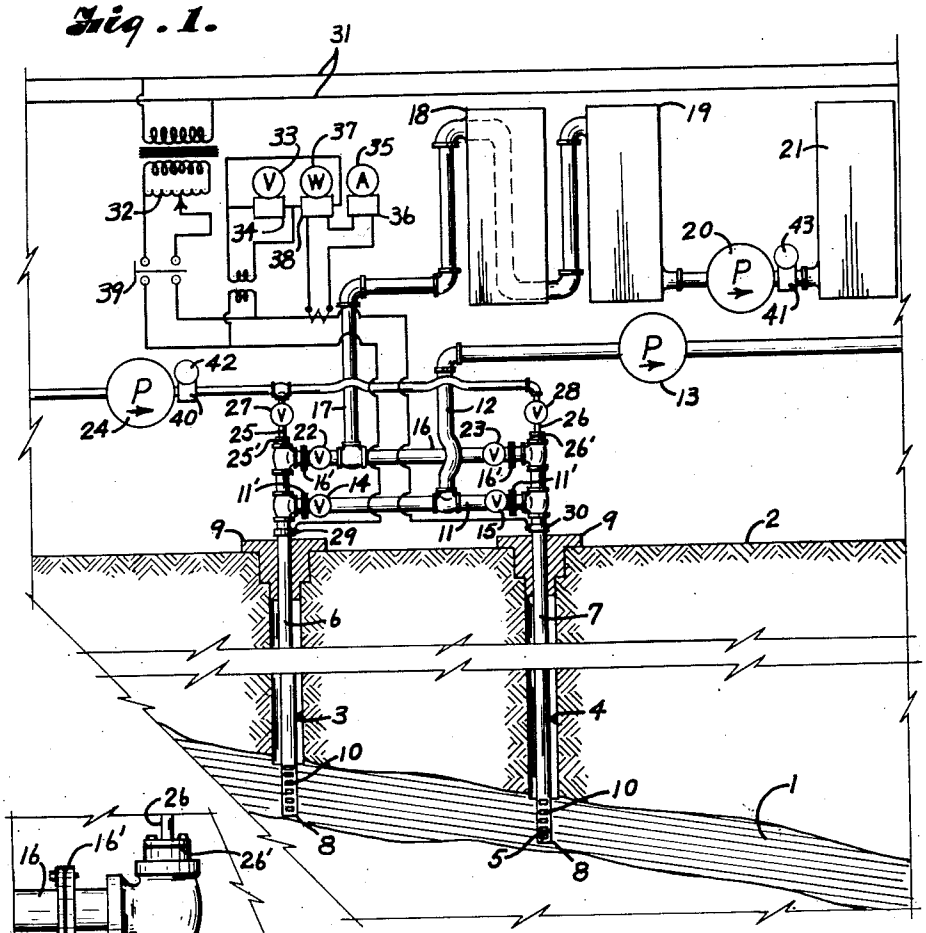
June 11, 1957 E. SARAPUU 2,795,279

METHOD OF UNDERGROUND ELECTROLINKING AND ELECTROCARBONIZATION OF MINERAL FUELS

Filed April 17, 1952

Fig. 1.



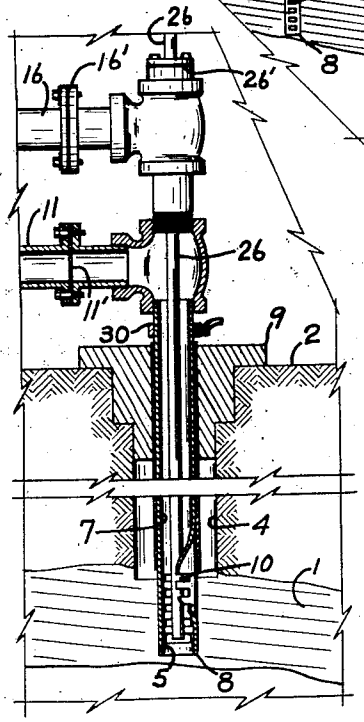


Fig. 2.

INVENTOR.
Erich Sarapuu.

BY
Fishburn & Mulkerne

ATTORNEYS.

