channel, and the linkage effect and efficiency are poor, etc.; when the hydraulic pressure fracture method is applied to a water-sensitive coal seam or a fluffy stratum, because argillization tends to occur on the coal seam and the fissure generated by fracture tends to be blocked again, it is difficult to attain the prospective effect; the electric power linkage method may cause a too high current dropout, etc., for a coal seam and a stratum with a high water content;

2) Short linkage distance: as indicated by the data, the linkage distance is generally less than 50 meters, if it wants to increase the linkage distance, the pressure or current intensity must be increased; as a result, the wall rock structure of the coal seam will be destroyed, or the linkage time will be increased;

3) Inhomogeneous permeability and poor directivity of the channel: because of the anisotropy of the pore and fissure structure of the coal seam itself, a homogeneous fissure of the coal seam cannot be obtained by the above methods; although channels with high permeability can be formed between drilled wells, these channels are not in line, and inhomogeneous gasification tends to occur, thus coal loss will be increased.

[0007] In view of the above defects of traditional linkage methods, in recent decades, in addition to improving the traditional linkage methods, foreign research communities and industrial enterprises have researched and developed several novel linkage methods respectively, mainly including: directional drilling, atomic energy blasting and chemical liquid crushing, etc., wherein, because directional drilling has the advantages of 1) small influence of coal seam and stratum condition; 2) long linkage distance; 3) strong channel directivity, regular channel section and homogeneous gas permeability, it has been widely applied to underground coal gasification engineering at home and abroad.

[0008] According to disclosed literature data and patents, in directional drilling, a drill directing and measuring device is used, and it may reach a predetermined target stratum by controlling the slope and direction of the drilled well in real time, so that a directional channel with a certain diameter may be formed in the coal seam. The directional channel can replace the narrow fissure channel formed by traditional linkage method, and connect the vertical wells.

[0009] The existing directional drilling method generally employs a cold-state connection, that is, directional drilling technology is firstly used to directly connect the vertical well and the horizontal well in the coal seam during the construction of a horizontal well, and in order to prevent hole collapse and hole shrinkage, a sieve tube is generally placed in the horizontal well. After the cold-state connection, ignition and gasification are implemented directly, and in the specific implementation mode, for example, in a Controlled Retraction Injection Point (CRIP) technology from USA, ignition is directly implemented in the directional channel with the aid of a special mechanical device, and changing the gasification agent injection point by controlling the mechanical device in the well, without the need to perform a heating process on the horizontal well coal seam. And in another method comprises the steps of implementing ignition in a vertical well and performing a heating process in the horizontal well to the coal seam, for example, a shaftless underground gasification process of patent CN/ 01382065. It is indicated by the practice result that, for the former, because it needs to remote control the ignition device in the well, the ignition device is complex, and its operation is difficult, the success of ignition cannot be guaranteed; and for the latter, if there is a large amount of ground water in the coal seam, extra drainage wells must be constructed first to drain off the ground water, and then to start ignition, but in a high temperature, pressurized and aired condition, the drainage of the coal seam is difficult, and water may not be drained in certain cases, thereby the ignition process will be more difficult; additionally, one a directionally-drilled directional channel is formed, if no operation for a long time, hole collapse and hole shrinkage tend to occur easily, further channel block may be caused.

[0010] In addition, for the existing heating process for gasification channel, because air is employed as the gasification agent, for a thin coal seam (with a thickness less than 2.0 m), a water-containing coal seam and a coal seam containing a large gangue, problems such as slow flame moving speed, long linkage period and poor channel section stability, etc., may occur, the key reasons that cause the above problem lie in the anisotropy of the coal seam structure (for example, containing a gangue), the great heat dissipation, the low temperature at the flame front and the lack of necessary monitoring measures.

Definition of terms:

[0011] Combustion linking: it refers to a process in which a coal seam is combusted by injected air and the fissure channel section is further enlarged after the coal seam is combusted. Generally, it may be further divided into reverse combustion linking and forward combustion linking according to the relation between the gas admission direction and the flame front moving direction. In general, in the reverse combustion linking process, the gas admission direction is opposite to the flame front moving direction; while in the forward combustion linking process, i the gas admission direction is the same as the flame front moving direction.

[0012] Fissure channel: a coal seam has a natural void, pore and fissure structure, and under the action of an external force, the voids, pores and fissures contained by the coal body may be connected, and a channel with certain permeability can be formed; when the external force exceeds the maximum stress the coal body can bear, the coal body may crack, and an artificial fissure channel with a certain width may be formed.

[0013] Directional channel: a drill directing and measuring device is used, and it may reach a predetermined target stratum by controlling the slope and direction of the drilled well in real time, so that a directional channel with a certain diameter may be formed in the coal seam.

[0014] Gasification channel: it refers to enlarging the size of the section of a crack channel or directional channel by performing hole expansion on the crack channel or the directional channel so as to form a channel with a stable section, small resistance, high permeability and large gas throughput, thereby the requirements of the underground gasification process may be met.

[0015] Oxygen-containing gas: for convenient illustration, a gas containing oxygen is referred to as oxygen-containing gas, the oxygen content of the oxygen-containing gas is between 0~100%, and it generally includes: air, oxygen-enriched gas and pure oxygen, and it may also be prepared by mixing pure oxygen with carbon dioxide, or it may be prepared by mixing pure oxygen with an inert gas such as argon gas, etc.

[0016] Oxygen-enriched gas: generally, the content of oxygen in the air is 20.93%, the content of nitrogen is 78.1%, and the rest is a small amount of inert gas, etc.; for convenient illustration, a gas with an oxygen content of greater than 20.93% is referred to as oxygen-enriched gas. Generally, it is prepared by mixing the air with pure oxygen, or it may be prepared by mixing pure oxygen with carbon dioxide, or it may be prepared by mixing pure oxygen with an inert gas such as argon gas, etc., or it may be prepared by mixing pure oxygen, carbon dioxide, air and inert gas according to a required concentration in any proportion.

[0017] Burning zone of a well: it refers to a combusting zone or a high temperature zone established after directly igniting in a coal seam at the bottom of a well, wherein the bottom of the well is in direct communication with the burning zone; or, a bottom-hole high temperature zone or combusting zone is formed by guiding the burning zone to the bottom of the well via combustion linking technology.

SUMMARY OF THE INVENTION

[0018] As described above, due to the influence by coal seam and stratum conditions, the traditional linkage method has technical defects of a short linkage distance, poor channel directivity, a slow linkage speed and the like in practice. With the current directional drilling linkage method, the linkage distance may be increased, the channel directivity may be improved, and the linkage speed may be improved. However, there still exist problems that the initial ignition process tends to be influenced by ground water, that the flame moving speed in the heating process is slow, and that hole collapse, hole shrinkage and channel block tend to occur after the channel distance is increased.

