Jan. 17, 1967 T. T. GRAHAM 3,298,434

GASIFICATION OF COAL

Filed May 27, 1964 4 Sheets-Sheet 1

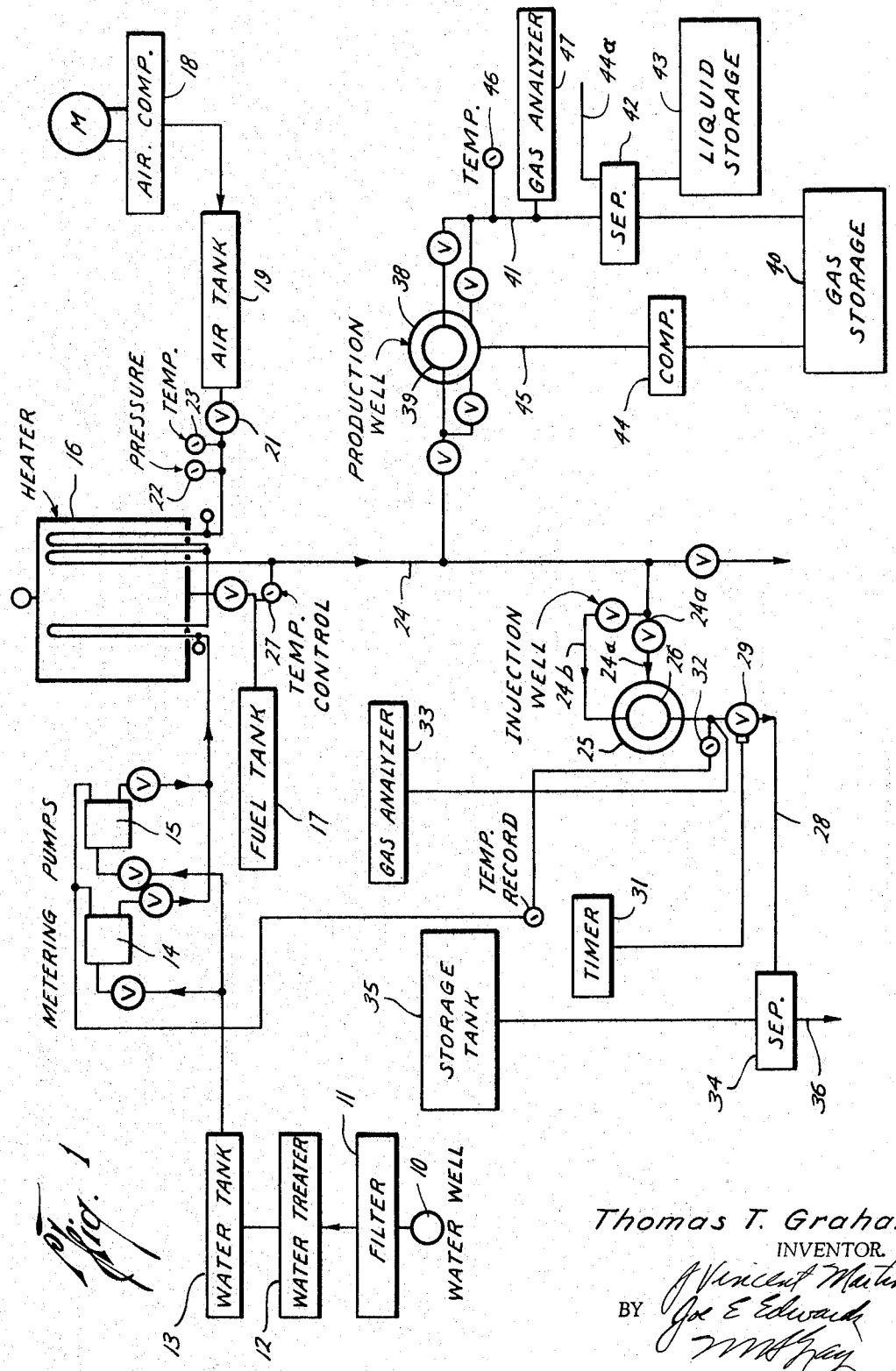


Fig. 1

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GASIFICATION OF COAL

Filed May 27, 1964 4 Sheets-Sheet 2

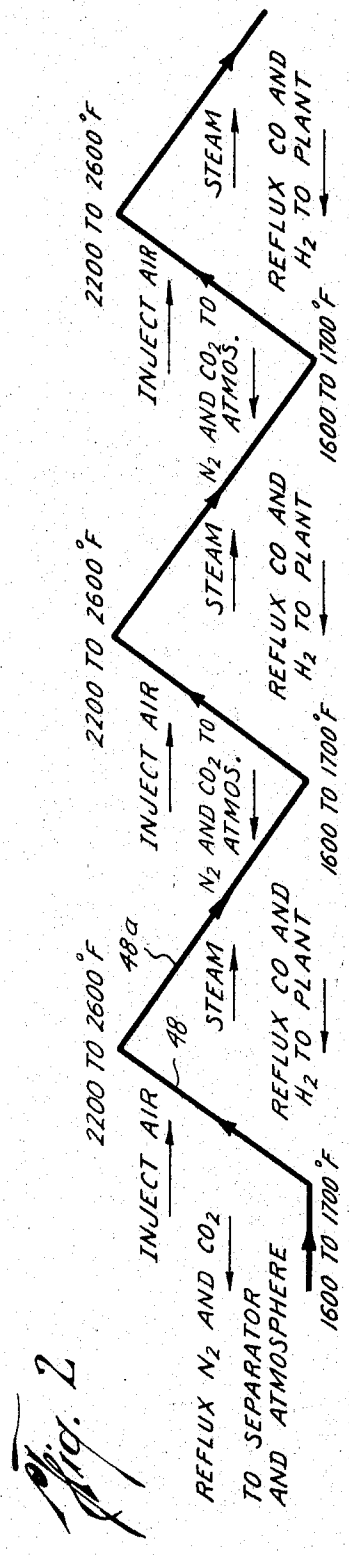


Fig. 2

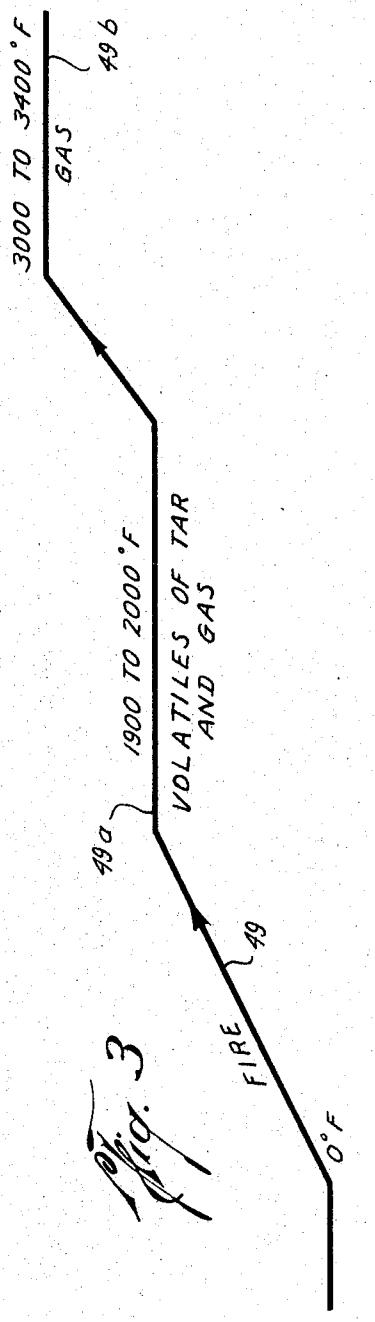


Fig. 3

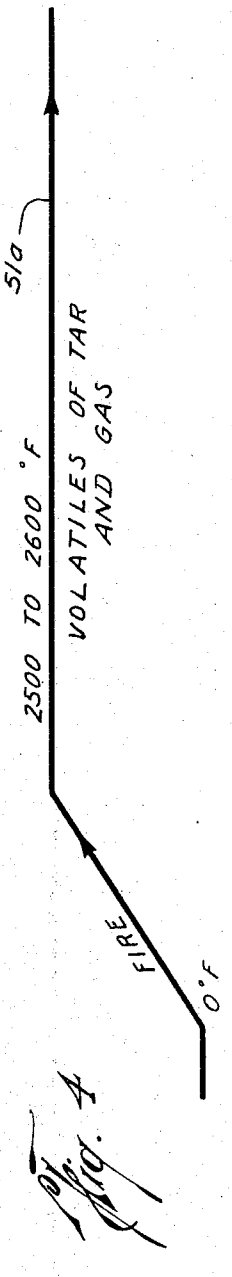


Fig. 4

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GASIFICATION OF COAL

Filed May 27, 1964 4 Sheets-Sheet 3

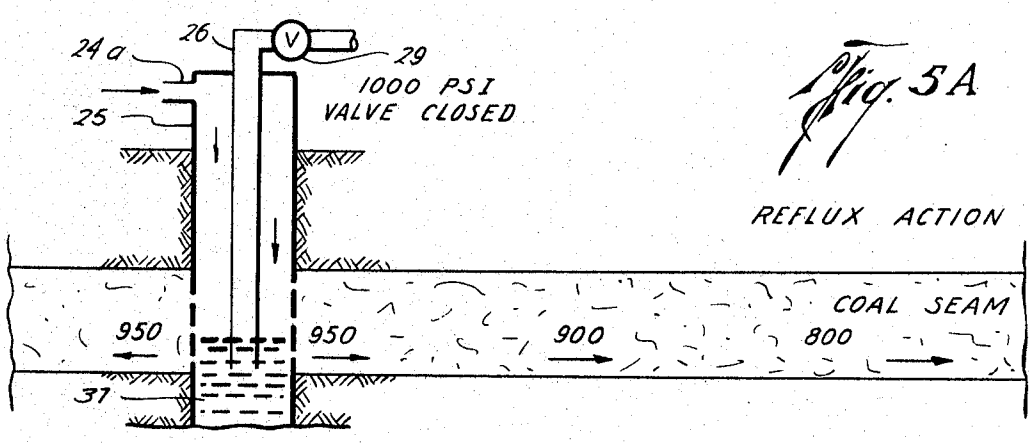


Fig. 5A