United States Patent Office 2,795,279 Patented June 11, 1957

2,795,279

METHOD OF UNDERGROUND ELECTROLINKING AND ELECTROCARBONIZATION OF MINERAL FUELS

Erich Sarapuu, Kansas City, Mo., assignor to Electrotherm Research Corporation, Minneapolis, Minn., a corporation of Minnesota

Application April 17, 1952, Serial No. 282,922

2 Claims. (Cl. 166—11)

This invention relates to the recovery of solid, liquid and gaseous carbonaceous fuels such as coal, oil, gas and the like in their native position without underground mining operation and more particularly to a method of applying and utilizing electric current to open up, carbonize and gasify and/or pressurize the fuels in situ permitting subsequent recovery of residual coke and original fuel to be accomplished by any conventional gasification technique.

Underground gasification or the conversion of mineral carbonaceous fuels such as coal and oil shale into gaseous or liquid form by a gasification process in situ has great possibilities in obtaining higher efficiencies and lower production costs. The materials from high grade fuel deposits commonly have been recovered by mining processes and the like and the reserves of inferior value have been neglected, and thus many deposits have been declared exhausted when the ordinary mining and recovery processes become uneconomical or impractical. Underground gasification as a general process is applicable to several types of natural fuel occurrences whether they are of high grade or of inferior value. However, it is of particular importance in the more complete exploitation and recovery of these fuels from reserves of inferior value and where the ordinary mining and recovery processes are uneconomical or impractical.

The underground gasification of coal and the other fuels in their native position may be accomplished by producing a system of fractures in a fuel bed and boreholes leading from the surface to such bed for introduction of gasification fluid or medium to support gasification of the fuel, the gasification gases being withdrawn through other boreholes spaced from the inlet holes and leading to the surface and suitable gas collecting and utilization equipment.

The actual gasification of the fuel may be carried out with air, steam and oxygen. However, for successful gasification of the fuels in situ it is first necessary to produce a channel or fire drift between the inlet and outlet boreholes or ducts and/or a system of fractures or crevices in the fuel bed whereby gasification medium or the like will pass from the inlet boreholes to the outlet boreholes.

The method of underground electrocarbonization utilized for the above mentioned purposes actually consists of three different phases of operation:

1. Electrolinking,
2. Electrocarbonization, and
3. Electrogasification.

The electrolinking is a short duration electrical heating, utilizing the conductivity of a carbonaceous fuel bed. The resulting heating and carbonization creates a fracture system in the fuel bed which supports the succeeding gasification by air or any gasification fluid. The electrolinking is initiated by sending current through the ground. The actual electrolinking is only possible when the temperature is raised far above the boiling point of water.

The temperature should be raised to the point of decomposition of hydrocarbons whereby fixed carbon is released during the heating. The fixed carbon replaces the electrolytical conductivity and gradually forms a carbon link between boreholes from which actual carbonization can proceed and electrical heating be continued.

The underground electrocarbonization refers to a long duration electrical underground carbonization, which with coal or the like is comparable to the coke furnace operation. The electrocarbonization itself is an extended form of electrolinking and can be accomplished only after electrolinking has formed the carbon linkage from which carbonization may proceed. This entire concept is new as from previous scientific knowledge on ground heating it was thought 100° C. or the boiling point of water was the limit of heating of the ground by electric current. The carbonization yields high B. t. u. gas with an average value of 550 to 600 B. t. u. cu. ft. and by-products such as coal tar and ammonia. The residual hot coke forms an ideal fuel bed which can be gasified by air or mined under certain conditions in strip mining areas.

The electrogasification process consists of simultaneous operation of electrical heating and blast by air or steam. The enriched producer gas or water gas can be produced or oil flow stimulated from oil wells by this method. This is still the high temperature electrical heating which can only be accomplished after the basic idea of electrolinking technique has been successfully utilized. The idea of using gasification media and electric current in a fuel bed is very important and can not be compared with ordinary gasification technique. In underground there are tremendous heat losses in the surrounding area and by influx of moisture, which can be only compensated by additional outside or external heat source. In order to accomplish gasification, there are certain preliminary requirements to be fulfilled. First the conditioning of the fuel bed; second, the conditioning of the blast; and third, the amount of the blast. Therefore, the underground carbonization at high temperatures is very important as the only means at the present time to prepare the fuel bed from which gasification gas can be produced. In this respect, electrogasification makes successful underground gasification feasible. The utilization of underground electrocarbonization makes obsolete any underground mining or drifting for gasification purposes.

