March 26, 1957 C. E. ALLEMAN 2,786,660

APPARATUS FOR GASIFYING COAL

Original Filed Jan. 5, 1948 2 Sheets-Sheet 1

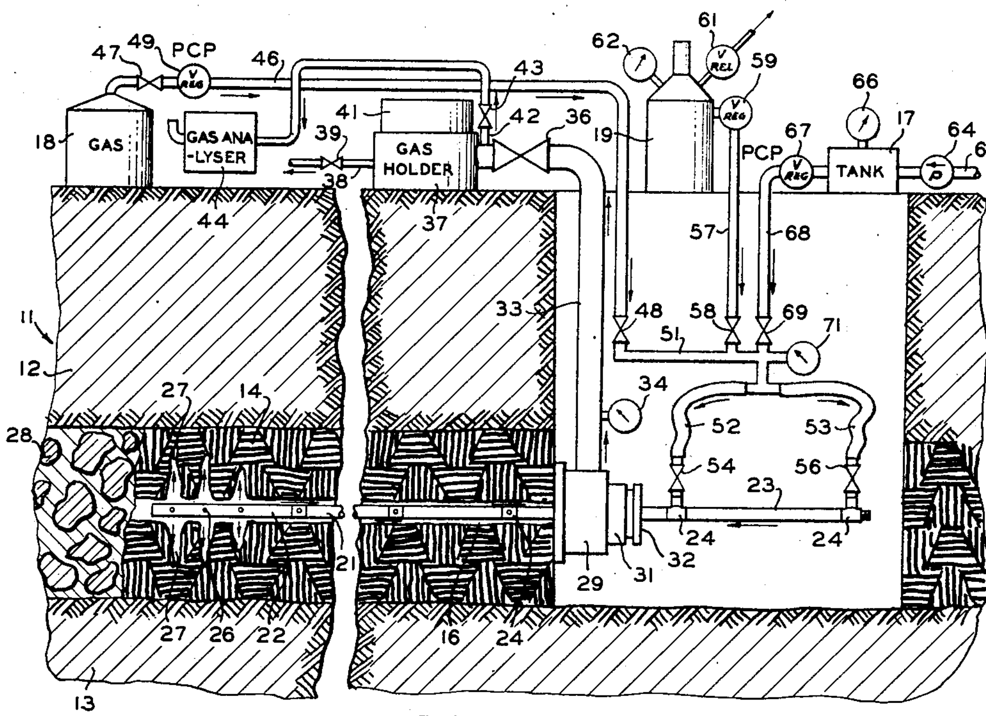

FIG. 1

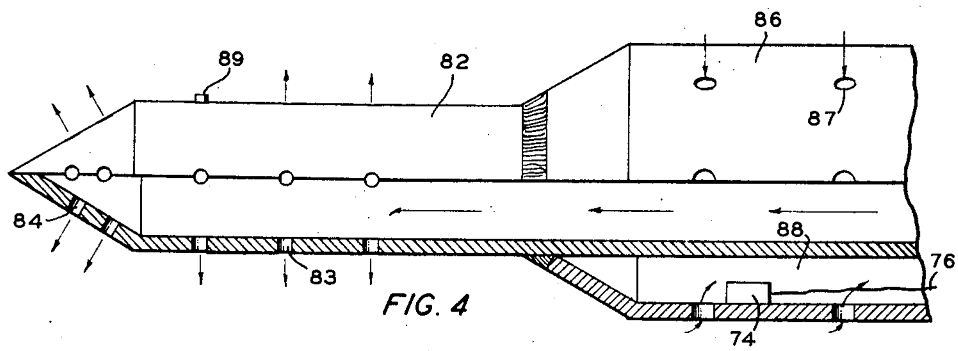

FIG. 4

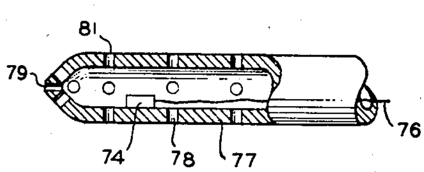

FIG. 3

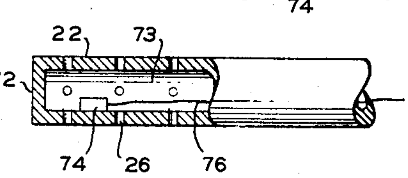

FIG. 2

FIG. 5

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APPARATUS FOR GASIFYING COAL