[0019] It has been found by the inventors that, the key reasons that cause the above problems of the current directional drilling linkage method lie in that the connection between the directional drilled well and the vertical well is performed in a cold-state condition (that is, the connection between the directional channel and the vertical well is formed by means of a directional drilling technology, and then ignition or coal gasification is performed in the directional channel or the vertical well), but water is contained in the pores and fissures of a natural coal seam, and a gangue is generally contained in the coal seam, thus when a directional channel is formed, the catchment zone is hence increased, as a result, the water in the coal seam will infiltrate into the free directional channel, which leads to channel flowage; when the channel flowage is caused, it is difficult to perform the ignition process, and flameout will be caused, or even ignition cannot be accomplished; moreover, during the heating process, the heat dissipation is considerable, the temperature at the flame front is low, and the flame moving speed is slow because of the channel flowage; similarly, because of the channel flowage, argillization may occur in the gangue, which will cause hole shrinkage, block and the like in the free directional channel.

[0020] Based on the above findings by the inventors, an object of the invention is to solve the problems of the existing directional drilling linkage method that the initial ignition process tends to be influenced by ground water, the flame moving speed during the heating process is slow, hole collapse, hole shrinkage and channel block tend to occur, and to provide a method for underground coal gasification and linkage, thereby improving the efficiency and reliability of the linkage process.

[0021] In order to realize the above object of the invention, according to a first aspect of the invention, there provides an underground coal gasification and linkage method, which employs a directional drilling and thermal-state connection technology and an oxygen-enriched air linkage technology, and is applied to construct a gasification channel for an underground coal gasifying furnace in the vicinity of the bottom of at least one substantially vertical first well, where the method includes steps of:

a) establishing a burning zone in a coal seam at the bottom of the first well;

b) performing mechanical directional drilling in the coal seam nearby the bottom of the first drilled well in the vicinity of the burning zone, connecting the bottom of the second well, so that the coal seam nearby the bottom of the first well is pre-perforated to form a directional channel in communication with the burning zone in the coal seam nearby the bottom of the first drilled well, wherein the second well is an existing drilled well or a newly-drilled well outside the burning zone; and

c) an oxygen-containing gas is injected into the burning zone via the second well and the directional channel, and performing a heating process on the directional channel, to enlarge the directional channel to form the gasification channel for the underground coal gasification.

[0022] In the above first aspect of the invention, one or more of the following additional technical solutions may be employed:

[0023] The burning zone is established by means of electric ignition, solid fuel ignition or coke ignition, or a high-temperature coal seam of an existing burning zone or cavity in an operation zone is taken as the burning zone

[0024] The directional drilling is performed by means of any one of directional well technology, horizontal well technology, lateral drilling technology, radial horizontal well technology, branched well technology, cluster well technology and extended reach well technology of the petroleum or coal seam gas drilling technology.

[0025] The heating process is implemented by forward combustion linking and reverse combustion linking, and the medium used in the combustion linking comprises air, pure oxygen, propane, silicane, diesel fuel or liquid hydrocarbon, or a combination thereof.

[0026] The oxygen-containing gas includes any one of: air, oxygen-enriched gas and pure oxygen.

[0027] The oxygen-containing gas is mixed with at least one of propane, silicane, diesel fuel and liquid hydrocarbon that function as a combustion improver.

[0028] The mixing is performed on the ground or underground.

[0029] The oxygen-containing gas and the combustion improver are conveyed to the burning zone via an annulus conduit pipe, or directly conveyed from the ground to the burning zone via a well.

[0030] The directional channel is located in the coal seam and has a length of 10~1000m, and the directional channel is a non-supported channel or a supported channel that is supported by a sieve tube.

[0031] According to a second aspect of the invention, an underground coal gasification and linkage method is provided, and the method includes steps of:

a) establishing a burning zone in a coal seam at the bottom of a well;

b) performing a pre-perforating operation at the bottom of the drilled well outside the burning zone by directional drilling along the coal seam to form a drilled directional channel, wherein a reserved coal seam without drilled well is reserved between an end of the directional channel and the burning zone;

c) performing a fissure enlarging operation in the reserved coal seam so as to form a fissure in communication with the burning zone; and

d) conveying an oxygen-containing gas to the burning zone via the drilled well for the pre-perforating operation, and performing a heating process on the fissure formed in the reserved coal seam to enlarge the fissure into a gasification channel, so that the directional channel is in communication with the burning zone via the gasification channel.

[0032] In the above second aspect of the invention, one or more of the following additional technical solutions may be employed.

[0033] The method may further include a step of: e) performing a heating process on the directional channel from the burning zone to the position where the directional drilling reaches the coal seam, to form a horizontal gasification channel along the directional channel.

[0034] The burning zone is established by means of electric ignition, solid fuel ignition or coke ignition, or a high-temperature coal seam of an existing burning zone or cavity in an operation zone is taken as the burning zone.

[0035] At least one production well and at least one injection well are formed and in communication with the burning zone.

[0036] The directional drilling is performed by means of any one of directional well technology, horizontal well technology, lateral drilling technology, radial horizontal well technology, branched well technology, cluster well technology and extended reach well technology of the petroleum or coal seam gas drilling technology.

[0037] During the fissure enlarging operation, a pressure variation of compressed air in the injection well is monitored, and when the pressure of the compressed air in the injection well decreases rapidly, it is indicated that a crack has been formed in the reserved coal seam and the fissure enlarging operation has been completed.

[0038] During the heating process on the crack formed in the reserved coal seam, the pressure in the injection well and temperature at the bottom of the production well are monitored, and when the pressure of the directional drilled well decreases and the temperature at the bottom of the production well rises, it is indicated that a gasification channel has been formed along the crack in the reserved coal seam and the heating process has been completed.

[0039] The heating process is performed by means of forward combustion linking or reverse combustion linking, and the medium used in the combustion linking comprises air, pure oxygen, propane, silicane, diesel fuel or liquid hydrocarbon, or a combination thereof.

[0040] The above described directional channel is located in the coal seam and generally has a length of 10~1000m, and the directional channel may be a non-supported channel or a supported channel that is supported by a sieve tube.

[0041] The beginning end of the above described directional channel may be located in a coal seam at the bottom of an existing drilled well in the operation zone; or, a new drilled well may be constructed according to the designed trajectory of the gasification channel.