The underground electrocarbonization of coal and other carbonaceous fuels is classified as a shaftless underground gasification method. It means that no underground mining is necessary to accomplish the opening of gasification drift in the fuel bed. The access to the fuel deposit seam is made by vertical boreholes which may be placed several hundred feet apart. The electric current is transferred to the fuel bed by means of electrodes. The resulting coking of fuel along the carbonization channel between the boreholes forms a permeable zone for further gasification by air or other suitable medium.

The objects of the present invention are to provide an underground electrocarbonization and gasification of solid and liquid fuels without underground drifting or shaft sinking for the preparation of the fuel bed; to provide scientific fundamentals and apparatus for accomplishing underground electrolinkage and electrocarbonization by introducing a series of electrodes spaced in a fuel vein in situ and effecting a high voltage electric current of sufficient power through the fuel between the electrodes to electrically heat same to produce a coke or ramified fixed carbon channels between said electrodes; to introduce a high voltage electric current of short duration in a mineral fuel bed to open up same and produce a channel or fire drift between spaced boreholes in which electrodes are located; to provide an electrolinking in fuel, coal seam or the like and then effect an electric current

of relatively lower voltage between spaced electrodes to gradually, progressively and continually heat and coke the seam of fuel, the gases or liquids produced during the carbonization, distillation or coking process being removed through selected boreholes and/or tubular electrodes; to introduce gasification fluid into a fuel seam or the like adjacent one end of a fire drift or channel during electrical heating of the mineral fuel and remove gases from the fuel through a borehole adjacent an opposite end of the fire drift or channel; to provide spaced, tubular ducts leading from above surface to a fuel vein in native position, the lower ends of said ducts being electrodes connected in electrical circuit capable of effecting high voltage current through the vein and then reduced voltage for continued long heating of the fuel; and to provide apparatus including a compressor for introducing gasification medium into selected boreholes during application of electric current to the fuel in situ and apparatus connected to the other duct for withdrawing gases produced by the heating of the fuel and storing or otherwise utilizing said gas.

In accomplishing these and other objects of the present invention, I have provided improved details of structure and arrangement of apparatus the preferred form of which is illustrated in the accompanying drawings, wherein:

Fig. 1 is a diagrammatic view of an underground fuel vein and apparatus with connections thereto for underground electrocarbonization of the fuel.

Fig. 2 is a vertical sectional view through a borehole and electrode constructed in accordance with the present invention.

Referring more in detail to the drawings:

1 designates a strata of underground fuel. A plurality of boreholes are drilled from the top of the ground 2 into the mineral fuel strata. Two such holes are illustrated and designated 3 and 4 respectively. The boreholes preferably terminate adjacent the upper portion of the fuel strata and smaller holes 5 are drilled further into the fuel strata, preferably terminating adjacent the lower surface thereof. Tubular members 6 and 7, preferably of noncorrosive electrical conducting material such as steel, extend downwardly through the boreholes 3 and 4 in spaced relation to the walls thereof. Tubular electrodes 8 of stainless steel or carbon are mounted on the lower ends of the tubular members 6 and 7 and extend into the holes 5 in the fuel strata in electrical contact therewith.

Suitable insulators or the like 9 are arranged on the tubular members 6 and 7 to maintain same spaced from the walls of the boreholes 3 and 4 and also electrically insulate the tubular members from the ground strata surrounding the fuel bearing strata whereby all electrical contact of the electrodes 8 with any underground formation is with the fuel bearing strata. The electrodes 8 on the lower ends of the tubular members are perforated as at 10 for flow of fluids to and from the strata of fuel. The tubular members 6 and 7 are preferably connected adjacent their upper ends to a pipe 11 communicating therewith, and intermediate the tubular members said pipe is connected to an inlet duct 12 of a pump 13 or other liquid lifting apparatus for removing liquids from the boreholes. Valves 14 and 15 are arranged in the pipe 11 between the duct 12 and the respective tubular members for selectively shutting off connection of the tubular members to the pump. Suitable insulators 11' are preferably arranged in the pipe 11 between the valves 14 and 15 and the respective tubular members 6 and 7.

A pipe 16 preferably connects the upper ends of the tubular members 6 and 7 and intermediate the tubular members said pipe communicates with a duct 17 which leads to a heat exchanger 18, then through an electrofilter 19 to the intake of a gas exhaust blower 20, the discharge of the exhaust blower being connected to a gas holder 21 or other suitable apparatus for processing, utilizing and/or distributing the products recovered from the fuel strata. The heat exchanger 18 is for abstracting some heat from the gas for utilization as desired, for example for generating power, preheating air, or other use of available heat. Valves 22 and 23 are arranged in the pipe 16 between the tubular members 6 and 7 and the duct 17 whereby gas may be selectively withdrawn from the fuel strata through the tubular members and delivered to the gas holder for subsequent use as desired. Suitable insulators 16' are arranged in the pipe 16 between the valves 22 and 23 and the respective tubular members 6 and 7.