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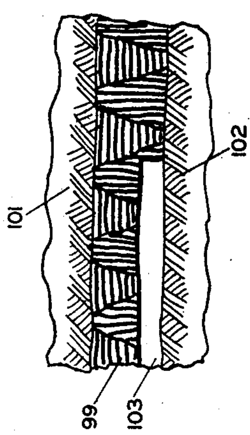

FIG. 7

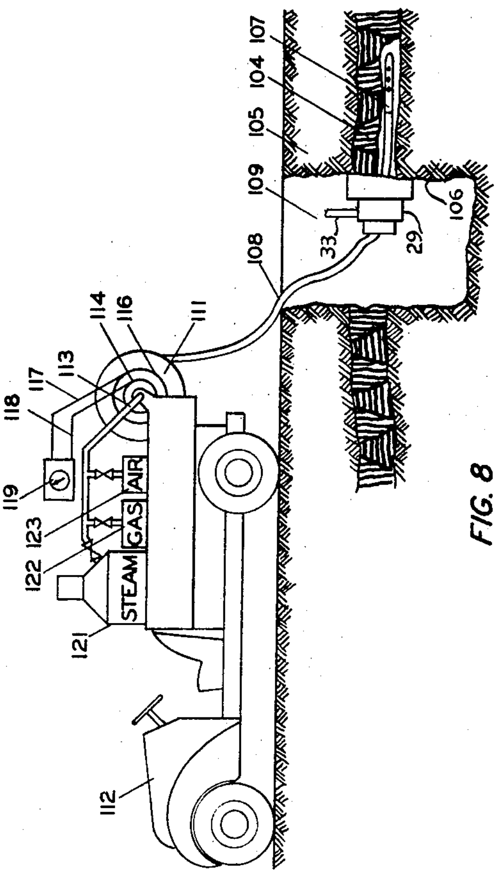

FIG. 8

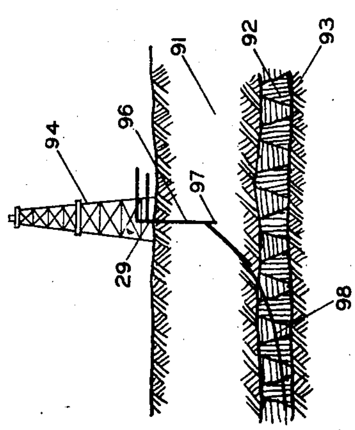

FIG. 6

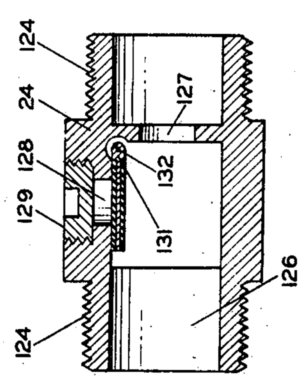

FIG. 9

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APPARATUS FOR GASIFYING COAL

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Original application January 5, 1948, Serial No. 601. Divided and this application December 29, 1952. Serial No. 328,477

8 Claims. (Cl. 262—3)

This invention relates to the gasification of coal in underground formations. In one specific embodiment it relates to the method of making gas mixtures rich in hydrogen and carbon monoxide by the reaction of methane with steam, methane with carbon dioxide, or controlled partial oxidation of methane with air or oxygen. Other specific aspects involve the novel apparatus employed in producing various valuable gases from coal by underground gasification and/or burning of the coal in situ.

The present application is a division of my copending application Serial No. 601, filed January 5, 1948, now abandoned, for "Method and Apparatus for Gasifying Coal."

Numerous valuable chemical processes are being developed in the United States and elsewhere employing so-called synthesis gas or other gaseous mixtures rich in hydrogen and carbon monoxide, which gases are reacted in various chemical processes to produce hydrocarbons, alcohols and other products of value. Also gases rich in hydrogen and/or carbon monoxide are valuable as fuels. At the same time many coal deposits in the United States and elsewhere cannot be mined in a profitable manner by ordinary mining methods because of the low grade of the coal, the thinness of the coal seam, the steep angle of dip of the seam, the tendencies to spontaneous combustion, dangerous gas content, high ash content, or other disadvantageous or hazardous characteristics. While the coal deposits valuable for conventional mining are relatively restricted in area, there is practically an unlimited amount of low grade coal in thin seams which is not worth mining. A number of plans for underground gasification of such coal have been made in the prior art and it is understood that some of these plans have been tried out in Russia. None of these prior art plans for underground gasification of coal has ever achieved any commercial success and workers in this field have been unable to determine exactly what is wrong with the proposed processes.

