

United States Patent [19]**Green**[11] **3,780,805**[45] **Dec. 25, 1973**[54] **VISCOUS OIL RECOVERY SYSTEM**[76] Inventor: **William G. Green**, 10614
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77002[22] Filed: **Sept. 7, 1971**[21] Appl. No.: **178,287**[52] U.S. Cl. **166/266, 166/271, 166/273**[51] Int. Cl. **E21b 43/22, E21b 43/27**[58] Field of Search **166/268, 266, 267,**
166/265, 271, 273, 274, 245[56] **References Cited****UNITED STATES PATENTS**

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[57] **ABSTRACT**

A system to provide means for recovering crude oils known to exist in production formations which cannot be produced economically by systems now in operation and known to the industry. This type of oil will not flow into the wells drilled to produce it because it is too viscous, and has no mobility.

8 Claims, 5 Drawing Figures

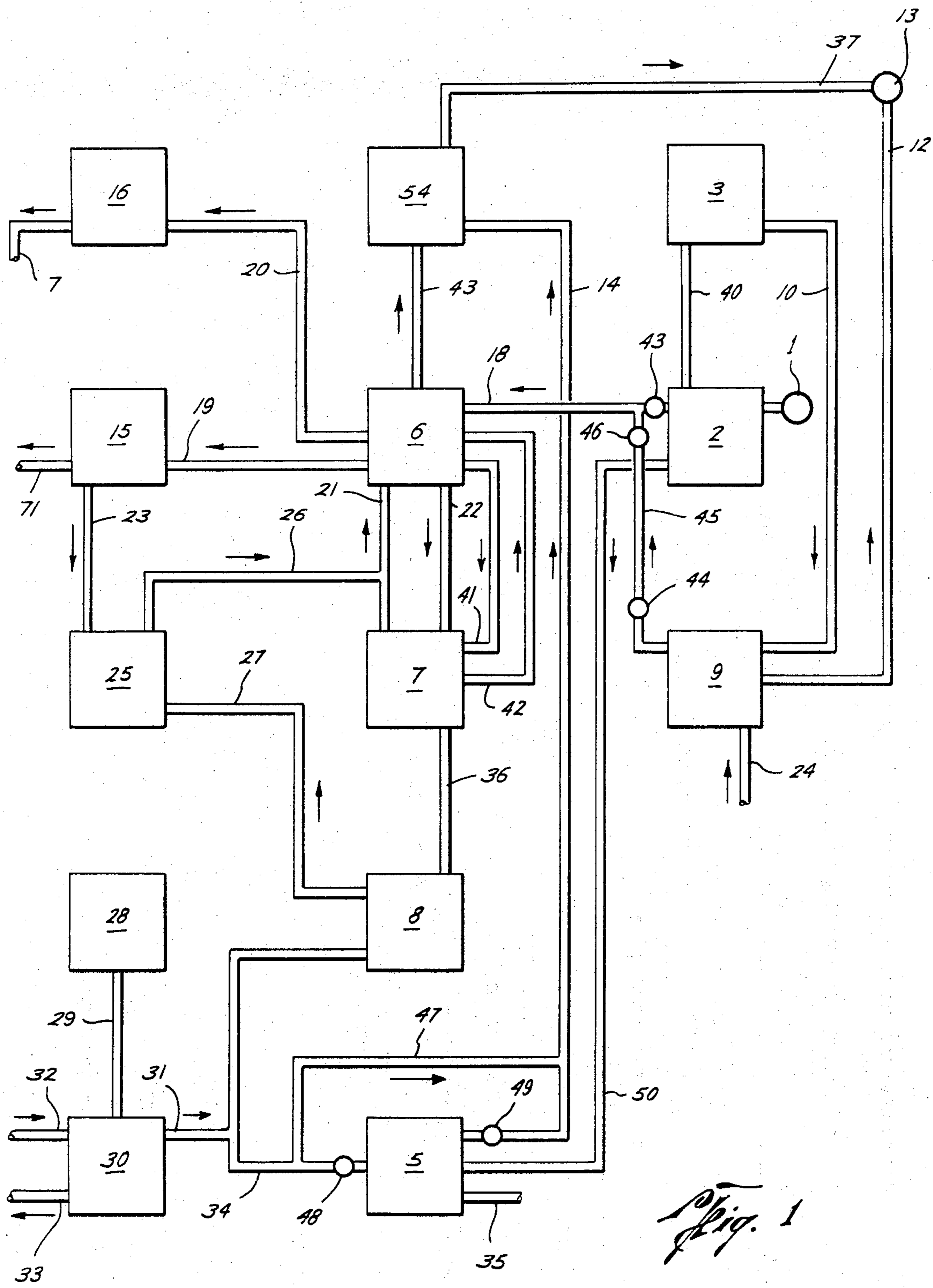


Fig. 1

Fig. 2

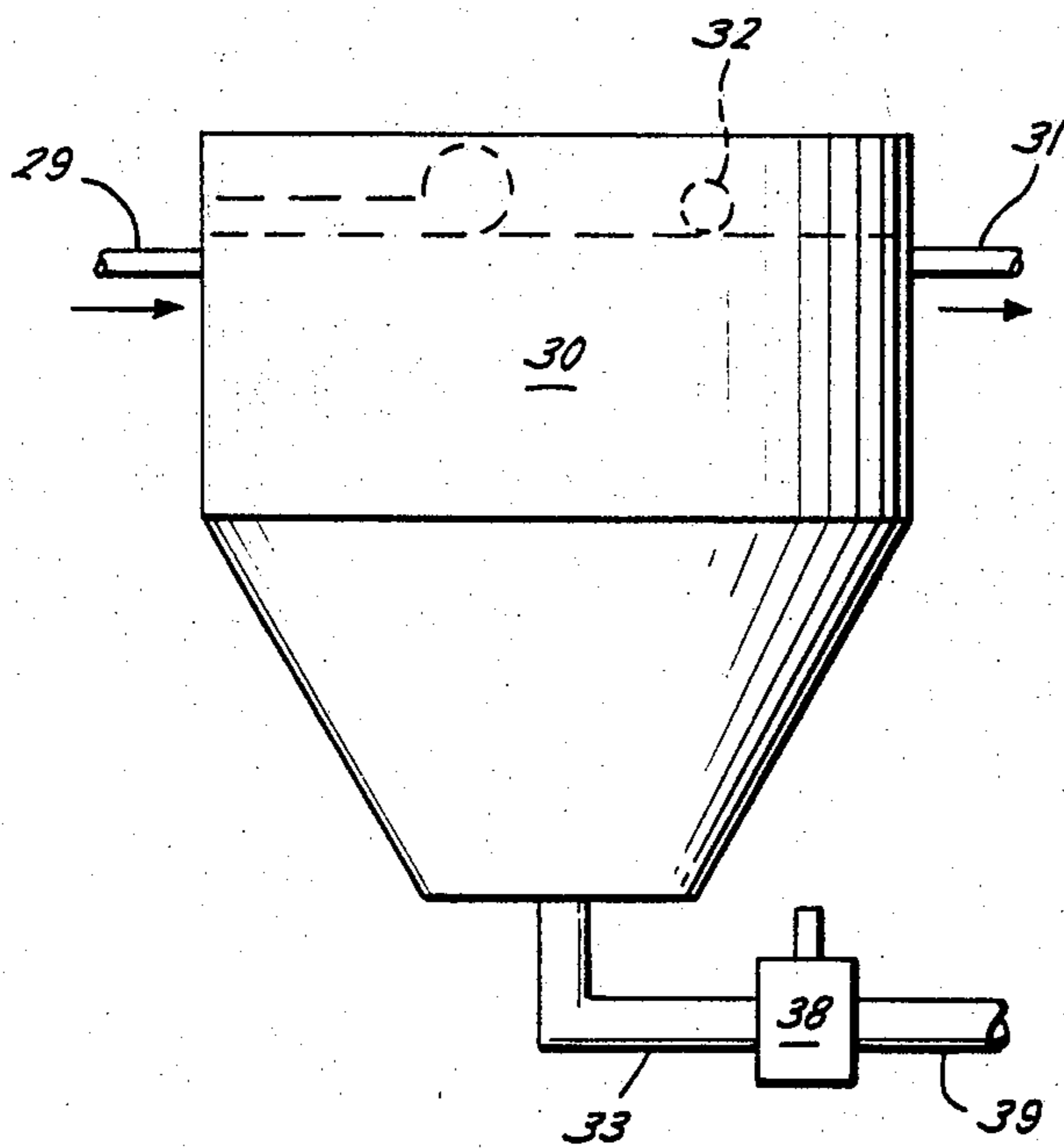
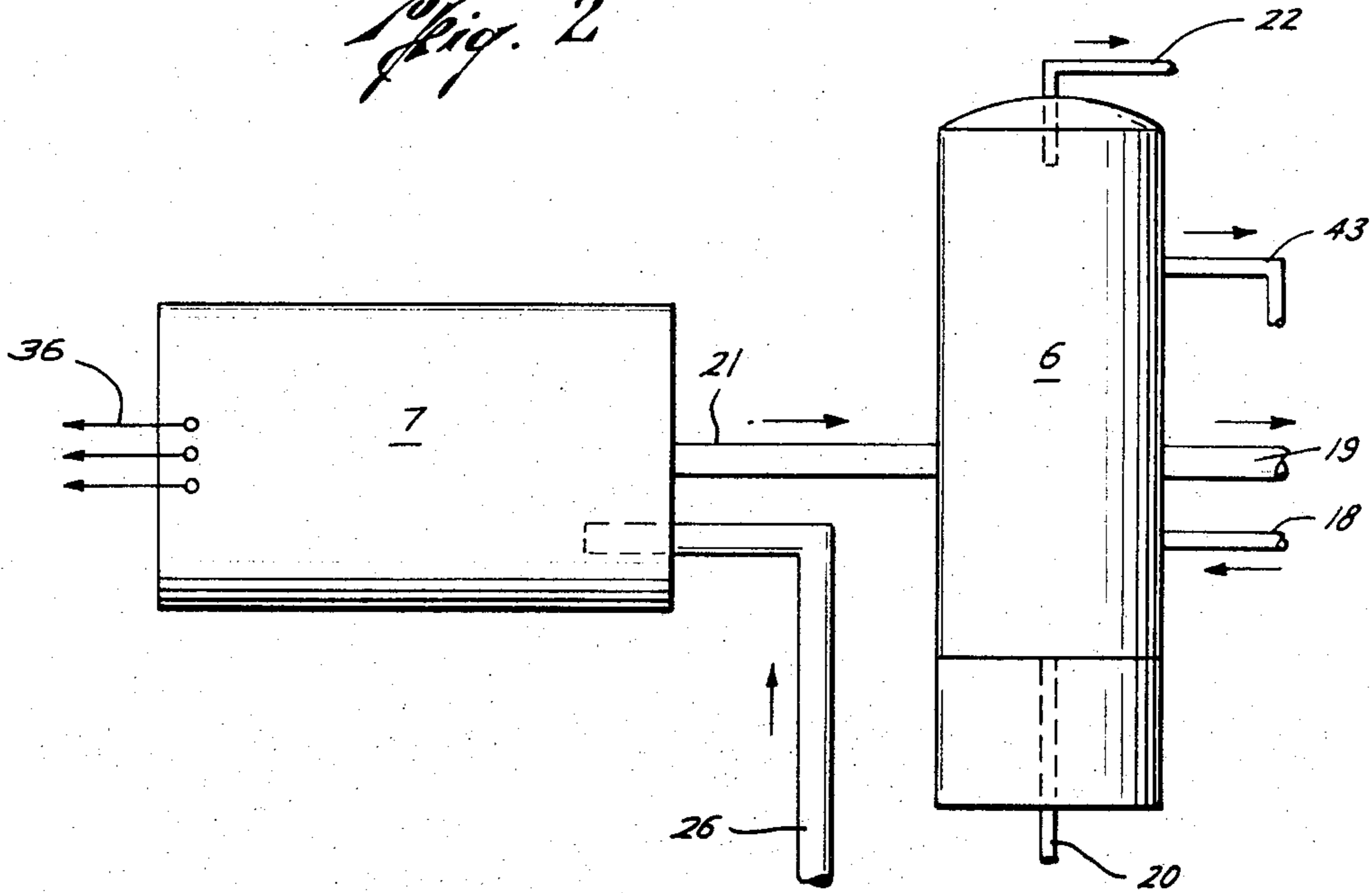