REFLUX ACTION

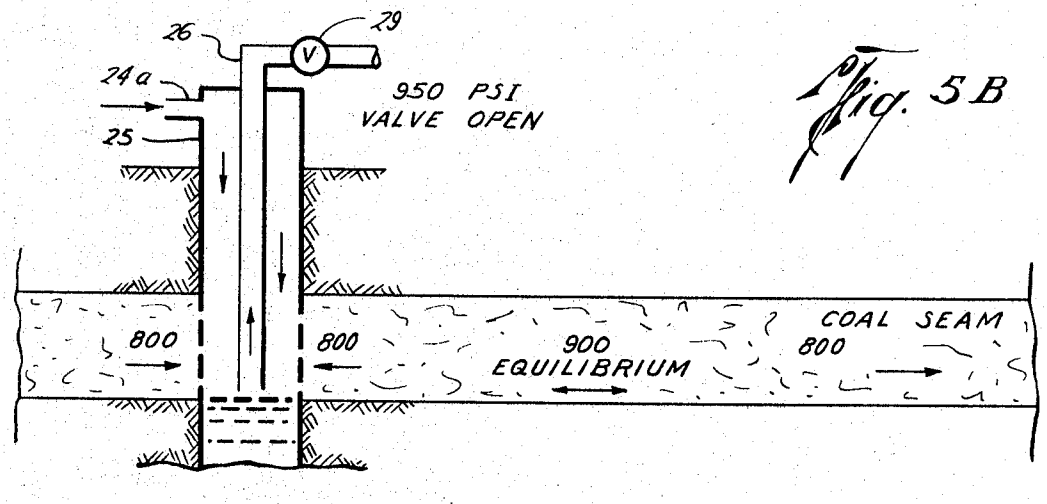


Fig. 5B

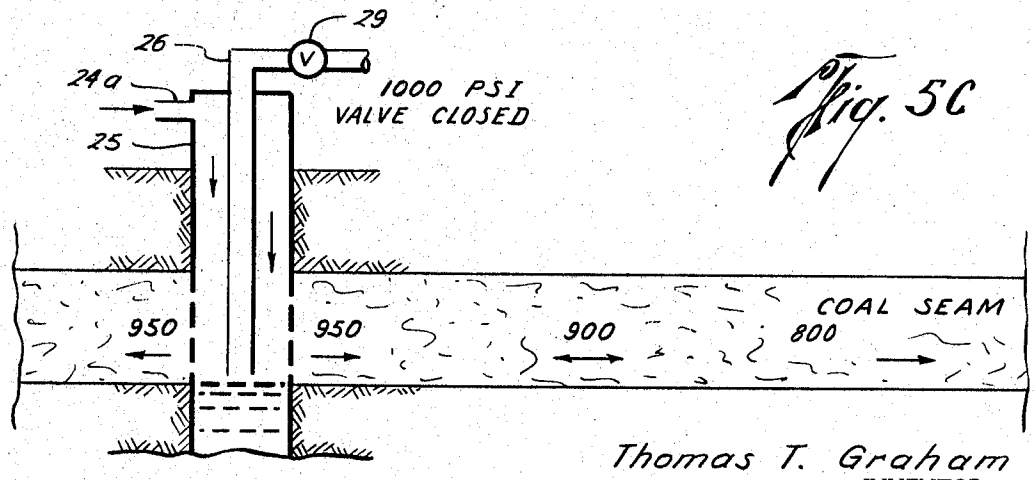


Fig. 5C

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GASIFICATION OF COAL

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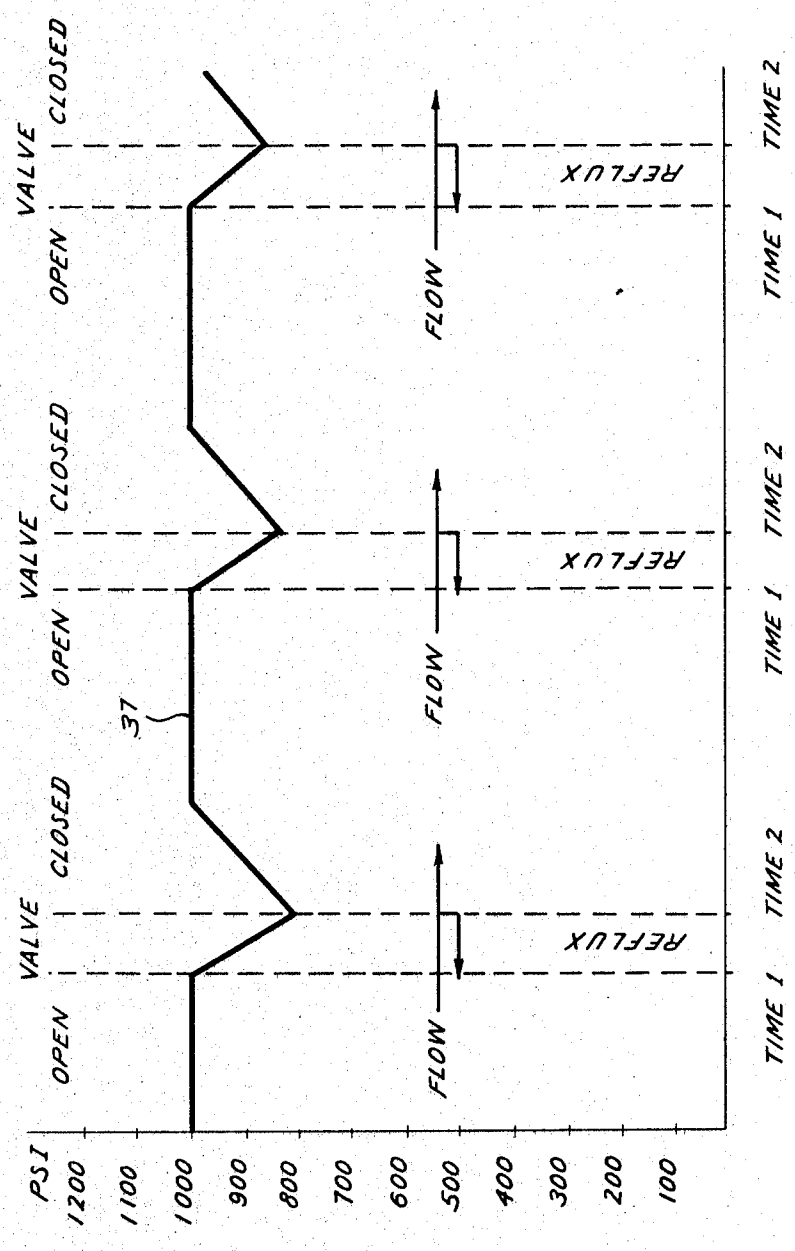


Fig. 6

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3,298,434

GASIFICATION OF COAL

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6 Claims. (Cl. 166—2)

This invention relates to a process for the gasification of coal in situ.

Coal is frequently burned under controlled conditions to gasify the volatile matter and to manufacture producer gas, synthesis gas, etc. It would be advantageous to be able to burn the coal in situ to obtain these volatiles and gases, but up until this time no practical economic method has been available for burning the coal in situ.

It is an object of this invention to provide a method of burning coal in situ to obtain the tars, oils, fuel gases, etc. available when coal is burned under controlled conditions.

Another object is to provide a method of burning coal in situ wherein a constant check is kept of temperature conditions to permit burning the coal under controlled conditions.

Another object is to provide a method of burning coal in situ in which the burning is carried out at selected temperature levels.

Another object is to provide a method of burning coal in situ using steam and air injected into the coal seam in which the injection well is kept free of condensate so that the hot steam and air can freely reach the flame front.

Other objects, features and advantages of the invention will be apparent from the drawings, specification and the claims.