A compressor 24 having its inlet connected to a suitable source of supply of air, oxygen, steam or other gasification medium has its discharge connected to pipes 25 and 26 extending downwardly through the tubular members 6 and 7 respectively, said pipes 25 and 26 terminating adjacent the lower ends of the tubular members for discharge of the gasification medium into the strata. Valves 27 and 28 are arranged in the pipes 25 and 26 for selectively controlling the distribution of the gasification medium to the portions of the fuel strata. Suitable insulators 25' and 26' are arranged in the respective pipes 25 and 26 between the valves 27 and 28 and the respective tubular members 6 and 7. The arrangement of the various pipes and ducts is designed for flexibility of operation and directional control of the various fluids, although other suitable arrangements of the pipes and valves may be utilized.

A suitable electric circuit is arranged whereby one terminal 29 is connected to the tubular member 6 and another terminal 30 to the tubular member 7, said electric circuit having a suitable source 31 of electric energy. A voltage regulator 32 is arranged in the electric circuit for controlling the voltage applied to the terminals. The electric circuit is so connected whereby the tubular member 6 is one electrode and the tubular member 7 another electrode for flow of current from the electric circuit through the tubular member 6, the fuel strata 1, tubular member 7 and back to the electric circuit. It is preferable that the electric circuit include an indicating volt meter 33, a recording volt meter 34, an indicating ammeter 35, a recording ammeter 36, an indicating watt meter 37, a recording watt meter 38, an oil switch 39, and any other suitable electrical instruments to provide operating information whereby the electrical current can be controlled to provide desired treatment of the fuel strata and optimum recovery therefrom.

Orifice meters 40 and 41 are preferably arranged in the discharge of the compressor and exhaust blower respectively. Also pressure gauges 42 and 43 are arranged with the orifice meters. Other instruments may be suitably arranged in the apparatus for indicating the characteristics of the gas and provide other desirable information regarding the operation and products recovered, for example the character of the gas recovered is indicative of the temperatures in the fuel strata being processed.

While only two boreholes and electrodes have been illustrated and described, it is believed obvious that any desired number of boreholes, tubular members and connections may be provided for operating same in pairs or selected multiples. Also one or more input holes may be arranged with a plurality of output holes.

In operating the apparatus described, any excess water or liquids are pumped from the boreholes. Then the valves 14 and 15 are closed and the oil switch 39 closed to complete a circuit to apply high voltage current to the tubular member 6 and/or electrode 8 thereon. This high voltage current passes through the strata 1, taking the path of least resistance to the tubular member 7 to complete the electric circuit.

The conductivity of porous material in earth strata is always larger than the conductivity of the components of the rock which generally are non-conductors. The increased conductivity is dependent on the presence of electrolytes. When the electrolyte is evaporated, a nonconducting rock forms a substantially complete resistance

around the electrodes. When the temperature is raised to the boiling point of water, there will be a drop of conductivity which may be 40% to 60% before the water is evaporated and all that ground conductivity is interrupted. However with electrolinking the electric current is of sufficient voltage and amperage to overcome the resistance in the fuel bed and forms a fixed carbon channel between the electrodes. It has been found that the resistivity change of mineral fuels does not obey Ohm's law but instead follows the equation:

$$\frac{dU}{di}=R(i)+\frac{idR}{di}$$

wherein:

dU=voltage differential
di=current differential
$R(i)$=Ohm's resistance
dR=resistance differential
i=current

This indicates that an increase of temperature with proper condition of fuel decreases the resistance and in turn progressively increases the current and subsequently the temperature of coal. The conductivity of hydrocarbons appears to be similar to the conductivity of ionized gases, but in fact is a function of graphitization of carbon in coal or the like due to heat. The electrical heating of fuel will start along the line of least electrical resistance within the seam and gradually will progress until the required amount of fuel is carbonized or distilled. The carbonized mass between the electrodes is an ellipsoid whose size and shape depends on the spacing of electrodes, the thickness of the seam, and the electrical anisotrophism of the mineral fuel. The electrical conductivity of fixed carbon in the fuel increases with increasing temperature.