Fig. 2A

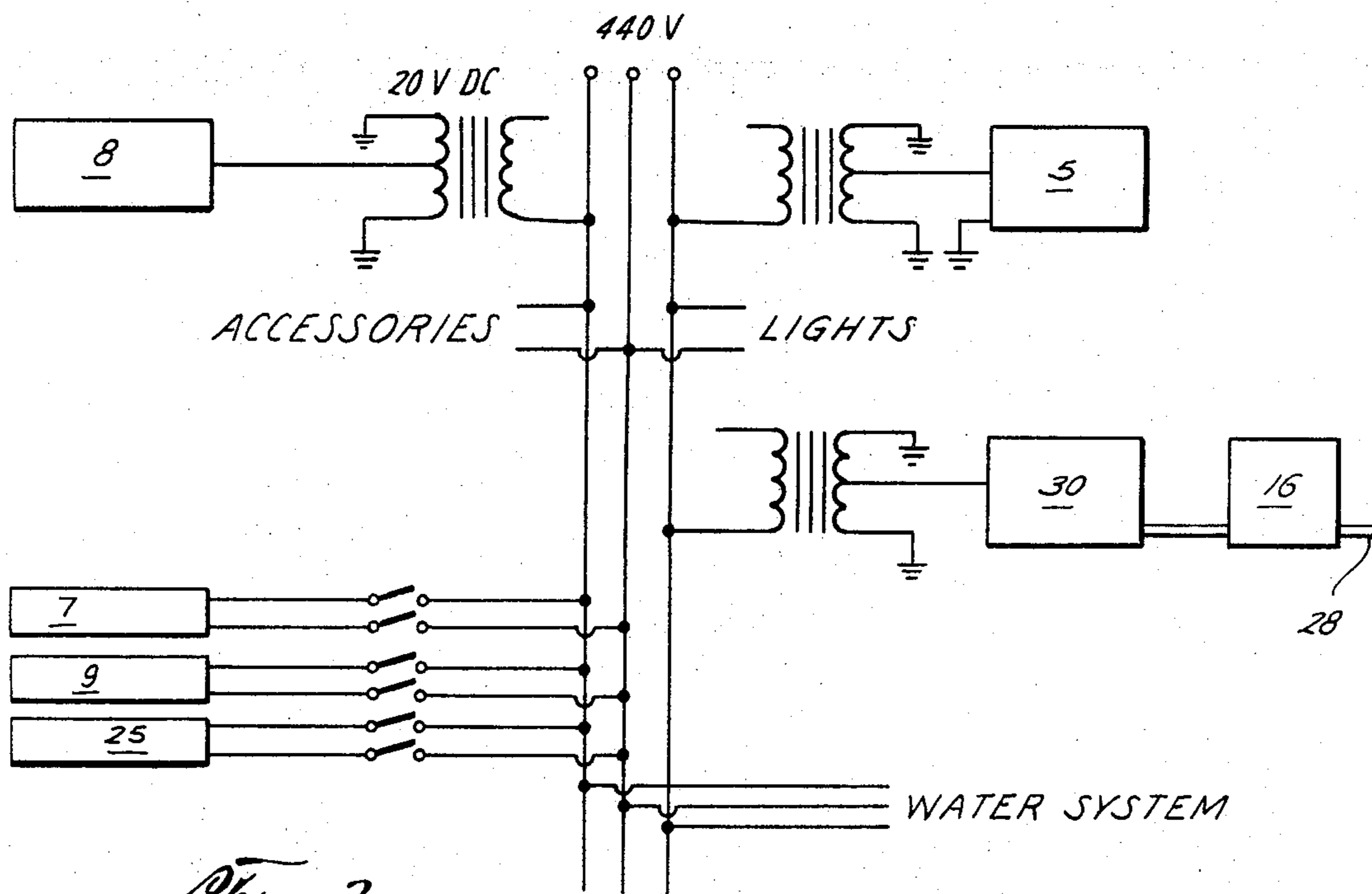


Fig. 3

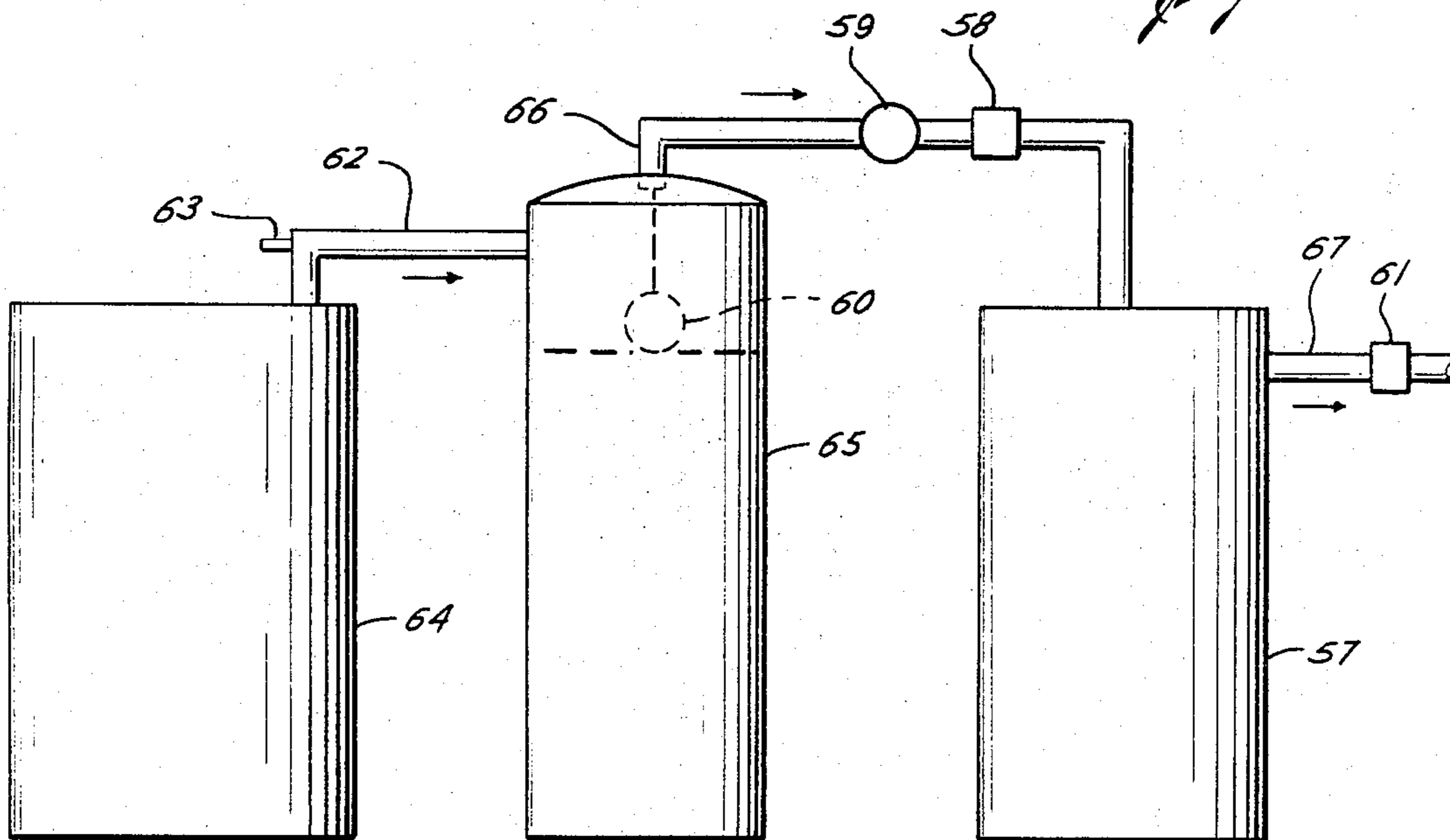


Fig. 4

VISCOUS OIL RECOVERY SYSTEM

Two known means exist to increase the mobility and reduce the viscosity of this oil. They are heat and solvents. The heat requirement is so great as to be of questionable economy. Solvent, although the most effective means known, is similarly too expensive in the quantities required.

This invention entails a group of practical component systems, by which the heavy oil in the formation is thinned by solvents, extracted from the extracted crude oil, and recovered by an on the spot refinery known as the Fuel and Solvent Generator, and the rate and efficiency of production is increased by the use of a continuous acidizing system, which, on the spot, converts saline water into Cl, and HCL; and the effectiveness of acidizing is increased by removing the calcium and magnesium carbonates (limestone) from the acid salt-water, thus increasing the solubility of those constituents in the acid water and lowering the cost of the fuel required for electric generation, air compression and other auxiliary services and the cost of lifting, or pumping, for bringing the crude oil to the surface and, where necessary, to institute the first mobility by electric heating of the formation by a few degrees Fahrenheit, wherein the electricity is generated from fuel refined from the produced crude oil, utilizing the reject heat from the engine driving the generator and replacing the crude oil depleted by the refining process by injecting CO and H under the proper conditions of catalyst, temperature and pressure, to form a hydrocarbon of the ethanal type, and producing hydrogen from electrolysis of water, using the same economical electricity, and separating from the exhaust gases of the engine a supply of CO, to provide a free source of this fuel, and means to inject the remaining CO₂ of the exhaust into the water-acid solution being injected for the purpose of diluting the oil and increasing its mobility to accomplish the lowest lifting or producing cost yet achieved.