In the drawings, wherein like reference numerals indicate like parts, and wherein the methods of this invention are depicted:

FIGURE 1 is a schematic view of surface equipment used in practicing this invention;

FIGURE 2 illustrates one process in accordance with this invention;

FIGURE 3 illustrates one process in accordance with this invention;

FIGURE 4 illustrates another process in accordance with this invention;

FIGURES 5*a*, 5*b* and 5*c* are schematic views showing a well penetrating a coal seam and illustrating in successive stages refluxing of the injection well in accordance with this invention; and

FIGURE 6 is a chart of pressure and time illustrating these values during refluxing.

In practicing this invention, a well is first sunk to the coal seam. As substantial pressures are to be used, a seam should be selected where a suitable cap and overburden will contain the pressure. In one form of the invention, the fluids are injected and the gases recovered from the same injection well. In other forms of the invention, production wells are drilled into the coal seam. Where production wells are drilled, channels of communication are provided between the injection and production wells in any desired manner to permit flow of gases between the wells. It is well known that this may be done by mining, by hydrofracing, or electrolinking-carbonization.

Air and stream are then injected through the injection well and the coal ignited. In some forms of the mehod the air and steam are injected as a mixture, and in others they are injected alternately. The time of injection of the alternate air and steam and the ratio of air to steam in mixed injection controls the temperature at the flame front. Of course, as soon as injection is commenced, the formation is set on fire in any well known manner. For instance, the use of a sufficiently hot injection fluid will

ignite the coal seam. Many other well known means of igniting the seam may be practiced.

As the flame front moves away from the well, the heat at the well decreases and condensates collect in the well. By this invention these condensates are periodically removed from the well so that they do not interfere with the injection of air and steam. At the time that these condensates are removed from the well, fluids from the vicinity of the flame front are also returned to the surface and their condition ascertained so that the temperature at the flame front will be known. Their condition may be readily determined by measuring the temperature of the fluids or by analyzing the fluids to determine the content of carbon monoxide and carbon dioxide. Either or both methods may be used under varying circumstances. According to the temperature found to exist, the time of injection of alternate air and steam or the ratio of air and steam when injected in a mixture may be varied to maintain the desired temperature at the flame front.

At a relatively low temperature from below around 1200° F. most if not all of the volatile products will be volatilized.

Where air and water vapor are present, burning of coal will result in a carbon dioxide and hydrogen product if the temperature is below 1832° F. Above 1832° F. a fuel mixture of carbon monoxide and hydrogen will be produced. Where steam is not present, the burning of coal below 1832° F. will give a relatively inert carbon monoxide and nitrogen product.

From the above it is obvious that the volatiles can be obtained at a lower temperature, but they would thus be obtained in the absence of a usable fuel gas. The coal must be burned at about 1832° F. to give a fuel gas. The higher the temperature above this point, the more carbon gasified, and hence the more fuel gas. However, normal iron equipment can only withstand around 2600° F., and if the coal is to be burned at a temperature such that the equipment in the bottom of the well will be exposed to more than 2600° F., then special heat-resistant equipment should be used.

By utilizing this process, fuel gas made up principally of carbon monoxide and hydrogen may be recovered. Also, there will be recovered the light oil products benzene, toluene, xylene and naphtha. The gas chemicals ammonium sulfate, cyanide chemicals and sulphur will also be recovered. Also the tar chemicals naphthalene, the tar acids and tar bases will be recovered.

Referring to FIGURE 1, water is obtained from a suitable water well **10** and purified in filter **11** and water treater **12**. The purified water is stored for use in tank **13**. As needed the water is withdrawn from tank **13** by the metering pumps **14** and **15** and delivered to the heater **16**. The heater **16** may be the conventional gas-fired type with fuel obtained from a storage tank **17**.

Air compressor **18** maintains a supply of air under pressure in air tank **19**. This air is metered as needed by valve **21** and delivered to the heaters **16**. The pressure and temperature of the air leaving the tank may be recorded by the pressure-sensitive instrument **22** and the temperature-sensitive instrument **23**. The air is heated in the heater **16** and combined with the steam. The combined air and steam is then delivered through line **24** to the injection well casing **25**. Normally the steam-air mixture will be introduced into the casing **25** through branch line **24***a*, but, if desired, it may pass through branch line **24***b* to the tubing.

Also, it is apparent that the system just explained may be utilized to alternately inject air and steam by suitable control of the air tank valve **21** and the water metering pumps **14** and **15**.

A suitable temperature control device **27** is sensitive to the temperature in line **24** and controls the flow of fuel

from tank 17 to heater 16 to permit maintaining of a desired temperature in line 24.