The electric current passing through the fuel strata must be of sufficient voltage and amperage to overcome whatever resistance there may be and raise the temperature to the point of decomposition of the hydrocarbons which is above 300° C. to form a coke or ramified fixed carbon channel or zone to complete an electrolinking between the electrodes or tubular members **6** and **7**. It is preferable that the voltage and current be such that the initial heating is relatively fast to provide the electrolinking.

The execution of the method will require application of predetermined amounts of electrical power in order that whenever electrical power is applied, heating will start decomposition of hydrocarbons in the bed of fuel. The resultant effect of this heating can be followed by means of a resistance curve. In order to carry electrolinkage to completion it is required to maintain the predetermined power so that the resistance of the electrodes continuously decreases. This is accomplished by voltage regulation, as will be noted from the following test data, so that the voltage multiplied by amperage is approximately constant until the formation of a carbonization zone linked between the electrodes is completed. After such electrolinkage, the power load for carbonization will be adjusted in accordance with the desired gas composition.

In actual field test (coal) using four electrodes in a line with a spacing of thirty feet between electrodes, the electrical characteristics of operation between a pair of electrodes were as shown in the following table:

This table is exemplary only as the spacing of the electrodes may be at any desired distance and the voltage and amperage of the current varied accordingly to obtain optimum results.

After the electrolinking is established, electric current is continued to progressively heat the strata surrounding the path of the first carbon channel or zone established. This continued heating is electrocarbonization of the mineral fuel progressively carbonizing the fuel or forming a coke or the like in the fuel strata which, as the current is continued, and the heating resulting therefrom, expands the carbonized or coked area in the form of an expanding ellipsoid. This continued heating and carbonization makes a system of fractures in the fuel strata similar to coke in a retort. During the electrocarbonization the gases evolved are drawn from the strata through the tubular members **6** and **7**, pipe **16**, duct **17** by the exhaust blower **20** and delivered to the gas holder **21** for further processing or use as desired.

After a suitable period of electrocarbonization gasification medium such as air, oxygen or steam is delivered through the pipe **25** and discharged at the lower end of the tubular member **6**, said gasification medium passing through the apertures in the lower portion of the tubular member **6** and through the fractures in the fuel strata to the lower end of the tubular member **7**. During the introduction of the gasification medium, electric current may be continued to be applied to the electrodes or may be cut off as desired. The gasification medium passing through the heated fuel strata promotes combustion to effect gasification of the fuel, and the products of such combustion are drawn from the strata through the tubular member **7**, pipe **16**, inlet duct **17** of the exhaust blower and delivered to the gas holder. During the introduction of the gasifying medium, the valve **22** is shut off and the valve **23** is open to control the direction of the flow.

By electrolinking a carbon chain is effected which increases the conductivity through the fuel strata preparatory to the electrocarbonization. The long duration electrical heating (electrocarbonization) is the carbonization or coking process of fuel in situ, during which the carbonization gas and related by-products are recovered. The residual coke may then be recovered by conventional processes such as gasification with an air or other suitable blast. The recovery of the constituents of the coal or other fuel strata is also accomplished by simultaneous gasification with air or the like and the heating of an electric current. This process is defined as electrogasification. The simultaneous gasification with air and the heating by an electric current produces a gas suitable for domestic and industrial use in an economical manner without requiring mining operations.

The treatment of oil shales, oil sands and the like permits some variation in the recovery of the fuel. The voltage and amperage of the current applied and passed through the fuel strata will provide a resistance heating of the fuel for what may be termed a thermal recovery of the crude oil. Moderate heating will effect a reduction in the viscosity of the oil, reduction of surface tension and reduction of specific gravity. Such heating can also effect removal of hydrocarbons restricting oil flow whereby there is increased flow of liquid oil which can be recovered through conventional pumping methods. In such heating it is preferable to raise the temperature of the oil sands to above the boiling point of water to in-

Time, Min.	0	30	60	90	120	150	180	195	278	400
No. 1. Voltage, V.	2,120	1,860	1,600	1,640	1,520	1,400	1,280	200	200	200
No. 2. Amperage, A.	96.0	266	306	408	456	456	480	324	600	2,000
No. 3. K. V. A., VA.	210	495	490	669	693	638	614	638	120	400
No. 4, KW., KW.	192	480	480	650	672	625	600	625	118	----
No. 5. Power factor, Cos ϕ	0.91	0.97	0.97	0.97	0.99	0.99	0.97	0.99	0.98	----
No. 6, Current density, A/cm.^{2}	0.06	0.17	0.20	0.26	0.30	0.30	0.31	0.21	0.39	1.30
No. 7. Impedence, Z.	22.1	7.00	5.0	4.0	3.3	3.1	2.7	0.6	0.3	0.1

crease the pressure in the formation for aiding in effecting the flow of oil therethrough.