BACKGROUND OF THE INVENTION

The U. S. Bureau of Mines has placed the total number of barrels of crude petroleum discovered since the first well was drilled by Drake, in 1859, at approximately 375 billion barrels. Of this total, some 250 billion barrels are classified as "unrecoverable reserves." These reserves of "unrecoverable" oil are about three times the total oil produced to date. The oil is classified as "unrecoverable" because it is so thick, or viscous, that it will not flow into the wells drilled, and will not be driven through the formations by cold water, or air. Steam has been widely used, but is quite expensive. Many cases are recorded where the cost of steam exceeded the value of the recovered petroleum. There are also a number of cases where solvents have been used, with great success, but not economically. In one case, the cost of the solvent and operation amounted to \$6.00 per produced barrel, and the posted price for the oil was \$3.00 per barrel.

For normal producible oil, the efficiency of the recovery is 25-30 percent of the in situ petroleum. One system has succeeded in producing all of the oil in a core sample of the formation, that is to say, one hundred percent of the hydrocarbons was recovered by washing out the porous formation with a solvent. The solvent used was a slug of methyl alcohol 4 percent and 4 percent of isopropyl alcohol. Although the most ef-

fective system found, the high cost of the solvent precludes its commercial application.

A considerable amount of work has been done in electrical heating of the formations, but this has been quite costly, since the electricity must be produced with purchased fuel, in these viscous petroleum areas, or be purchased outright from power companies.

Well services, usually purchased from well service companies, have developed to the point that the services frequently aggregate more than the cost of the bore-hole and equipment installed therein.

The major oil companies find their profits continually reduced, and run up against the inability to get a higher price for the crude oil, particularly in view of the lower cost petroleum available from Venezuela, Iran, Bahrein and other places having a surplus of crude petroleum. But they have improved their refining technics by utilizing all possible byproducts, and by actually increasing the volume of petroleum by means of hydrogenation, thus increasing their cash flow from total sales. The non-refiner, or independent oil producer, however, who has no sales outlets, must sell to the refiners — at posted prices. Sometimes it is a moot question as to whether such producer makes profits or loses money.

The objective of industry has been for many years to analyze the requirements for producing oil, and to try to devise economical means for reducing the cost, and improve the recovery and increase the rate.

Many people do not appreciate the fact that if a given operation produces 100 parts in a day, for a total cost of \$100.00, that if 200 parts were to be produced in the same day, for the same cost of facilities and manpower, the cost per unit would have dropped from \$1.00 each to 50¢ each. Utilizing this principle, if the oil can be produced twice as fast, with the same equipment, etc., then it will be produced at approximately one half the original amount. In one oil field near San Antonio, Texas, in the 30 years since it was first brought in, a total of 175,000 bbls of oil were produced from a total calculated 16,000,000 bbls in situ. At this rate, no one has made any money, and the properties have changed hands a number of times. If they could have been produced at twice the rate, everyone would have made a little profit.

Viscosity is defined as the internal friction of a fluid in motion. It is measured by timing the fall of a steel ball down a tube of given length, or of observing the time for a given amount of fluid to flow through an orifice, or a funnel. A poise is the unit— $\frac{\text{dyne sec.}}{\text{cm.}^2}$. Centipoise is the term usually used for oil. Examples:

Castor oil at 20°C.	9.86 poises
Glycerin at 20°C.	8.5 poises
Water at 20°C.	0.01006 poises
Ethyl alcohol	0.012 poises

Many of the viscous petroleum have 600 centipoises, but at 80°F. some have a certain "gel" strength, which increases the apparent viscosity. Tar has this gel strength or rigidity. One API 15° crude oil had the following viscosities, vs temperature:

55°F viscosity	700 Centi- poises
60° F viscosity	550 Centi- poises

80° F viscosity

275
Centi-
poises

100° F viscosity

150
Centi-
poises

120° F viscosity

120
Centi-
poises

Thus it may be seen that warming the oil 5° F will make a substantial change in the viscosity, and consequently in the mobility. From the definition of the poise, increasing the force, or pressure, will increase the flow rate, too. Thus, if pressure is cheaper to arrive at than temperature, this would be the way to go.

Looking at the examples above, if a quantity of alcohol could be mixed with either castor oil or glycerin, a small amount of the alcohol would produce a substantial reduction of viscosity of the heavier substance. Thus, if the solvent can be obtained economically, it may readily replace heat, and, if the solvent may be recovered and used again, or be recycled, the economics are further advanced.

SUMMARY OF THE INVENTION

The method of producing viscous oil employing a system of operation including: extracting engine operating fuel from the production fluid by means of a fuel and solvent generator, similar to that described in U.S. Pat. No. 3,447,511 to Franklin Beard and W.G. Green, and the improvements thereon, to be the subject matter of other applications for patent. This device is a small refinery, in which crude oil is passed through the heat exchanger and is heated by all the rejected heat from the engine exhaust and cooling systems, to a temperature that will provide 10-15 percent of the oil as a fuel gas to operate the engine, and as a condensate with solvent properties. The design of the generator is such that the condensate is cooled to a stable, condensed, state.

Another step in the system is hydrogenation. Hydrogen is produced from water by electrolysis, and is pumped through the heat exchanger of the fuel and solvent generator, along with CO which is separated from the engine exhaust gases (about 6 percent of such gas may be expected to be CO). The combination of CO and H may be expected to result in a hydrocarbon of the general type: CH_3CHO (Ethanal) or CH_3COOH , if extra O is supplied. This forms readily at 200A and 200-300 F°.

Another step is the gas lift system. The pressures put upon the oil in the formation by the injection of solvent and CO_2 and air, cause the producing wells to flow their production naturally, when the proper arrangements are made, well pressure is maintained, and no gases are allowed to escape through open holes. Therefore, the lifting costs are borne by the operation of the rest of the systems. However, for the intended production of an oil field now being studied, the cost of preparation of the wells for free flowing would be about \$2,500.00 per well, and the anticipated production would make an amortization of \$0.0871/bbl.