After injection of air or air and steam is begun, the well may be set on fire either due to the heat of the injected fluids or by a special formation-lighting device. As there are no fuel gases available until after the formation is on fire, it is not necessary to initially inject steam, and only air will normally be used. A mixture of air and steam could be used if desired.

After the formation is on fire, air and steam are injected as a mixture, or alternatively, depending on the method used.

In accordance with this invention, the well is now periodically refluxed to reflux the formation and to remove from the well condensates which may have collected therein. For this purpose, the outlet line 28 from tubing 26 is provided with a quick-opening valve 29. The valve 29 may be controlled by a suitable timer 31. As the valve 29 opens, the pressure in the well forces the liquids above the level of the tubing 26 up through the tubing to the surface and out-line 28. As these fluids leave the well, their temperature may be determined by instrument 32 and, if desired, gas analyzer 33 may be utilized to determine the condition of the reflux gases. From line 28 the reflux gases pass to the separator 34 and liquids separated out pass to storage tank 35. Gases pass off through line 36.

Reference is made to FIGURES 5*a* through 5*c* wherein the reflux action on the coal seam is depicted. In FIGURE 5*a* the condition is depicted in which the injection well is under a pressure of 1,000 p.s.i. Fluids are being injected through line 24*a*. This will result in a pressure in the bottom of the hole of around 950 pounds. This pressure will reduce progressively away from the well. It is noted that the bottom of the tubing 26 extends down to at least the level of the coal seam and preferably extends to approximately the bottom of the coal seam. Thus as liquids 37 accumulate, they rise above the bottom of the tubing 26.

FIGURE 5*b* shows the cleaning of the well and refluxing of the coal seam when the valve 29 in the tubing is open. The accumulated pressure within the well, assisted by the pressure continuously being injected through inlet line 24*a*, drives the liquids accumulated above the lower end of the tubing up through the tubing to the surface. After the refluxing action, the well will be in the condition shown in FIGURE 5*c* in which liquids have been cleaned out and the coal seam is open and free to receive fluids thereafter being injected.

FIGURE 6 depicts the periodic refluxing and the change in pressures which occur as represented by line 37. It will be noted that when the valve is open, the pressure drops fairly rapidly to about 800 p.s.i.; when the valve is closed, it again rises fairly rapidly to the 1000-pound injection pressure. As depicted, the well is refluxed for only a short period of time.

While the illustrated embodiment employs an injection pressure of 1000 pounds, it will be appreciated that other injection pressures may be used, depending upon the circumstances encountered in the particular coal seam.

Where the system includes one or more production wells, the coal seam will first be fractured as hereinabove discussed to provide channels between the injection well and the production well. As shown in FIGURE 1, the production well may include a casing 38 with a tubing 39 therein. Preferably the tubing 39 will extend down to the bottom of the coal seam. As the gases from the burning coal reach the production well, they will normally rise up the tubing 39 and pass out through line 41 to the separator 42. At the surface the volatiles will liquefy and be separated out in separator 42 and pass to the storage tank 43. Fuel gas is taken off of separator 42 through line 44*a* and sent to distribution.

In the event the production well is a sufficient distance from the flame front, the gases may cool sufficiently in the production well to result in condensate collecting in the bottom of the well. Condensate may also form before the gases reach the well. To raise this liquid to the surface, a portion of the gas from separator 42 is stored in tank 40 and is returned to the well by compressor 44 through line 45. This compressed gas is introduced into the casing and gas lifts the liquid in the bottom of the production well through the tubing.

A suitable temperature instrument 46 records the temperature of the fluids leaving the production well and a gas analyzer 47 may be utilized to determine the composition of the gas. This temperature and composition information may be correleated with that obtained from the reflux on the injection well to determine the temperature at the flame front. Obviously, if fuel gas is desired and carbon dioxide is shown to be present in large volume by the gas analyzers, the temperature in the well would be permitted to rise by reducing the amount of steam introduced, as it would be known that the flame front was burning at a temperature less than 1832° F. On the other hand, if the temperature indicators show an elevated temperatur, say 2700 or 2800° F., and the flame front is fairly close to either the injection or production well, that must be taken that the temperature is now greater than the equipment in the well will withstand, and the amount of steam might be increased to reduce the temperature at the flame front. Of course, where special heat-resistant materials are used, the temperature might be permitted to go much higher.