I have found that the reason for failure of the prior art methods to produce operable results is that they are incapable of operating at a temperature high enough to properly carry out the reactions necessary to produce the desired product or products. For example, one of the chief reactions involved is the reaction of methane with steam to form hydrogen and carbon monoxide according to the following formulae:

(1) $CH_4+H_2O \rightarrow 3H_2+CO$ (−50.7 K cals.)

In order for this reaction to occur properly a temperature preferably above 1500° F. is desirable because with a temperature of about 1200° F. the reaction tends to follow the following equation:

(2) $CH_4+2H_2O \rightarrow CO_2+4H_2$

In the absence of catalysts the rate of the methane steam reaction is said to be slow, becoming appreciable only at temperatures above 2370° F. While some underground deposits may have catalytic value, generally the underground gasification of coal may be regarded as more nearly non-catalytic than catalytic.

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Obviously, other reactions are occurring along with the two reactions with steam mentioned above, such as the reaction with carbon dioxide:

(3) $CH_4+CO_2 \rightarrow 2CO+2H_2$ (−60 K cals.)

And some controlled oxidation:

(4) $2CH_4+O_2 \rightarrow 2CO+4H_2$ (+7.2 K cals.)

Another reaction which takes place is a combination reaction according to the following equation:

(5) $3CH_4+2H_2O+CO_2 \rightarrow 4CO+8H_2$

I have found that the difficulty in the prior art is not capable of solution by merely increasing the amount of air as the relative heat losses are roughly inversely proportional to the square root of the intensity of gasification. The present invention is a solution to the difficulties of the prior art by supplying streams of air or oxygen and/or steam or other gases or fluids at high pressures in the vicinity of the point at which the combustion is taking place so that said combustion or gasification of the coal may be controlled in such manner as to produce a better product with less expense and difficulty. The apparatus of the present invention provides for moving the point of application of the high pressure fluids so that a progressive process may be practiced enabling temperature control which will maintain the temperature of reaction at a level more nearly optimum to the desired reactions and thereby minimize the undesired reactions which occur.

One object of the present invention is to provide apparatus for the underground gasification of coal.

Another object is to provide such apparatus as is particularly useful in coal seams that are unprofitable to work by ordinary mining methods, especially low grade coal, coal in thin seams, coal seams dipping sharply, gassy coal, coal having a tendency to spontaneous combustion, coal having a high ash content, or coal having other characteristics making mining unprofitable. However, it should be understood that my apparatus is perfectly capable of operation in coal seams suitable for mining, and with proper development, it is an object of my invention to provide means capable of competing with present systems of mining coal.

A further object is to provide apparatus and means for operating the same to practice methods that will permit more complete recovery of coal in situ in the form of valuable gases.

Another object is to provide suitable apparatus for gasifiyng coal underground.

Numerous other objects and advantages will be apparent to those skilled in the art upon reading the accompanying specification, drawings and claims.

In the drawings:

Figure 1 is a cross sectional elevational view taken through a portion of the earth containing a coal seam showing apparatus embodying certain aspects of the present invention and illustrating one point in the operation of a method embodying specific aspects of the present invention.

Figure 2 is a cross sectional view of one form of jet tube which is shown in Figure 1.

Figure 3 is a view similar to Figure 2 of a second type of jet tube which may be employed in the practice of this invention.

Figure 4 is a quarter sawed elevational view of a third form of jet tube which may be employed in the practice of the present invention.

Figure 5 is an elevational view of tapered plug 89 which may be employed in plugging any of the holes of the jet tubes of Figures 1 to 4, inclusive, when it is desired to modify direction of the jet action.

Figure 6 is a cross sectional view of a portion of the earth showing how the methods and apparatus of the present invention may be adapted to use in the deflected well.

Figure 7 shows a preferred position for a drill hole or burned hole in a coal seam.

Figure 8 is a cross sectional elevational view of a portion of the earth showing a modified form of apparatus being employed in burning a hole in the lower portion of the coal seam.

Figure 9 is a cross sectional view taken through one of the valve units employed in the apparatus shown in Figure 1.

In Figure 1 a cross section of earth formations generally designated as **11** may contain non-productive earth formations **12** and **13** and a vein or seam of coal **14**. Coal seam **14** may be one that is either profitable or unprofitable to mine by conventional mining methods, as the present invention applies to either type of coal seam; however, the present invention has a special value when the coal seam **14** is of a type unprofitable to mine by conventional mining methods.

In coal seam **14** a hole **16** has been drilled by any conventional method of drilling holes, or holes **16** may be burned into coal by methods to be discussed later. Hole **16** may be in the center of the coal seam as shown but often it is preferably located in the lower portion of the coal seam as will be explained with relation to Figure 7 later in this disclosure.