Another step is the gas recycling system. All of the air and CO_2 put into the oil formation will be recovered. Since it now carries a modicum of dissolved hydrocarbon gases, it becomes a better solvent each time it is recycled, until it is the equal of, or richer than, natural gas. Thus in the interest of pollution control, as well as economics, this gas will be separated from the oil and water produced, and recycled back to the air compres-

sor, for re-injection. As the oil is depleted from the formation, additional air will have to be injected to maintain the pressure. This is shown in the schematic of the plant.

Another step is the continuous acidizing system. The acidizing of lime wells, limed boilers, and limed air conditioning systems, has generally been done by non experts. They have not realized that acid can not dissolve limestone (CaCO_3) to any extent, except when liberally diluted in water. The solubility of CaCO_3 in water is about 7,000 ppm. When the acid solution has dissolved this amount of calcium carbonate, it stops dissolving. When the acid stops working, analysis of the CaCO_3 content comes up to about 7,000 ppm. The addition of more acid does very little, since the dilution of the commercial acid is comparatively small, but the addition of fresh water immediately restarts the dissolving process. I have shown that a small amount of acid, with copious dilution, will dissolve more limestone than a larger amount of acid, with insufficient dilution.

In limestone oil formations the oil is generally trapped in crevases or fractures in the rock. But, under certain conditions, the oil is trapped in vugs, or cavities, in the rock. Sometimes a significant percentage of the oil is trapped in vugs or cavities, which are not connected, or conductive into the larger cavities. When the production of a limestone oil field falls to an uneconomical level, a common practice is to acidize the formation, by injecting several thousand gallons of dilute acid (usually HCl) into the formation, to dissolve some of the limestone and release the trapped oil. This greatly increases the flow of oil, but inevitably a decline sets in, and eventually the field is again uneconomical. Many oil fields, for instance, at Luling, Texas, there is a tremendous oil field, in limestone, and the wells of this field have been acidized dozens of times. There are many commercial operating companies which do nothing except provide this acidizing service. It is expensive and rewarding — to the service people. The acid is provided in this system by applicant's acid generating apparatus, which produces chlorine by electrolysis of salt-water as described in U.S. Pat. Nos. 3,241,512 and 3,379,633 issued to this applicant. There are many systems for converting the chlorine to acid, inasmuch as one of the products of electrolysis is hydrogen which is easily collected.

One form of this chlorine generator has been evaluated by the National Sanitation Foundation, Ann Arbor, Michigan, and shown to produce 2 pounds of Cl_2 per day, from a comparatively small generator cell. I have shown that the output of Cl_2 is linear with the number of square inches of electrode surface, if the critical value of current is maintained. Thus, no special problem exists to make the chlorine generator any desirable dimensions, thus producing the amount of chlorine and/or acid desired.

Since salt water is produced with oil, the brine for the chlorine generator is free; and since electricity is produced at an extremely low price, the acid so produced is less costly than any purchased.

Another step is the water treatment. All water treating authorities agree that the reactive power of water increases with its purity. Absolutely pure H_2O will dissolve a little of almost everything — even glass, and thus it is nearly impossible to make and store completely pure H_2O . Since the brine from the oil wells is saturated with CaCO_3 , it is necessary to precipitate the

limestone by treating the water. Since the other constituents are relatively unimportant, the carbonates and silicates are precipitated by treating the salt water to above the pH of saturation (pHs). For the purposes this pH may be adjusted to a value of 11, upon which the hardness will drop to about 3 ppm. Decanting the softened water off the precipitate, or removing the precipitate which has settled, permits its use, then, as a diluent for the acid. Additional quantities may be used for the electrolysis of chlorine and the making of hydrochloric acid. The complete water treatment, using this principle, is the subject of another application for patent, as is the production of HCl from brine.

The recovered or produced brine will ultimately become saturated with carbonates, due to the action of the acid on the formations, and it will have to be recycled, or resoftened before it may be reused. Under the present laws, all salt water produced must be reinjected into the producing formation, or into a salt water aquifer. Either of these operations is quite expensive, and the use of the produced brine for the above purposes is most economical, since the reinjection would have to be done, in any event.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view of the system.

FIG. 2 is a diagrammatic view of the super heater employed.

FIG. 2A is a diagrammatic view of the water purifier.

FIG. 3 is a diagrammatic view of the electrical circuits employed, and

FIG. 4 is a diagrammatic view of another form of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The system herein defined is designed to be established in an oil production field, having injection wells and having production wells in a suitable pattern, preferably the injection wells being axial, with the production wells extending around the injection area.

Crude petroleum from wells flows through line 1 to the separator 2 where the gas is separated and flows through line 40 to recycle system 3, where gas is scrubbed and passes through line 10 to the compressor 9, and is reinjected into wells 13 through the line 12. Oil flows from the separator 2 through line 18 into the fuel and solvent generator 6, where reject heat from the engine-generator 7 flows through line 21 into the fuel generator 6 to heat the oil. Waste heat from the coolant system of the engine 7 flows through line 41 into the fuel generator 6 and is returned to the engine through the line 42. The heated oil in the fuel generator 6 vaporizes and some of the gas flows through the line 22 to the carburetor of the engine 7, to supply fuel thereto. To provide pressure for the gas to the engine, particularly for supercharged engines, which require a minimum of 15 psi, a bleed-off from the engine compressor 9 flows through line 45 to pressure regulator 44, thence through a check valve 46 into line 18, and into the fuel generator 6.