Reference is now made to FIGURE 2 wherein a system is depicted which utilizes the injection well only. As shown, the operation of this system begins after the formation is on fire and ready to produce. The cycle has a low temperature of around 1600 to 1700° F. at the surface, as this would reflect a temperature of around 1832° F. at the flame front. Of course, as the flame front moves away from the well, these surface temperatures would reduce. As shown by the graph line 48, air is injected through the injection well until such time as the reflux fluids from the well indicate that the flame front temperature is a substantial value above 1832° F. Depending upon the installation, this may vary from about 2200° F. to 2600° F. Where special heat-resistant equipment is used, the temperature might be greater. In any event, it is a substantial value above 1832° F. so that a substantial amount of steam will be necessary to reduce the temperature at the flame front back to 1832° F. because the passing of steam over the hot coal will result in manufacturing of fuel gas consisting primarily of carbon monoxide and hydrogen. Also, the volatiles of the coal will be volatilized as the flame front moves back in the coal seam and these volatiles will be recovered. During this stage of the proceeding, steam is injected and fuel gas is refluxed out of the injection well. The periodic introduction of steam and alternate refluxing may be carried out at such time intervals as are appropriate for the best efficiency. This introduction of steam and refluxing of fuel gas is indicated by the line 48*a*. The alternate introduction of steam and refluxing of fuel gas is continued until the temperature at the flame front reduces to about 1832° F. This will be apparent from the reduction in temperature of the reflux at the surface, and the operator will be able to approximate the temperature at which he should return to the air injection cycle to reheat the coal. Of course, the gas analyzer would be the most sensitive means of determining when the formation temperature falls below 1832° F., as the production of carbon monoxide begins to give way to the production of carbon dioxide. As shown, the cycle is continuously repeated in the manner explained, with fuel gas and volatiles being recovered during the steam cycle, and with volatiles being recovered during the air cycle and the inert gas released to atmosphere.

In FIGURE 3, an alternate method of operation is shown in which the production well is used to recover

the gases. Air is first introduced and the formation set on fire as depicted by line 49. As the temperature rises, the volatiles are gasified and are pushed on toward the production well due to the pressure of the fluids being introduced. Of course, the well would have been treated to provide channels through which the gas may pass to the production well. After the flame front comes up to a temperature above 1832° F., as possibly indicated by a surface temperature of 1900 to 2000° F., the burning coal will produce a fuel gas of carbon monoxide and hydrogen, as depicted by line 49*a*. During periodic refluxing of the well, any condensate in the injection well will be recovered and the temperature in the flame front will be held at the desired level by varying the proportions of the air and steam injected as called for by the temperature indicator 32 and the gas analyzer 33. In accordance with this form of the invention, the formation between the injection and production well is made to burn at a temperature slightly greater than 1832° F. until the flame front reaches the production well. At this time, the burned coal is still capable of generating additional fuel gas if burned at a higher temperature, and the formation may be reburned at very high temperatures, say 3000 to 3400° F., to produce this gas as indicated by line 49*b*. At this time the production well may be utilized as the injection well and the injection well as the production well, and the flame front forced to move back towards the injection well. The steam injected in the injection well will normally keep the injection well temperature down. Where the equipment in the production well will not withstand the high temperature, additional steam may be injected into the production well to hold its temperature down to a permissible level.

FIGURE 4 shows a still further method of practicing this invention. Again air is injected as indicated by line 51 and the formation set on fire. The coal seam is brought up to the maximum temperature at which it is to be maintained. For instance, this may be 2500 to 2600° F. Utilizing the principle of reflux and controlling the temperature as explained hereinabove, the coal seam will be forced to burn at this selected temperature from the injection well to the production well. During this time, the volatiles of tar and the fuel gas produced will be recovered through the production well as indicated by line 51*a*.

From the above explanation of three illustrative methods in accordance with this invention, it is apparent that the coal seam may be burned in situ in any desired manner and the flame front temperature controlled by refluxing the injection well to determine the temperature and then varying the ratio or time of injection of air and steam to obtain the desired temperature. It is this principle of refluxing and control in accordance with the condition of the reflux fluids which characterizes this invention and makes it possible to control the in situ burning of coal.

Any desired equipment may be used in practicing the method. However, the injection tubing should extend down to the coal seam and preferably to the bottom of the coal seam so that condensates, and particularly water, condensed in the well can be removed. While it is desirable to have steam present at the flame front, it is not desirable to have slugs of water present. Steam in small amounts will decompose in a controlled manner to provide oxygen for combining with the carbon. Where slugs of water are present, they would tend to blanket a section of the flame front and interfere with this action.

The foregoing disclosure and description of the invention is illustrative and explanatory thereof, and various changes in the method may be made within the scope of the appended claims without departing from the spirit of the invention.