Air or oxygen from tank **17**, fuel gas from tank **18**, and/or steam from boiler **19** in any combination or singly may be introduced into hole **16** through a pipe **21** as will be set forth later.

Pipe **21** comprises a jet nozzle portion **22**, pipe sections **23** and valve connector sections **24**. The valve connector sections **24** are more fully illustrated in Figure 9.

The fluid or fluids being forced into hole **16** through pipe **21** emerge from radial jet holes **26** in the jet nozzle **22** and burn, erode and otherwise enter coal vein **14** along planes **27**, causing a rapid burning or gasification of the coal to proceed at a relatively high temperature whereby optimum amounts of gas having a valuable composition are produced and the coal **14** is reduced to ashes and/or coke **28**. When the coal **14** is reduced to ashes **28** at a point adjacent jet nozzle **22**, the jet nozzle is then moved through hole **16** to a new position where it will operate on fresh coal, and this movement may be either uniform or by steps as desired, as will be explained below.

As the coal is gasified the gases pass out hole **16** and around the outside of pipe **21** and are collected by a casing head **29** which may be sealed to the coal seam **14** by any conventional means, such as cement. Casing head **29** has a stuffing box **31** and stuffing box follower **32** for packing around pipe **21** especially as pipe **21** is moved in or out of hole **16**.

Casing head **29** is provided with a product flow line **33** which may have the usual pressure gauge **34**. Line **33** may lead through a suitable cut-off valve **36** into a gas holder **37** from which the gas may be withdrawn through a product line **38** controlled by valve **39** for use as fuel gas or as a reactant gas in a Fischer-Tropsch or other chemical process (not shown). Gas holder **37** is shown with a conventional floating roof **41** but obviously any type of gas holder may be employed.

In order to provide information as to the value of gas being produced, which information may also be valuable in directing the control of the process, it is desirable to sample the gas in conduit **33** by means of a sample line **42** controlled by valve **43** which leads to any suitable type of gas analyzing apparatus **44**. Such analyzing apparatus is well known to the art and, therefore, is not described further except to state that gas may be analyzed for the amount of water, carbon monoxide, carbon dioxide, hydrogen, oxygen, nitrogen, methane and other products which it may be expected to contain.

Gas (such as fuel gas) may be supplied from tank **18** through conduit **46** controlled by valves **47** and **48** and pressure regulator **49** to a manifold **51** from which it may be introduced into pipe **21** through either or both flexible hose **52** and **53** controlled by valves **54** and **56** all in the manner as will be more fully described with reference to Figure 9.

Steam from boiler **19** is similarly supplied to manifold **51** through conduit **57** controlled by valve **58** and pressure regulator **59**. Boiler **19** may, of course, be supplied with all the usual equipment such as relief valve **61** and pressure gauge **62**.

In a similar manner oxygen from the tank (not shown) or from an oxygen producing plant (not shown) may enter the system at **63** and be compressed by compressor **64** and stored in tank **17** which may be provided with a relief valve (not shown), pressure gauge **66** and other regular equipment. From tank **17** the air or oxygen may pass through a regulator **67** and conduit **68** controlled by valve **69** into manifold **51**, and the pressure in manifold **51** is indicated by pressure gauge **71**.

Figure 2 shows the jet nozzle **22** of Figure 1 on a large scale and with parts in cross-section broken away to show details of construction. While in many instances nozzle **22** can be made out of steel or other metal, I prefer to make the same out of a hard ceramic material which is capable of withstanding higher temperatures than metal and this is of particular value when oxygen is being employed in the burning out process as sometimes when oxygen is being introduced through a steel pipe, the pipe may catch fire and burn or become melted in some way or other. In the form shown in Figure 2, nozzle **22** has closed or blank end **72** and a hollow interior **73** communicating with the interior of pipe **21** to receive fluids therefrom. Nozzle **22** is, of course, provided with jet holes **26** which direct fluids emerging therefrom as radial jets. The nozzle **22** may be provided with a thermocouple **74** having an electric cable **76** connected to a suitable indicating instrument as will be shown in Figure 8.

Figure 3 shows a modified type of jet nozzle **77** having radial jet **78** but also having axial jet **79** and other forwardly directed jets **81**. **77** is preferably made of steel or other material of considerable strength because jet **77** is employed in modified forms of my process in which the hole is burned into coal by the progress of jet **77** instead of having the hole **16** first drilled and jet **22** merely inserted and withdrawn in a preformed hole.