Back pressure on the separator 2 is prevented by the check valve 43 in line 18. The exhaust of engine 7 has been shown to pass through line 21 into the fuel generator 6, and thence through line 19 into the CO-CO₂ separator 15. CO has the atomic weight of 28, as op-

posed to the atomic weight of 44 for CO₂. They are thus separated by gravity in a very large, baffled, tank. Six percent, plus or minus, of the exhaust is CO. This will settle to the top of the CO separator 15. The excess exhaust then discharges through line 11 to the air line 24 into the engine compressor where it is compressed and injected into the wells 13 through line 12.

The residual oil, which is sometimes asphalt, flows from the fuel generator 6 through line 20, into stock tanks or to the asphalt refinery (not shown). The fuel generator 6 is operated at the temperature necessary for production of all the 550° F end products, which will be all the solvent materials from the treated oil. This solvent flows from the fuel generator 6 through line 43' to the pump 54 where it is pressurized for injection into wells 13 through line 37.

The fuel consumed by the engines 7 and 9 is replaced, in whole or in part, by the process of hydrogenation. In this case, hydrogen is obtained by electrolysis of fresh water from water well 28, and line 29, into the water purifier 30. This water contains calcium and magnesium carbonates, which will form scale on the electrodes of the electrolysis cell unless removed. Therefore, it is passed to the purifier 30, through float valve 30' where its pH is increased to 11, which causes precipitation of the carbonates, which settle to the bottom of the tank 30 and are removed through line 33, FIG. 2, by operation of the solenoid valve 38, and is wasted through line 39. This material, however, is not a pollutant. The NaOH used to increase the pH is obtained from the chlorine generator through line 35, into line 32, to tank 30. Some of the same softened water is passed through line 31, into the hydrogen generator. Some also is proportioned into the Cl₂ generator 5 through line 34. Hydrogen from the hydrogen generator 8 passes through the line 27 into the motor-pump 25 where it is mixed with CO from separation tank 15, and expelled through line 26, into line 21, for raising its temperature to 500-600° F. The outlet into the fuel generator 6, shown on FIG. 2, has an orifice on the end inside the fuel generator 6 to increase the pressure thereon, while subjected to the heat in line 21, which conditions are necessary to convert the H and CO into a hydrocarbon of the CH₃COH family. The amount of hydrogen and CO will be proportioned to approximately replace the fuel removed for the engine.

The chlorine generator 6 disassociates the Cl₂ and Na ions in a water solution, by electrolysis. If a membrane is placed between the two electrodes (not shown), the output of chlorine is very much greater than without separation, since recombination starts at a fairly low concentration. With a membrane separator, the products Cl₂ and H₂ may be drawn off the positive electrode side of the cell, and NaOH and O₂ from the negative electrode side. Passage of the H₂ and Cl₂ through a seeded bubble or glass bead tower will cause a partial combination and formation of HCl. The gases may be drawn through the bubble tower by a vacuum as from flow of water through a venturi. The HCl may be drawn off the lower part of the tower.

Water flows from line 31-34 into the chlorine generator, and salt is added. If saltwater is available, the saltwater must be purified as in previous softening of hard well water hereinbefore defined to prevent scaling of the electrodes, or water may be added from the separator 2, through line 50 into the positive side of the generator cell. By osmosis the negative side is kept full. Elec-

tricity (direct current) of about 5 volts, and 0.5 amperes per in² of plate or electrode surface, is passed through the brine solution in the cell. Hydrochloric acid is passed through line 14 to the injection pump, after being diluted with water, or saltwater, as through lines 31, 34-47 to line 14 to pump 54, and thence to the wells through the lines 37-12.

Recycled gases from 3, through line 10 to the compressor 9, augmented by the residual CO₂ from the exhaust line 24 from the CO separator 15, and into line 11 to the compressor 9, are injected into the wells 13 through the line 12. If there is an insufficiency of these gases, enough air to satisfy the compressor is inducted through a suitable air inlet. Thus pressure is maintained, either with recycled gas, or with solvent and hydrocarbon synthetically produced, or with air, or with a combination thereof.

Thus, diluted hydrochloric acid, solvent, and rich, recycled gases, are simultaneously injected into the injection well of a pattern of wells, and this pressure, so created, drives the petroleum toward production wells. During the drive, some of the heavy oil is diluted and made to speed through the formation to be produced; some of the limestone is dissolved by the acid and water, and the oil trapped in the sealed vugs is released for production and the gases enriched by a trip through the oil formation, are recycled back into the formation to provide a drive pressure and to mix with and dilute further, the heavy oil with which it comingles, to further thin it out, reduce its viscosity, and speed it toward the production wells. The produced oil is stripped of the solvent injected into the wells, and in addition, whatever additional solvent is in the heavy oil, is also stripped off by the fuel generator, and the hydrogen generator and the CO-CO₂ separator remove some of the CO and add it to H₂ to form, under the required circumstances, a modicum of newly formed hydrocarbon, which is added to the solvent stripped from the produced fluid, and reinjected into the wells. This all adds up to more and faster production, and an ever increasing amount of solvent, until finally the whole formation will be swept clean with the solvent, and then the solvent will be produced by air pressure and, if necessary, by water flood.

A modified form of the invention is shown in FIG. 4 wherein a vacuum pump 59 is mounted in the gas line 66 leading from the top of the fuel generator 65, between said fuel generator and the surge tank 57. The surge tank 57 is mounted between the vacuum pump 59 and the carburetor line 67. Two check valves are provided, one, 58, at the outlet of the vacuum pump 57, on the carburetor side, and one, 61, in the carburetor line 67.

A float valve 60 is inserted before the gas take off line 66, at the top of the fuel generator, to prevent liquid from flowing into the surge chamber 57 and carburetor. Since the fluid level in the fuel generator is designed to be several feet below the top, and the outlet of the fuel is above the fluid level, the vacuum would have to exceed 5 pounds for oil to reach up to the outlet pipe. As the fluid level reaches this predetermined point, the float 60 will close the valve, preventing the fluid level from moving above that point.