What is claimed is:

1. A method of recovering gases from a coal seam into which a well bore extends, said bore having a tubing therein extending down to at least the coal seam comprising,
- injecting air into said coal,
- igniting the coal and continuing the air injection until the temperature of the burning coal is substantially in excess of 1832° F.,
- periodically opening said tubing at the surface during the air injection period to reflux the coal seam and remove from the well bore liquids which may have accumulated therein and the gaseous products of combustion from said coal seam,
- determining the temperature in the coal seam by determining the condition of the reflux fluids,
- then upon the burning coal reaching the desired temperature stopping the injection of air and injecting steam,
- periodically opening said tubing at the surface during the steam injection period to reflux the coal seam and remove from the well bore any liquids which may have accumulated therein and the gaseous products of combustion from said coal seam,
- determining the temperature in the coal seam by determining the condition of said last mentioned reflux fluids,
- repeating the air injection cycle after the temperature of the burning coal has been reduced to about 1832° F.,
- and thereafter repeating the alternate air and steam injection steps.

2. A method of recovering gases from a coal seam into which a well bore extends, said bore having a tubing therein extending down to at least the coal seam comprising,
- injecting air into said coal,
- igniting the coal,
- thereafter injecting air and steam into the coal,
- periodically opening said tubing at the surface to reflux the coal seam and remove from the well bore liquids which may have accumulated therein,
- determining the temperature in the coal seam by determining the condition of the reflux fluids,
- controlling the injection of steam and air as required by the condition of the reflux fluids to obtain selected temperature conditions in the well,
- and recovering the gaseous products of combustion from said coal seam.

3. A method of recovering gases from a coal seam into which a plurality of well bores extend, at least one of said bores having a tubing therein extending down to at least the coal seam and providing an injection well, said other bore providing a production well, comprising
- injecting air into the injection well,
- igniting the coal and continuing the air injection until the coal reaches a temperature of 1832° F.,
- thereafter injecting a mixture of air and steam into the injection well,
- periodically opening said tubing at the surface to reflux the coal seam and remove from the injection well bore liquids which may have accumulated therein,
- determining the temperature in the coal seam by determining the condition of the reflux fluids,
- controlling the temperature of the burning coal by varying the ratio of steam and air injected to burn the coal at a temperature below 1832° F. but above the temperature at which all of the volatiles of the coal are gasified,
- then burning the coal at a temperature slightly above 1832° F. to make carbon monoxide gas,
- then burning the coal at a temperature over 3000° F. to make additional gas,
- and recovering said gases from the production well.

4. A method of recovering gases from a coal seam into which a plurality of well bores extend, at least one of said bores having a tubing therein extending down to at least the coal seam and providing an injection well,

said other bore providing a production well, comprising,
injecting air into the injection well,
igniting the coal and continuing the air injection until the coal reaches a temperature of 1832° F.,
thereafter injecting a mixture of air and steam into the injection well,
periodically opening said tubing at the surface to reflux the coal seam and remove from the injection well bore liquids which may have accumulated therein,
determining the temperature in the coal seam by determining the condition of the reflux fluid,
controlling the temperature of the burning coal by varying the ratio of steam and air injected to burn the coal at a temperature above 1832° F. but below about 2600° F.,
and recovering the gases from the burning coal from the production well.

5. A method of recovering gases from a coal seam into which a plurality of well bores extend, at least one of said bores having a tubing therein extending down to at least the coal seam and providing an injection well, said other bore providing a production well, comprising,
injecting air into said coal,
igniting said coal,
thereafter injecting air and steam into the coal,
periodically opening said tubing at the surface to reflux the coal seam and remove from the well bore fluids which may have accumulated therein,
recovering the gaseous fluids resulting from combustion of said coal through said production well,
determining the temperature in the coal seam by determining the condition of one of said fluids from the injection and production wells,
and controlling the injection of steam and air as required by the temperature in the coal seam to obtain selected temperature conditions in the well.

6. A method of recovering gases from a coal seam into which a plurality of well bores extend, at least one of said bores having a tubing therein extending down to at least the coal seam and providing an injection well, said other bore providing a production well, comprising,
injecting air into said coal,
igniting said coal,
thereafter injecting air and steam into the coal,
periodically opening said tubing at the surface to reflux the coal seam and remove from the well bore fluids which may have accumulated therein,
recovering the gaseous fluids resulting from combustion of said coal through said production well,
determining the temperature in the coal seam by determining the condition of one of said fluids from the injection and production wells,
controlling the injection of steam and air as required by the temperature in the coal seam to obtain selected temperature conditions in the well,
and controlling the temperature in the production well independently of the temperature of the burning coal.

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