Additional current may be utilized to provide sufficient heat in the oil shale, sand and the like to provide a temperature effecting partial distillation of the oil to further increase the pressure in the formation and also to provide a recovery of synthesis gas, the result of such heating being in the increased flow of liquid oil as well as the recovery of gas. Applying sufficient current and voltage to heat the oil formation to the ignition stage will develop reaction channels and effect loosening of the formation. The carbonization can be continued then by a combustion of fixed carbon. In such a practice the electrical carbonization should be continued as long as it is economically feasible before air is introduced and fixed carbon burned for the electrogasification of oil deposits.

In utilizing the present method and the current carrying capacity of ground electrodes for heating of the oil sand over the temperature of 212° F. a long duration loading of electrodes at high current density is preferred. The advantage is the high power density obtainable per unit of formation space and the penetration of energy through the formation. This is possible when the carbon chain formed by electrolinking is replacing the electrolytic conductivity of oil sand. Controlling of the current and application of electrical heating gives stimulation of oil flow from stripper fields or depleted fields by melting and removing the congested constituents that restrict the flow of oil into the well. It will also stimulate oil flow from depleted fields and stripper fields by means of additional fractioning of oil sand formation by means of electric current. It stimulates oil flow in highly viscous oil sand deposits with the combined gasification of residual oil. It increases the pressure in the oil reservoir by electrical heating, providing a hot oil gas drive in the oil reservoir. Use of the higher temperatures and particularly the overheating of electrodes will simplify the ignition of oil in the well and the gasification of depleted oil fields provides recovery after all other methods have failed to produce any oil.

It is believed obvious that I have provided a method of recovery of fuel that is applicable to several types of natural fuel occurrences by electrically heating the fuel in its natural state underground.

What I claim and desire to secure by Letters Patent is:

1. The method of recovering the valuable constituent parts of hydrocarbon mineral fuels by means of underground electro-carbonization and conversion of such fuels in their native positions and which in their initial state

provide a definite value of electrical resistances, which consist of drilling a plurality of appreciably spaced bore holes in the ground with lower terminal ends directly in a substrata hydrocarbon fuel bed, positioning electrodes in the lower terminal ends of the bore holes directly in such bed of hydrocarbon fuel with said electrodes connected in an electric circuit which is insulated from the earth strata, applying to the electrodes through said circuit a current density at or above 0.06 ampere per square centimeter of electrode surface such as to cause the electric current to pass along and through the bed of fuel lying between said electrodes, continuing such heating using a current density at or above 0.06 ampere per square centimeter by regulating the voltage input in said circuit while the resistance of the fuel bed continuously decreases so that the total power input is maintained within predetermined limits until a continuous and fixed carbon zone is formed between and in contact with said electrodes to produce a high electrical conductivity linkage between the electrodes such as will thereafter enable substantially a full electric current value to pass directly through the fuel bed between said electrodes, continuing the electroheating of said fuel bed to the point of substantially total decomposition of the stratum of hydrocarbon fuel in which the electrodes are positioned, and withdrawing through said bore holes the valuable constituent parts resulting from such decomposition of the fuel bed.

2. The process of claim 1 in which a gasification medium such as air or steam is introduced through the bore holes into the fuel bed after the carbonized zone has been formed and while the electro-heating of the fuel bed is being carried out for the purpose of promoting combuston and improving the production and quality of the removed valuable hydrocarbon constituents.

References Cited in the file of this patent

UNITED STATES PATENTS

849,524	Baker	Apr. 9, 1907
1,372,743	Gardner	Mar. 29, 1921
1,457,479	Wolcott	June 5, 1923
1,913,395	Karrick	June 13, 1933
2,497,868	Dalin	Feb. 21, 1950
2,593,477	Newman et al.	Apr. 22, 1952
2,685,930	Albaugh	Aug. 10, 1954

OTHER REFERENCES

Mining Congress Journal, October 1949, pages 57.