The objective of the vacuum on the oil charge in the fuel generator is to permit the vaporizing of the fuel at a lower temperature, in order to conserve the heat rejected from the engine, and used to heat the charge.

Since the heat rejected is a fixed amount, at maximum load, and this heat must heat the charge sent through the fuel generator to the cracking temperature, which would be say 700° F at atmospheric, if a vacuum of 5 pounds is maintained on the fuel generator, the cracking point will then be reduced to perhaps 600° F. This will obviously reduce the heat required by 100° F, times the number of pounds of charge put through the fuel generator per hour, times the latent heat of the oil.

The vacuum pump provides pressure to the surge tank, which, in turn, provides fuel for the carburetor and delivers same to the carburetor under pressure, a necessity where supercharged engines are employed.

In this form the stock tank 64 provides the petroleum to be heated, which passes through line 62 into the fuel generator 65, and a back pressure valve 63, set usually for about four pounds, will provide relief from over pressure in the tank 65.

What I claim is:

1. In a viscous oil recovery method comprising the steps of forming a pattern for injection wells and production wells, constructing a plant consisting of a fuel generator, a field of stock tanks, and an engine and compressor and a separator and recycling tank, and directing the production flow from the production wells through a separator and collecting gas in the recycling tank that has been separated from the said production, directing the flow of production from the separator to the fuel generator, extracting fuel and solvents from the production in said fuel generator and distributing the fuel from the fuel generator to the engines and distributing the solvents to the injection wells and the residue to the stock tanks for storage and directing exhaust from the fuel generator into a CO separator and recycling the CO separated therefrom into the fuel generator.

2. The method defined in claim 1 wherein water is taken from a well and treated, and the treated water passed through a hydrogen generator and a Cl₂-HClO₃ generator to produce hydrochloric acid, which is injected into the injection wells with the solvents.

3. The method defined in claim 1 wherein saltwater separated from the production fluid is directed into a Cl₂-HClO₃ generator and then into a water treating means, and water from the water treating means is directed into a hydrogen generator, and hydrogen from said hydrogen generator is directed into the solvents which are injected into the injection wells.

4. The method defined in claim 1 wherein the reject heat from the engines exhaust and cooling system is employed to operate the fuel generator.

5. The method described in claim 1 wherein the gaseous fuel for the engine is removed from the fuel generator by a vacuum pump, which, on its exhaust side, compresses the fuel into a surge tank, under sufficient pressure to operate the pressure regulator attached to the engine carburetor to maintain the correct operating pressure for the carburetor.

6. The method described in claim 5 in which the vacuum on the fuel generator charge is maintained at level to cause a substantial reduction of the heat required for the distillation.

7. In a method as described in claim 1 having a modification in which a fluid actuated float valve at the gaseous fuel outlet of the fuel generator closes the outlet port when oil fills the generator chamber to a danger-

ous level, thus preventing the feeding of solid liquid crude oil into the carburetor of the engine.

8. A method for recovering viscous petroleum comprising the steps of:

- a. Distilling solvent from the produced oil from a production formation produced by lifting means having engines to actuate same to bring the production to the surface, using the waste heat from said engines for distilling the light ends producing a solvent, and
- b. injecting the said solvent into the production formation for the dilution of the viscous oil, causing the less viscous oil to flow more rapidly into production wells and to the surface, and
- c. injecting air, or other gases, simultaneously into the production formation for maintaining the material balance therein, wherein additional drive pressure is generated with further increase in quantity and flow rate of the viscous petroleum, and
- d. recovering the fluids so injected into the formation as they are produced, recycling the light ends as additional solvent is produced and injected, and
- e. replacing the losses in material balance of the formation thereby improving the gas-oil ratio, thus replacing the solvent and gas temporarily invested in the dilution process by the injection, under conditions proper for hydrogenation, of CO and CO₂ gases from the engine exhaust with hydrogen produced by the electrolysis of water, thus producing methane gas and methanol liquid, both of which are solvents, the methane increasing the volume and pressure of the oil, and the methanol reducing the viscosity of the oil, and increasing its API gravity number, and
- f. recovering and recycling some portion of the gases produced along with the oil, to save the dissolved

petroleum therein, and further increase the amount of solvent being injected, thus increasing the flow rate of the oil, and

- g. generating chlorine and HCL or hydrochlorous acid, by electrolysis of the salt brine always present in some amount from oil wells along with the petroleum, and injecting the HCl or hydrochlorous acid into the reservoir to dissolve limestone formations, thereby improving the oil conduit therethrough, and increasing the total flow by dissolving and opening passageways between sealed vugs containing sealed oil, and recovering the water and acid residue along with the oil production, and recycling such part as is still reactive, for additional efficiency, and
- h. improving the production ability of each well in the field by the combination of injecting solvent and air into the borehole of each production well for a period of a few days under sufficient pressure and for long enough to have filled several hundred cubic feet of the formation adjacent to the borehole of the production well with air, utilizing the air to drive the solvent and oil deeper into the reservoir and under the requisite pressure its solubility for water vapor becomes quite large, thus the water in the pore spaces of the sandstone, is evaporated into the air, and when this has been done, the air is permitted to escape from the formation into the borehole of the production well, releasing said air while maintaining sufficient pressure to retain most of the water in solution with the air increasing the effective conduit for the viscous oil by the ratio of the water filled porous zone, to the total pore space, which may be 100 percent increase or more, effectively increasing the flow rate.

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