[0042] For the communication between the above described directional channel and the burning zone, the end of the directional channel may be located in the burning zone after the drilling by a drilling machine; or, the directional channel does not reach the burning zone after the drilling, instead, a segment of reserved coal seam without drilled well may be reserved between the end of the directional channel and the burning zone, and a fissure may be formed by performing a fissure enlarging operation on the reserved coal seam so as to make the directional channel to be in communication with the burning zone.

[0043] The above described reserved coal seam has a length of 0~50 meters, which depends on the change of the permeability of the coal seam subjected to heat and ground stress, and may be specifically determined according to the construction process of horizontal drilling.

[0044] Specifically, the fissure enlarging of the above described reserved coal seam may be implemented by, but is not limited to, a hydraulic fracture method, a pressurized air penetrating method, a blasting method or a chemical liquid crushing method.

[0045] Specifically, the above described oxygen-containing gas includes, but is not limited to, air, oxygen-enriched gas and pure oxygen; and the oxygen-containing gas may be mixed with at least one of propane, silicane, diesel fuel or liquid hydrocarbon that function as a combustion improver.

[0046] The oxygen concentration of the above described oxygen-containing gas is 0~100%, the oxygen-containing gas may be prepared on the ground or underground, and the oxygen-containing gas may be mixed with the combustion improver on the ground or underground.

[0047] The above described oxygen-containing gas may be conveyed from ground to the burning zone via an annulus conduit pipe, or be directly conveyed from ground to the burning zone via a well.

[0048] The above described method for performing a heating process on the directional channel mainly employs reverse combustion linking, or a combination of forward combustion linking and reverse combustion linking; and the heating process is performed from the end of the directional channel gradually to the beginning end of the directional channel.

[0049] The above described method may be applied for the linkage of gasification channels of the existing underground gasifying furnace or a newly constructed underground gasifying furnace.

[0050] The invention has advantages as follows.

1) The directional channel is directionally drilled and connected the burning zone in a thermal state, that is, even if the water inflow in the coal seam enters the burning zone, the water may react in the burning zone or heated and converted into steam and carried out in a gas state along with the coal gas, so that the case that the water inflow in the coal seam influences the initial-stage igniting or sparking process (for example, flameout, channel flowage, etc.) may be avoided, thereby the reliability of the process may be improved.

2) A coal seam is reserved between the directional channel and the burning zone, thus the problem of drill pipe burying, drill pipe sticking and the like caused by mud leakage after the directional channel is completely drilled to be in communication with the burning zone may be avoided, thereby the construction difficulty of directional drilling may be lowered, and the security and reliability of directional drilling may be improved.

3) An oxygen-enriched gas or a combustion improver is employed to realize the quick sparking in the coal seam of the burning zone and form a char layer, and the problem such as well collapse or well shrinkage of the initially formed directional channel due to the water influx may be avoided, thereby the stability of the channel section structure may be improved.

4) The temperature at the flame front may be adjusted by adjusting and controlling the composition and flow quantity of the oxygen-enriched gas or the combustion improver, and the linkage speed of the gasification channels may be increased, so that the linkage period may be shortened.

5) A suitable oxygen-enriched gas or combustion improver may be selected according to the buried depth of the coal seam, the coal seam thickness, the gangue distribution situation, the coal seam water content, etc., so that the efficiency of the linkage process may be increased, and the flexibility and reliability of the process may be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0051]

Fig. 1A and Fig. 1B are simplified schematic front sectional views of the process flow according to a first embodiment of the invention, where Fig. 1A shows an initial directional channel formed by directional drilling, and Fig. 1B shows a gasification channel formed after a heating process is performed on the initial directional channel;

Fig. 2 is a simplified schematic front sectional view of the process flow according to a second embodiment of the invention; and

Fig. 3A and Fig. 3B are simplified schematic diagrams showing the process flow according to a third embodiment of the invention, where Fig. 3A is a top view, and Fig. 3B is a corresponding front sectional view taken along the horizontal dashed line in Fig. 3A.

List of numeral signs

[0052]

1:	Vertical well
2:	Directional drilled well
3:	Coal seam
4:	Burning zone
5:	Directional channel
6:	Oxygen-containing gas
7:	Pressurizing system
8:	Mixing system
9:	Gasification channel
11, 12:	Drilled well (linked)
13:	Drilled well (being linked)
14:	Drilled well (to be linked)
15:	Drilled well (to be linked)

16:	Coal seam
17:	Gasification channel
18:	Flame front
19:	Directional channel
21:	Burning zone
22:	Production well
23, 24, 25:	Vertical well
26:	Directional drilled well
27:	Directional channel
28:	Fissure in reserved coal seam

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0053] The following embodiments are provided for better understanding of the invention, rather than limiting the scope of the invention.

First Embodiment

[0054] As shown in Fig. 1A and Fig. 1B, a gasification channel is to be established with the method of the present invention between an existing vertical well 1 and a directional drilled well 2 constructed 200 meters (m) away from the vertical well 1, for the purpose of coal gasification within a certain zone. The corresponding implementation of the gasification channel is as follows.

[0055] A burning zone 4 is established in a coal seam 3 at the bottom of the vertical well 1 by means of electric ignition, and the temperature in the burning zone is controlled by adjusting the composition and flow quantity of a gasification agent depending upon the hydraulic discharge of the coal seam, temperature of the product gas, etc. Generally, the temperature in the burning zone is not lower than the autoignition temperature of the coal seam.

[0056] After the burning zone is established at the bottom of the vertical well 1, a directional channel 5 is constructed along the coal seam from the directional drilled well 2 through a directional drilling technology, where the directional channel 5 is in direct communication with the burning zone 4 and is not supported (in some other situations, the directional channel 5 may be generally supported by a sieve tube as desired). Therefore, the directional channel 5 is an unsupported well with a diameter of about 150 millimeters (mm) that is located about 0.5 meters above the bottom of the coal seam. After the directional drilling of the directional channel 5 is accomplished, a well head, a valve and an instrument are installed on the top of the directional drilled well 2, an oxygen-enriched gas is injected, and a heating process is started on the directional channel 5.

[0057] The oxygen-enriched gas is obtained by mixing on the ground. A mixing system 8 is adjusted to homogeneously mix a certain amount of oxygen with air to prepare the oxygen-enriched gas with a certain oxygen concentration, which may be 50~60%. By adjusting the pressure of a pressurizing system 7, the oxygen-enriched gas is forced into the coal seam along the directional drilled well 2 at a fixed flow quantity as required. Here, the fixed flow quantity is maintained, and the pressure in the directional drilled well 2 is monitored in real time.

[0058] The pressure is monitored by a pressure meter at the directional drilled well 2. When a considerable decrease of the pressure of the directional drilled well 2 (for example, generally a decrease of 10~60% of the initial pressure) is detected, the flow quantity or the oxygen concentration of the oxygen-enriched gas is increased; specifically, the flow quantity or the oxygen concentration is adjusted according to the gangue thickness and the water content in the coal seam, and the distance between the drilled wells, etc.