Figure 4 shows a third modification of a nozzle **82** provided with radial jet holes **83** and forwardly directed jet holes **84**. Surrounding nozzle **82** is a sleeve **86** containing inlet holes **87** so that the products of combustion may be removed through annular space **88** and their temperature taken by thermocouple **74** as they enter space **88**. This type of nozzle shown in Figure 4 is adapted to practice either the withdrawal operation in a preformed hole **16** or may be used to burn a hole through the coal, and in both instances the products of combustion are removed through annular space **88**.

Figure 5 is an elevational view of a tapered plug **89** which may be used to plug any undesired holes in the nozzle as shown in Figure 4. For example, holes **79** and **81** of Figure 3 may be plugged to provide a nozzle of the type having only radial holes, or the lower holes may be plugged in a nozzle so that the major portion or all of the fluid passing out through the nozzle may be directed upwardly which is preferable in many instances.

Figure 6 shows how the invention may be employed in a directional drill hole extending through non-productive formation **91** into coal vein **92** which lies between formations **91** and **93**. A conventional drilling rig **94** may be employed to sink a well **96** which well is deflected by any conventional method such as whipstocking at **97** into more or less horizontal bore **98** in the coal seam **92**. Either the apparatus of Figure 1 or that of Figure 8 may be employed. If the apparatus of Figure 1 is employed it is convenient to locate the casing head **29** at the surface of the ground. In either instance after the bore **98** is in the coal seam it may be extended therein by conventional drilling processes or by burning.

In Figure 7 a coal seam **99** is located between earth formations **101** and **102** and the bore hole or hole being burned **103** is located adjacent the bottom of the coal seam which is preferable in many instances as later burning or gasification of the coal occurs more easily in the upper direction in seam **99** because of the convection of hot products upwardly and cold products downwardly due to difference in specific gravity. Bore **103** may rest on formation **102** which may be a hard formation as will be explained with relation to Figure 8.

In Figure 8 a hole is being burned to the right in coal seam **104** located between earth formations **105** and **106** by a nozzle **107** on the end of a flexible conduit **108** inserted in a shaft **109**. Flexible conduit **108** is coiled on a drum **111** mounted on a truck **112** and fluids are supplied through conduit **108** by a pipe **113** leading to the inner end of the conduit **108** on drum **111** by suitable stuffing box arrangement. Nozzle **107** is provided with a thermocouple **74** (not shown) and the wires from the thermocouple lead to slip rings **114** and **116** on drum **111** from which suitable brushes pick up the potential developed and carry the same through wires **117** and **118** to a suitable indicating instrument **119**. As shown in the drawings, steam from boiler **121**, gas from gas container **122** and/or oxygen from container **123** may be supplied in any proportion to the conduit **108**.

In Figure 9 the valve connection **24** of Figure 1 is shown in greater detail. Valve connection **24** is provided with externally threaded ends **124** and contains a bore **126** having an axial valve seat **127** and a radial bore **128**. Radial bore **128** may be closed by a plug **129** or may be connected to one of conduits **52** or **53** of Figure 1 by means of a valve connection **54** or **56**. In connection **24** a valve **131** is pivoted at pivot **132** to swing from the position shown in which it closes bore **128** to a vertical position in which it will close bore **127** depending upon the relative pressure of fluids in bores **127** and **128** as will be explained under the operation of the invention.

Operation

In Figure 1 a bore hole **16** has been driven into the coal seam **14** either by drilling the bore hole with any conventional drilling equipment, such as a diamond core drill (not shown) or hole **16** may have been burned into the formation by a method similar to that shown in Figure 8. Regardless of how hole **16** is produced the method in Figure 1 is as follows:

A gas conducting conduit **21** is assembled out of pipes **23** and valved joints **24** with a jet nozzle **22** on its end and is inserted into bore hole **16** through stuffing box **31**, **32** of sealing head **29**. During this insertion air from pipe **68** and gas from pipe **46** may be forced through conduit **21** and having once been ignited by a match (not shown) will burn as it emerges from jets **26**.

The operation of valves **24** will be apparent from Figure 9. Valve head **131** is pivoted at **132** and will seat and close either passage **127** or passage **128** depending on which passage contains gas at the greater pressure. Obviously, the valve head **131** closes the passage having the least pressure, being blown shut against said passage by the flow of gas from the other passage through opening **126**. Returning to Figure 1 with valve **56** closed and valve **54** open, gases from manifold **51** pass through flexible conduit **52** and blow valve head **131** against seat **127** thus forcing the gases to proceed through pipe **21** and to emerge from holes **26** as jets. The gases cannot travel into the new section of pipe **23** which is being added. When a new valve section **24** is attached and valve **56** is opened and valve **54** is closed then the gas passes through flexible conduit **53** and blows the valve head **131** in the right hand valve **24** to close seat **127** whereas in all of the other valves **24** the valve head **131** is being blown against seat **128**. Valve **54** is then removed from valve section **24** and in order to obviate any difficulty the plug **129** is screwed into **24** to close opening **128** in a secure manner. Valve heads **131** act as check valves preventing backward flow through pipe **21** in case of any underground explosion.

Flexible conduit **52** and valve **54** are then free to be attached to the next valve **24** after the next pipe section **23** has been attached. In a similar and obvious manner the reverse of this process may be employed in removing pipe **21** section by section without at any moment interrupting the flow of gases therethrough.

Having inserted pipe **21** with a flame burning at the end through hole **26** into the coal seam preferably to the entire extent of hole **16**, it is then preferred to admit air or oxygen from line **68** under increased pressure causing localized burning of the coal in seam **16** adjacent jets **26**. When the coal has begun to burn valve **48** may be closed, turning off gas **18**.

It is not believed necessary to go into the various reactions which take place as coal burns in accordance with the amount of oxygen, nitrogen, water vapor and combustion gases which may be present. It is generally considered that the coal may break down to methane (CH_4) but this is not necessarily true in order to practice applicant's invention, which invention does not consist in any theory but which consists in certain process steps or combination of apparatus. The only purpose of mentioning a theory is merely to classify the operation of the invention.

In accordance with the theory that the coal will break down into methane, five equations have been given above. Equations 1, 3, 4 and 5 are desirable and obviously Equation 2 is undesirable. In order to avoid Equation 2 the temperature at the point of reaction should be above 1500° F., or at least closer to 1500° F. than to 1200° F. because at 1200° F. the reaction tends to obey Equation 2 whereas at 1500° F., and above, Equation 5 is favored, but the temperature at the point of burning should also be below 2370° F. where Equation 2 is again favored.

Jets **26** increase the intensity of burning of coal seam **14** so that the desired temperature may be maintained and this temperature may be estimated by readings taken with a thermocouple **74**. When the desired temperature is achieved, water vapor preferably in the form of steam may be admitted to the system through valve **58**.

In a certain length of time the coal in seam **14** adjacent jets **26** is burned to ashes **28** which may or may not contain a certain amount of coke. Either continuously during the burning operation, or in spaced steps, the pipe **21** is withdrawn from hole **16** placing jets **26** opposite fresh unburned coal where the jets start burning crevices **27** back into the coal, igniting the same and turning it into ashes **28**.

All of the time that this burning and various reactions are taking place the reaction gases are travelling through hole **16** around pipe **21** into head **29** and through pipe **23** to a gas holder **37** of the usual type. The pressure of the gas is preferably indicated on gauge **34** and samples of the gas being produced are preferably analyzed in the gas analyzer **44**. At the same time the composition of gases entering through valve **48**, **58** and **69** is preferably known and the pressure thereof is preferably measured by gauge **71**.

The process, therefore, can be controlled by various relationships, such as the difference in pressure between gauges **34** and **71**, which will indicate the progress of the burning and also control can be obtained by readings from thermocouple **74** which indicates the temperature and also the progress of the burning. Also gas analyzer **44** may be employed to indicate the nature and degree of the burning. When all are used in combination these various indicating means give a very thorough picture of what is going on so that the engineer may make desirable changes in the factors involved.

The gas in gas holder **37** is commercially valuable, consisting mostly of carbon monoxide and hydrogen with or without dilution by nitrogen depending on whether air or oxygen was introduced to the system through pipe **63**. Generally it is economically preferable to employ air especially when gas **37** is to be used as fuel gas, and especially when coal seam **14** is shattered so that extraneous air can enter the system. When the gas in gas holder **37** is to be employed in chemical reaction (for example, of the Fischer-Thopsch type) it is often desirable to employ oxygen in which case there is less nitrogen in the gas. The gas is taken through pipe **38** and valve **39** to whatever type of process the gas is to be employed for.

When pipe **21** is completely removed from coal seam **14**, another hole **16** is bored in some other portion of the coal seam and the process is repeated.

The operation of the device shown above ground in Figure 1 is believed obvious. **18** is any source of gas suitable for fuel. This gas may come from an oil well, pipe line, commercial gas plant, or be gas from gas holder **37** produced from another portion of coal seam **14**. The pressure of this gas may be regulated at **49**. **19** similarly is any source of steam and may be a boiler as shown or may be steam generated by some process utilizing gas from gas holder **37** (process not shown). Similarly tank **17** may contain any combination of air and/or oxygen which may come from an oxygen plant (not shown) attached to pipe **63**. If desired additional pumping means may be employed in pipes **33**, **46**, **57** and **68**, and a pumping means (not shown) in pipe **33** may be employed to operate hole **16** at a vacuum if desired.