[0059] When the pressure difference between the directional drilled well 2 and the vertical well 1 is insignificant (for example, the pressure difference is lower than 0.1MPa), it is indicated that linkage or gasification channel construction is accomplished between the vertical well 1 and the directional drilled well 2.

Second Embodiment

[0060] As shown in Fig. 2, in the field of underground coal gasification and linkage, a plurality of substantially vertically wells 11, 12, 13, 14, 15 are formed; moreover, the plurality of wells are apart by unequal distances along the horizontal direction (i.e. the direction from right to left or from left to right in Fig. 2). The lower ends of the plurality of wells that extend into the underground coal seam zone need to be linked with each other, so as to form a gasification channel as required by an underground coal gasifying furnace. As shown by the lower left part of Fig. 2, the lower ends of the wells 11, 12 have been linked with each other (by combustion linkage in the prior art), and a substantially horizontal gasification channel 17 has been formed. Then, the linkage operation is further performed on the lower ends of the wells 12, 13, 14 and 15 by the method of the present disclosure, so that the speed of forming the gasification channel is increased. The implementation of the linkage operation is basically as follows.

[0061] The well 11 is taken as a gas injection well for an oxygen-containing gas (specifically, the oxygen-containing gas may be air), the well 12 is taken as a production well, and a burning zone of the well 12 is established at a joint between the lower end of the well 12 and the gasification channel 17. The amount of the air injected to the well 11 downwards depends on the product gas temperature in the well 12 and the water content of the coal seam.

[0062] Lateral horizontal drilling is performed by directly opening in the vertical well 13 starting from the lower end of the well 13 along the direction toward the lower end of the well 12 (i.e., the direction from right to left in Fig. 2) by an ultra-short radius horizontal drilling technology, and the drilled directional channel is supported by a sieve tube and located about 0.5 meters above the bottom of the coal seam, and has a diameter of about 40 mm. The horizontal drilling of the directional channel is stopped at about 25 meters away from the lower end of the well 12, so that a reserved coal seam segment without horizontal drilled well is reserved in a zone about 25 meters to the right of the lower end of the well 12 (relative to Fig. 2). After the drill rod is removed, a well head, a valve and a pressure meter are installed on the top of the well 13, and pressurized water is fed to the well 13 by a high-pressure plunger pump, so that hydraulic fracturing is performed on the reserved coal seam segment between the lower end of the well 13 and the lower end of the well 12, until a coal seam fissure is generated in the reserved coal seam segment (generally, when the water pressure measured at the well 13 decreases apparently by over 60%, it is indicated that the fissure is formed), thus the drilled directional channel is made in communication with the gasification channel 17. After the hydraulic fracturing process is started, a part of the water will enter the gasification channel 17, in this case, the flow quantity of air injected from the well 11 is increased, so that the water and coal gas are carried out via the well 12 to prevent the water from staying in the gasification channel. Here, the flow quantity of air injected from the well 11 depends on the temperature and humidity of the gas produced from the well 12.

[0063] After the hydraulic fracturing operation is accomplished, an oxygen-enriched gas is fed via the well 13, and a heating process is started on the reserved coal seam segment and the drilled directional channel. The specific operation is as follows.

[0064] The oxygen-enriched gas with a certain oxygen concentration may be prepared by an adjustable high-pressure proportioning mixer, which for example homogeneously mixes a certain amount of oxygen with air. The oxygen concentration in the oxygen-enriched gas depends on the water content in the coal seam as well as the temperature and humidity of the coal gas produced from the well 12, and generally, the oxygen concentration of the oxygen-enriched gas is 50%~60%.

[0065] With the pressure adjustment by a pressurizing system, the oxygen-enriched gas is forced to flow into the burning zone of the well 12 along the well 13 at the fixed flow quantity as required, and the flow quantity of the oxygen-enriched gas fed along the well 13 depends on parameters such as a distance between wells, resistance of the directional channel, a bearing ability of the well and strength of the roof and floor of the coal seam. Thereafter, the flow quantity of the oxygen-enriched gas is maintained for reverse combustion (i.e., the extending direction of the flame front is opposite to the flow direction of the fed gas), and the pressure at the well 13 is monitored in real time.

[0066] When the pressure detected by the pressure meter on the top of the well 13 decreases apparently (generally by 10~60% of the initial pressure), it is indicated that the burning zone of the well 12 has been expanded to the vicinity of the bottom of the well 13. Thereafter, the flow quantity or the oxygen concentration of the oxygen-enriched gas supplied to the well 13 downwards from the top of the well 13 is increased for the purpose of forward hole expansion by fire; specifically, the flow quantity or oxygen concentration of the oxygen-enriched gas is adjusted according to the gangue thickness and the water content in the coal seam, a distance between the wells, etc. When the pressure difference between the well 13 and the well 12 is insignificant (or the pressure difference is lower than 0.1MPa), it is indicated that combustion linking has been accomplished on the coal seam segment between the lower end of the well 12 and the lower end of the well 13; that is, a gasification channel has been constructed successfully between the lower end of the well 12 and the lower end of the well 13.

[0067] After the burning zone of the well 12 has been expanded to the bottom of the well 13, a directional channel (denoted by a numeral 19 in Fig. 2) is further constructed starting from the lower end of the well 14 along the direction toward the lower end of the well 13 (i.e., the direction from right to left in Fig. 2) by the ultra-short radius horizontal drilling technology, so that the drilled directional channel is in communication with the burning zone of the well 13, where the directional channel is not supported by a sieve tube, is located about 0.5 meters above the bottom of the coal seam and has a diameter of about 40 mm. The drilling of the directional channel is stopped at about 15 meters away from the lower end of the well 13 so as to reserve a reserved coal seam segment. By a process similar to the above described process (including fracturing and fissure enlarging in the coal seam segment, directional channel processing and the subsequent processes) in which the linkage is accomplished between the lower end of the well 12 and the lower end of the well 13, the heating process is started on the directional channel, and the channel linkage between the lower end of the well 13 and the lower end of the well 14 is accomplished.

[0068] After the burning zone at the bottom of the well 13 expands to the bottom of the well 14, by a process similar to the above described processes (including fracturing and fissure enlarging in the coal seam segment, directional channel processing and the subsequent processes) in which the linkage is performed between the bottom of the well 12 and the bottom of the well 13 and between the bottom of the well 13 and the bottom of the well 14, a heating process is started between the lower end of the well 15 and the lower end of the well 14 (here, the length of the reserved coal seam segment between the lower end of the well 15 and the lower end of the well 14 is 50m), and the channel linkage is accomplished between the lower end of the well 14 and the lower end of the well 15.