The operation of Figure 6 is similar to that of Figure 1 except that hole **98** replaces hole **16** and hole **98** is drilled by a means of drilling a well **96** in a vertical direction through formation **91** and deflecting the same by whipstocking at **97**, or other well known deflective hole drilling methods.

The method shown in Figure 7 is adaptable to the method shown in Figure 1 and Figure 6 as Figure 7 merely emphasizes the desirability in many instances of running hole **103** at or near the bottom of coal seam **99** because, as well known, the burning of coal or other substances generally proceeds in an upward direction due to the fact that hot gases are lighter than cold gases and, therefore, are forced upward by the heavier cold gases. In order to direct these gases upwardly from the jets into coal **99** it is often desirable to plug some of the jet holes **26** and this may be done by employing tapered plugs such as **89** of Figure 5 which plugs may be placed in any of the holes shown in Figures 1, 2, 3, 4 and 8.

When employing the nozzle shown in Figure 4 it is not necessary to have a housing such as **29** as the combustion gases enter holes **87** and are drawn off through space **88** preferably by a vacuum pump of some type.

In the method shown in Figure 8 a portable apparatus **112** supplies steam, gas or air in the desired proportions to the end of hose **108** reeled on reel **111** and this flexible hose **108** may be forced into the coal so that a hole is burned in the coal by flames coming out of nozzle **107**. When this hole has been burned back into the coal a sufficient distance a split housing (not shown) similar to housing **29** may be placed around hose **108** and then with increased air pressure hose **108** may be withdrawn slowly through the coal **104**, the burning of which with or without the presence of steam from boiler **121** will produce valuable gases in the manner described relative to Figure 1.

When burning holes in the coal, it is often preferred to use jets such as shown in Figures 3 and 4 in which there are forwardly directed holes **79**, **81** and **84**. These forwardly directed holes can be plugged with plugs **89** if desired before burning the coal and withdrawing the pipe. However, in the process of burning the coal and withdrawing the pipe it is often preferable to employ a nozzle **22** made of ceramic material as illustrated in Figure 2 because such material is capable of withstanding higher temperatures which is also especially valuable when using oxygen in pipe **68** as it is well known that a steel pipe will burn if oxygen is being injected through it and it reaches sufficient temperature.

While I have described above certain specific forms and apparatus and certain specific sequences of process steps, it is understood that this has been done in order to give illustrative embodiments to the invention and that the invention is not limited thereby but instead is of a scope defined and limited only by the following claims.

Having described my invention, I claim:

1. A system for the underground gasification of coal in a coal vein which comprises a tube having a jetting nozzle having radial jets therein adapted to be disposed in said coal vein, a casing head sealed to said coal vein and to said tube, said tube comprising a plurality of connected and communicating sections, each section having an axial passage in communication with the next section and a radial passage communicating with said axial passage, check valve means controlling flow through said passages so that continued flow through said axial passage away from said nozzle and from said axial passage out through said radial passage is checked, a source of steam, a source of fuel gas, and a source of free oxygen containing gas, a manifold connecting said sources with at least one of said radial passages comprising two flexible conduits whereby fluids from said sources may be continuously supplied to said nozzle without interruption during the insertion and withdrawal of said tube through said casing head.

2. A system for the underground gasification of coal in a coal vein which comprises a tube having a jetting nozzle adapted to be disposed in said coal vein, a casing head sealed to said coal vein and to said tube, said tube comprising a plurality of connected and communicating sections, each section having an axial passage in communication with the next section and a radial passage communicating with said axial passage, check valve means controlling flow through said passages so that continued flow through said axial passage away from said nozzle and from said axial passage out through said radial passage is checked, a source of fuel gas, and a source of free oxygen containing gas, a manifold connecting said sources with at least one of said radial passages comprising two flexible conduits whereby fluids from said sources may be continuously supplied to said nozzle without interruption during the insertion and withdrawal of said tube through said casing head.

3. A system for the underground gasification of coal in a coal vein which comprises a tube having a jetting nozzle adapted to be disposed in said coal vein, a casing head sealed to said coal vein and to said tube, said tube comprising a plurality of connected and communicating sections, each section having an axial passage in communication with the next section and a radial passage communicating with said axial passage, check valve means controlling flow through said passages so that continued flow through said axial passage away from said nozzle and from said axial passage out through said radial passage is checked, a source of steam, and a source of free oxygen containing gas, a manifold connecting said sources with at least one of said radial passages comprising two flexible conduits whereby fluids from said sources may be continuously supplied to said nozzle without interruption during the insertion and withdrawal of said tube through said casing head.