[0069] Multiple tests have been performed by the applicant by employing the above linkage method of the invention to link the lower ends of the wells 12, 13, 14 and 15 in the coal seam, thereby constructing an underground coal gasification channel. Results of the tests show that the average linkage speed obtained by the linkage method of the invention is 1.0~1.2 meters per day, while the average speed of traditional air fire-penetrating linkage is 0.5~0.8 meters per day, thus the construction speed of the gasification channel may be improved apparently by employing the method according to this embodiment of the invention, and the linkage efficiency is high.

[0070] Additionally, it should be noted that, although there are four wells 12, 13, 14, 15 in the above second embodiment, the method according to the invention is not limited to this specific number of wells. It may be known from the above description that the method according to the invention can be applied for gasification and linkage among any number of wells as actually required.

Third Embodiment

[0071] Fig. 3A and Fig. 3B show an example of an existing underground gasifying furnace. According to the layout of the existing underground gasifying furnace, a plurality of vertical wells have been constructed. The coal seam at the lower end of the well 22 has been selected for ignition and a burning zone 21 of the well 22 is formed, but the lower ends of the existing wells 23, 24, 25 at the coal seam still need to be linked, and the wells 23, 24, 25 are used as production wells after the linkage is accomplished. The wells 23, 24, 25 are all vertical wells, and bottom ends of sleeves of these vertical wells are located 0.5 meters above the bottom of the coal seam, and centers of the wells are basically located on the same straight line (as indicated by the horizontal dashed line in Fig. 2A), where, the distance between adjacent ones from the wells 23, 24, 25 is about 50 meters, and the distance between the wells 22, 23 is also about 50 m. As described below, the linkage between the wells 23, 24, 25 is performed along the coal seam using the directional drilling technology, so that the wells 23, 24, 25 are in communication with the burning zone 21, and the processing of the gasification channel is accomplished according to the method of the invention.

[0072] A directional drilled well 26 is constructed generally along the direction of a line passing through the wells 22, 23, 24, 25 (i.e. the horizontal dashed line in Fig. 2A), the horizontal distance between the vertical upper segment of the directional drilled well 26 and the well 25 is about 150 meters, and the arched lower segment of the directional drilled well 26 is extended into the coal seam at a location apart from the lower end of the well 25 by a horizontal distance of about 30 meters; thereafter, a sleeve is placed in the directional drilled well 26, and a well cementing operation is performed.

[0073] A target point is placed in each of the wells 23, 24, 25, and directional drilling is started. The directional channel is located about 0.5 meters above the bottom of the coal seam and has a diameter of about 150 mm. The directional drilling is stopped at a location apart from the lower end of the well 22 by a horizontal distance of about 15 meters (in Fig. 3B) and the drill rod is pulled out, so that a reserved coal seam segment is reserved.

[0074] After the directional channel is constructed, a well head, a valve and an instrument are installed on the top of the directional drilled well 26, temperature measuring devices are installed in the wells 23, 24, 25, the valves on the tops of the wells 23, 24, 25 are closed, and pressurized air (with a pressure of 1.0~5.0MPa) is fed to the directional drilled well 26, so that pressurized fracturing is performed on the reserved coal seam segment between the lower end of the well 23 and the burning zone 21, to generate a coal seam fissure in the reserved coal seam segment. The valve and the instrument on the top of the directional drilled well 26 are monitored, to inspect changes of pressure and product gas compositions during the process; when the pressure detected by the valve on the top of the directional drilled well 26 decreases rapidly, it is indicated that a fissure 28 has been formed in the reserved coal seam segment.

[0075] After the fissure 28 in the reserved coal seam segment is formed, air may be fed into the burning zone 21 along the fissure 28, so that the residual slurry in the directional channel and the coal seam water inflow generated may be carried over to the burning zone 21. In addition, the air contacts high-temperature coal seam in the burning zone 21, to facilitate combustion and gasification action of the coal seam, meanwhile water is vaporized when it contacts the high-temperature coal seam (a part of the water participates in the gasification actions), and the resultant wet coal gas is discharged via the drilled well 22.

[0076] During the method of this embodiment, after the fissure 28 in the reserved coal seam is formed, the flow quantity of air fed to the directional drilled well 26 is adjusted to perform reverse combustion linking (i.e., the extending direction of the flame front is opposite to the flow direction of the fed gas), where the flow quantity of air depends on the coal gas compositions at the exit on the top of the well 22. During this process, changes of the pressure in the directional drilled well 26 and the temperature at the bottom of the well 23 are monitored. When the pressure in the directional drilled well 26 decreases to a certain degree (generally by 10~60% of the initial pressure), and/or the temperature at the bottom of the well 23 slowly rises to a certain degree (e.g. rises at a rate of 10~50°C/h), it is indicated that gasification channel linkage has been constructed in the reserved coal seam segment, and the gasification channel is in communication with the directional channel 27.

[0077] After the burning zone is extended to the directional channel 27, the flow quantity of air fed to the directional drilled well 26 is further adjusted to implement reverse combustion linking in the directional channel, where the flow quantity of air is depends on the change of temperature at the bottom of the wells 23, 24, 25. When the temperature at the bottom of the well 23 rises rapidly, it is indicated that the burning zone has expanded to the well 23; at this time, feeding of air to the well 23 is started for forward combustion linking, where the flow quantity of the air depends on the temperature at the bottom of the well 23 and the coal gas compositions in the well 22.

[0078] For each zone between the lower ends of adjacent ones from the wells 23, 24, 25, the flow quantity of the air fed to the directional drilled well 26 is adjusted according to the above method, to perform reverse combustion linking on the directional channel; at the same time, the gas fed to the wells 24, 25 is adjusted for the forward combustion linking. When the pressure difference between the directional drilled well 26 and the well 22 is insignificant or lower than 0.05 MPa, it is indicated that the gasification channel linkage has been accomplished among the wells 23, 24, 25.

[0079] Multiple tests have been performed by the applicant using the above linkage method of the invention so as to link the lower ends of the wells 23, 24, 25 in the coal seam, thereby constructing an underground coal gasification channel. Results of the tests show that, according to calculated time for the temperature changes of adjacent wells (for example, the wells 23, 24), the average linkage speed obtained by the linkage method of the invention is 1.2~1.5 meters per day, while the average speed of traditional combustion linkage is 0.5~0.8 meters per day; thus, the construction speed of the gasification channel may be improved apparently by employing the method according to this embodiment of the invention.

Fourth Embodiment

[0080] The scheme of the fourth embodiment is basically the same as the scheme according to the second embodiment. Although the air and the oxygen-enriched gas are employed for the reverse combustion linking, the fourth embodiment is different from the second embodiment in that the air and the oxygen-enriched gas are also mixed with propane functioning as a combustion improver within the wells, where the air and the propane may be conveyed to the burning zone from the ground via an annulus conduit pipe and mixed within the wells, so as to improve the efficiency of the combustion linking.

[0081] The average linkage speed obtained by this method is 1.4~1.8 meters per day, while the average linkage speed in the second embodiment based on the traditional oxygen-enriched gas and air is 1.0~1.2 meters per day, thus the channel construction speed may be improved apparently by employing the method of the present embodiment of the invention.

Fifth Embodiment

[0082] The scheme of the fifth embodiment is basically the same as the scheme in the third embodiment. Although air is employed for the reverse combustion linking, the fifth embodiment is different from the third embodiment in that the air may also be mixed on the ground with silicane functioning as a combustion improver. After the air and the silicane passing through conduit pipes are mixed on the ground and then conveyed to the burning zone so as to improve the efficiency of combustion linking.

[0083] The average linkage speed obtained by this method is 1.6~2.0 meters per day, while the average linkage speed based on air according to third embodiment is 1.2~1.5 meters per day, thus the channel construction speed may be improved apparently by employing this embodiment of the invention.

Claims

1. A method for underground coal gasification and linkage, which is applied to construct a gasification channel for an underground coal gasifying furnace in the vicinity of the bottom of at least one substantially vertical first well, wherein the method comprises steps of:

   a) establishing a burning zone in a coal seam at the bottom of the first well;
   b) performing mechanical directional drilling on a coal seam nearby the bottom of the first well in the vicinity of the burning zone, starting from a lower end of the second well, so that the coal seam nearby the bottom of the first well is preperforated to form a directional channel in communication with the burning zone in the coal seam nearby the bottom of the first well, wherein the second well is an existing well or a newly-drilled well outside the burning zone; and
   c) feeding an oxygen-containing gas to the burning zone via the second well and the directional channel, and performing a heating process on the directional channel, to enlarge the directional channel to form the gasification channel for the underground coal gasifying furnace.

2. The method for underground coal gasification and linkage of claim 1, wherein the burning zone is established by means of electric ignition, solid fuel ignition or coke ignition, or a high-temperature coal seam of an existing burning zone or combustion space zone in an operation zone is taken as the burning zone.

3. The method for underground coal gasification and linkage of claim 1, wherein the directional drilling is

performed by means of any one of directional well technology, horizontal well technology, lateral drilling technology, radial horizontal well technology, branched well technology, cluster well technology and extended reach well technology of the petroleum or coal seam gas drilling technology.

4. The method for underground coal gasification and linkage of claim 1, wherein the heating process is implemented by forward combustion linking and reverse combustion linking, and the medium used in the combustion linking comprises air, pure oxygen, propane, silicane, diesel fuel or liquid hydrocarbon, or a combination thereof.

5. The method for underground coal gasification and linkage of claim 1, wherein the oxygen-containing gas comprises any one of: air, oxygen-enriched gas and pure oxygen.

6. The method for underground coal gasification and linkage of claim 1, wherein the oxygen-containing gas is mixed with at least one of propane, silicane, diesel fuel and liquid hydrocarbon that function as a combustion improver.

7. The method for underground coal gasification and linkage of claim 6, wherein the mixing is performed on the ground or underground.

8. The method for underground coal gasification and linkage of claim 6, wherein the oxygen-containing gas and the combustion improver are conveyed to the burning zone via an annulus conduit pipe, or directly conveyed from the ground to the burning zone via a sleeve for drilled well.

9. The method for underground coal gasification and linkage of claim 1, wherein the directional channel is located in the coal seam and has a length of 10~1000m, and the directional channel is a non-supported channel or a supported channel that is supported by a sieve tube.

10. A method for underground coal gasification and linkage, comprising steps of:

a) establishing a burning zone in a coal seam at the bottom of a well;
b) performing a pre-perforating operation at the bottom of the well outside the burning zone by directional drilling along the coal seam to form a drilled directional channel, wherein a reserved coal seam without well is reserved between an end of the directional channel and the burning zone;
c) performing a fissure enlarging operation in the reserved coal seam so as to form a fissure in communication with the burning zone; and
d) conveying an oxygen-containing gas to the burning zone via the well for the pre-perforating operation, and performing a heating process on the fissure formed in the reserved coal seam to enlarge the fissure into a gasification channel, so that the directional channel is in communication with the burning zone via the gasification channel.

11. The method for underground coal gasification and linkage of claim 10, further comprising a step of:

e) starting from an end of the directional channel that abuts against the burning zone, performing a heating process on the directional channel until the bottom end of the well, to form a horizontal gasification channel along the directional channel.

12. The method for underground coal gasification and linkage of claim 10, wherein the burning zone is established by means of electric ignition, solid fuel ignition or coke ignition, or a high-temperature coal seam of an existing burning zone or combustion space zone in an operation zone is taken as the burning zone.

13. The method for underground coal gasification and linkage of claim 10, wherein at least one production well and at least one injection well are formed in the burning zone, and the bottom of the at least one production well and the bottom of the at least one injection well are in communication with the burning zone.

14. The method for underground coal gasification and linkage of claim 10, wherein the directional drilling is performed by means of any one of directional well technology, horizontal well technology, lateral drilling technology, radial horizontal well technology, branched well technology, cluster well technology and extended reach well technology of the petroleum or coal seam gas drilling technology.

15. The method for underground coal gasification and linkage of claim 10, wherein the length of the reserved coal seam is 0~50 meters, and the length at least depends on a change of permeability of the coal seam subjected to heat and ground stress.

16. The method for underground coal gasification and linkage of claim 13, wherein during the fissure enlarging operation, a pressure variation of compressed air in the injection well is monitored, and when the pressure of the compressed air in the injection well decreases rapidly, it is indicated that a crack has been formed in the reserved coal seam and the fissure enlarging operation has been completed.

17. The method for underground coal gasification and linkage of claim 13, wherein
during the heating process on the crack formed in the reserved coal seam, air pressure in the injection well and temperature at the bottom of the production well are monitored, and when the pressure of the directional drilled well decreases and the temperature at the bottom of the production well rises, it is indicated that a gasification channel has been formed along the crack formed in the reserved coal seam and the heating process has been completed.

18. The method for underground coal gasification and linkage of claim 10 or 11, wherein the heating process is performed by means of forward combustion linking or reverse combustion linking, and the medium used in the combustion linking comprises air, pure oxygen, propane, silicane, diesel fuel or liquid hydrocarbon, or a combination thereof.