4. A system for the underground gasification of coal in a coal vein which comprises a tube having a jetting nozzle adapted to be disposed in said coal vein, a casing head sealed to said coal vein and to said tube, said tube comprising a plurality of connected and communicating sections, each section having an axial passage in com-

munication with the next section and a radial passage communicating with said axial passage, check valve means controlling flow through said passages so that continued flow through said axial passage away from said nozzle and from said axial passage out through said radial passage is checked, a source of free oxygen containing gas, a manifold connecting said source with at least one of said radial passages comprising two flexible conduits whereby fluid from said source may be continuously supplied to said nozzle without interruption during the insertion and withdrawal of said tube through said casing head.

5. A system for the underground gasification of coal in a coal vein which comprises a tube having a jetting nozzle having radial jets and forwardly directed jets therein adapted to be disposed in said coal vein, a casing head sealed to said coal vein and to said tube, said tube comprising a plurality of connected and communicating sections, each section having an axial passage in communication with the next section and a radial passage communicating with said axial passage, check valve means controlling flow through said passages so that continued flow through said axial passage away from said nozzle and from said axial passage out through said radial passage is checked, a source of steam, a source of fuel gas, and a source of free oxygen containing gas, a manifold connecting said sources with at least one of said radial passages comprising two flexible conduits whereby fluids from said sources may be continuously supplied to said nozzle without interruption during the insertion and withdrawal of said tube through said casing head.

6. A system for the underground gasification of coal in a coal vein which comprises a tube having a jetting nozzle having radial jets therein adapted to be disposed in said coal vein, a casing head sealed to said coal vein and to said tube, said tube comprising a plurality of connected and communicating sections, each section having an axial passage in communication with the next section and a radial passage communicating with said axial passage, check valve means controlling flow through said passages so that continued flow through said axial passage away from said nozzle and from said axial passage out through said radial passage is checked, an annular sleeve having inlet holes and surrounding said tube, said sleeve axially extending from said nozzle to said casing whereby the products of combustion may be removed through the annular space defined by said annular sleeve and said tube, a source of steam, a source of fuel gas, and a source of free oxygen containing gas, a manifold connecting said sources to at least one of said radial passages comprising two flexible conduits whereby fluids from said sources may be continuously supplied to said nozzle without interruption during the insertion and withdrawal of said tube through said casing head.

7. A system for the underground gasification of coal in a coal vein which comprises a tube having a jetting nozzle having radial jets therein adapted to be disposed in said coal vein, a casing head sealed to said coal vein and to said tube, said tube comprising a plurality of connected and communicating sections, each section having an axial passage in communication with the next section and a radial passage communicating with said axial passage, check valve means controlling flow through said passage so that continued flow through said axial passage away from said nozzle and from said axial passage out through said radial passage is checked, an annular sleeve having inlet holes and surrounding said tube, said sleeve axially extending from said nozzle to said casing whereby the products of combustion may be removed through the annular space defined by said annular sleeve and said tube, a thermocouple in said annular space generally adjacent said nozzle, a source of steam, a source of fuel gas, and a source of free oxygen containing gas, a manifold connecting said sources to at least one of said radial passages comprising two flexible conduits whereby fluids from said sources may be continuously supplied to said nozzle without interruption during the insertion and withdrawal of said tube through said casing head.

8. A system for the underground gasification of coal in a coal vein which comprises a tube having a jetting nozzle having radial jets and forwardly directed jets therein adapted to be disposed in said coal vein, a casing head sealed to said coal vein and to said tube, said tube comprising a plurality of connected and communicating sections, each section having an axial passage in communication with the next section and a radial passage communicating with said axial passage, check valve means controlling flow through said passages so that continued flow through said axial passage away from said nozzle and from said axial passage out through said radial passage is checked, an annular sleeve having inlet holes and surrounding said tube, said sleeve axially extending from just back of said nozzle to said casing whereby the products of combustion may be removed through the annular space defined by said annular sleeve and said tube, a thermocouple in said annular space generally adjacent said nozzle, a source of steam, a source of fuel gas, and a source of free oxygen containing gas, a manifold connecting said sources to at least one of said radial passages comprising two flexible conduits whereby fluids from said sources may be continuously supplied to said nozzle without interruption during the insertion and withdrawal of said tube through said casing head.

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