19. The method for underground coal gasification and linkage of claim 10, wherein the fissure enlarging operation performed on the reserved coal seam comprises any one of or a combination of: a hydraulic fracture method, a pressurized air penetrating method, a blasting method and a chemical liquid crushing method.

20. The method for underground coal gasification and linkage of claim 10, wherein the oxygen-containing gas comprises any one of: air, oxygen-enriched gas and pure oxygen.

21. The method for underground coal gasification and linkage of claim 10, wherein the oxygen-containing gas is mixed with at least one of propane, silicane, diesel fuel and liquid hydrocarbon that function as a combustion improver.

22. The method for underground coal gasification and linkage of claim 21, wherein the mixing is performed on the ground or underground.

23. The method for underground coal gasification and linkage of claim 21, wherein the oxygen-containing gas and the combustion improver are conveyed to the burning zone via an annulus conduit pipe, or directly conveyed from the ground to the burning zone via a sleeve for drilled well.

24. The method for underground coal gasification and linkage of claim 10, wherein the directional channel is located in the coal seam and has a length of 10~1000m, and the directional channel is a non-supported channel or a supported channel that is supported by a sieve tube.

25. The method for underground coal gasification and linkage of any one of claims 1 to 24 is applied to linkage of the gasification channel for an existing or newly constructed underground coal gasifying furnace.

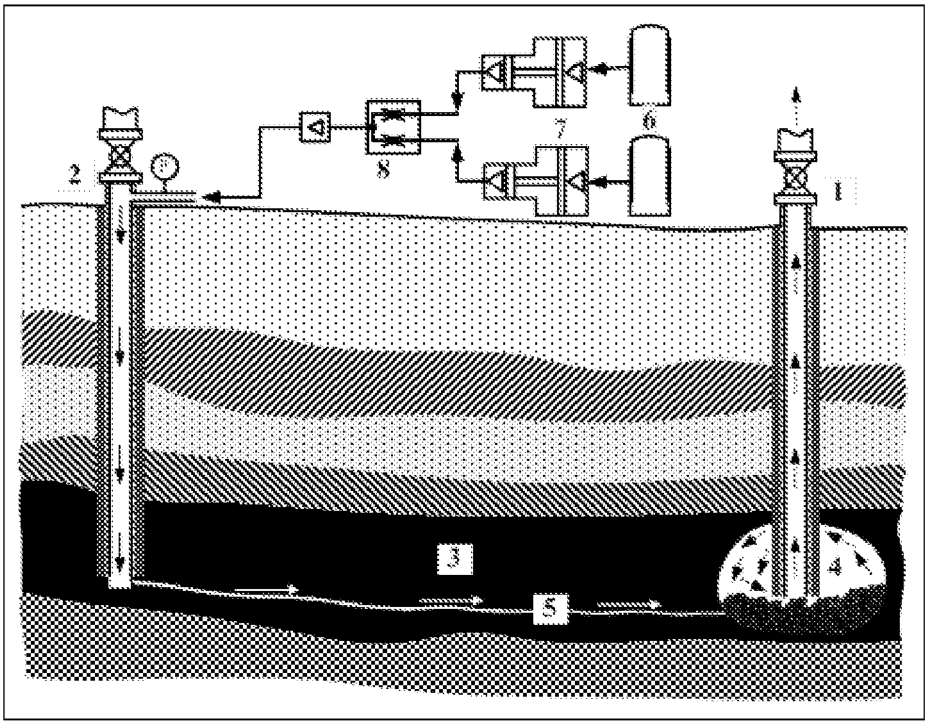

FIGURE 1A

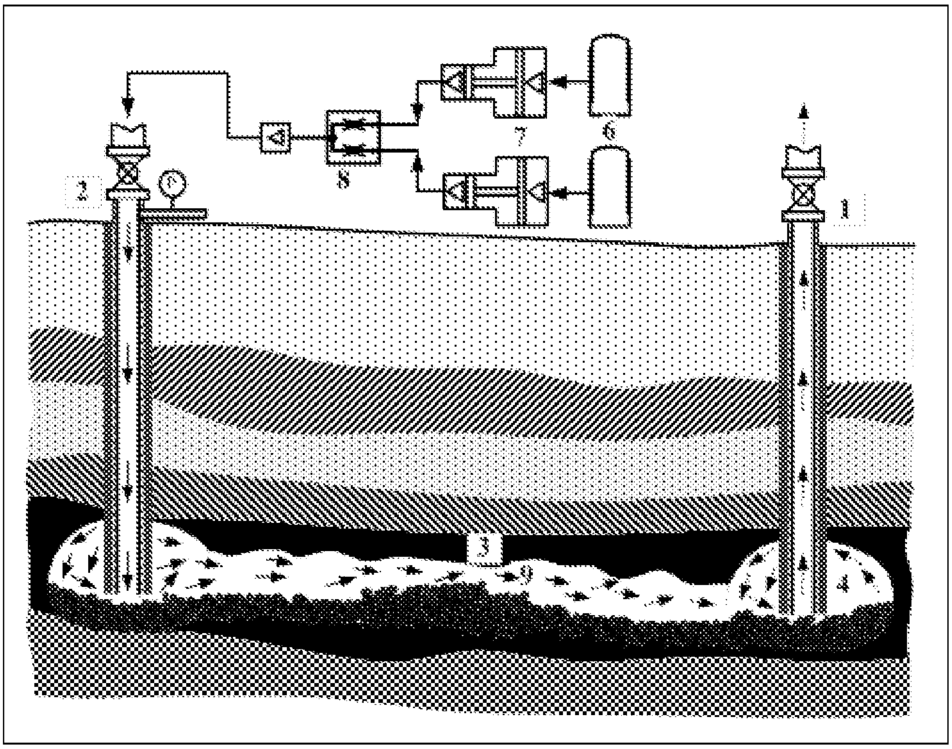

FIGURE 1B

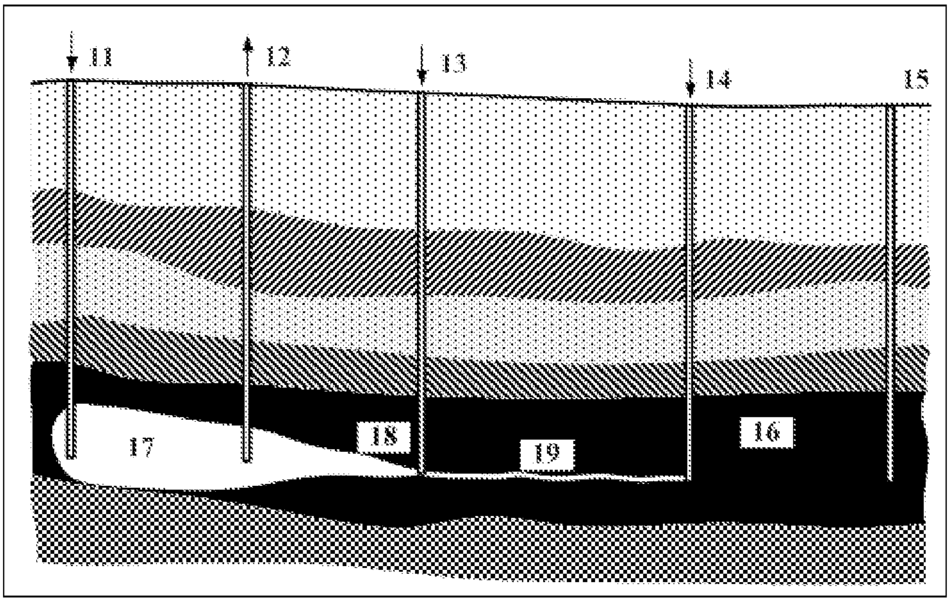

FIGURE 2

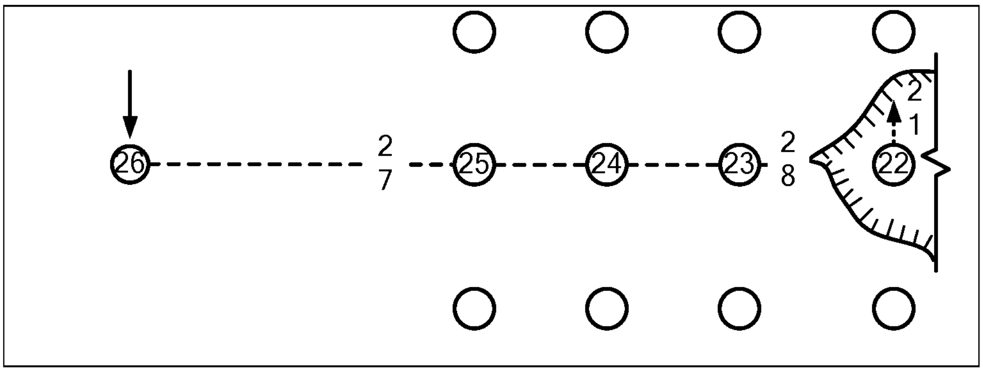

FIGURE 3A

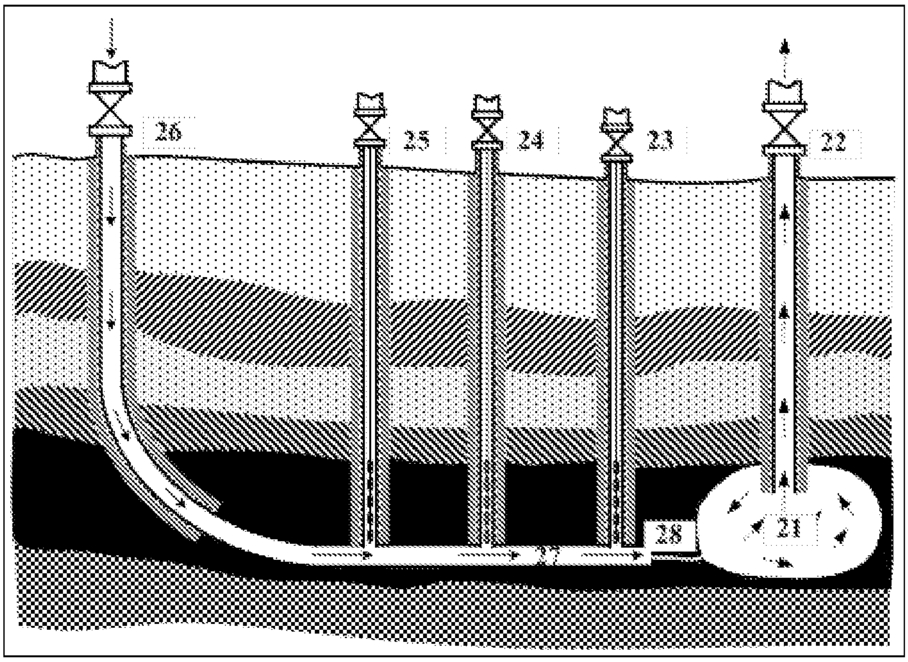

FIGURE 3B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2012/085354

A. CLASSIFICATION OF SUBJECT MATTER

E21B 43/295 (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: E21B43, E21F

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: coal, gasif+, underground, direct+, orient+, drill+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 101382065 A (WULANCHABU XINAO GASIFICATION COLA MINING TECHNOLOGY CO., LTD.) 11 March 2009 (11.03.2009) description, pages 2-4 and figures 1-3	1-9,25
P,X	CN 102477857 A (XINAO COAL GASIFICATION MINING CO., LTD.) 30 May 2012 (30.05.2012) description, pages 3-10, claims 1-25 and figures 1-3B	1-25
A	CN 101382061 A (XINAO TECHNOLOGY DEV CO., LTD.) 11 March 2009 (11.03.2009) the whole document	1-25
A	CN 101113670 A (XINAO ENERGY ACAD CO., LTD.) 30 January 2008 (30.01.2008) the whole document	1-25
A	CN 1854459 A (YU, Li) 01 November 2006 (01.11.2006) the whole document	1-25

☒ 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

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"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
25 February 2013 (25.02.2013)	**07 March 2013 (07.03.2013)**

Name and mailing address of the ISA	Authorized officer
State Intellectual Property Office of the P. R. China No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088, China Facsimile No.	SUI, Ziyu Telephone No. (86-10) **62085145**

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2012/085354

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RU 2319838 C1 (AS SIBE COAL & COAL CHEM) 20 March 2008 (20.03.2008) the whole document	1-25
A	RU 2392427 C1 (GAZPROM PROMGAZ STOCK CO.) 20 Junuary 2010 (20.06.2010) the whole document	1-25

Form PCT/ISA /210 (continuation of second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/CN2012/085354

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
CN 101382065 A	11.03.2009	None	
CN 102477857 A	30.05.2012	None	
CN 101382061 A	11.03.2009	None	
CN 101113670 A	30.01.2008	None	
CN 1854459 A	01.11.2006	None	
RU 2319838 C1	20.03.2008	None	
RU 2392427 C1	20.06.2010	None	

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

REFERENCES CITED IN THE DESCRIPTION

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- CN 201110388215 **[0001]**
- CN 01382065 **[0009]**