May 26, 1942. J. P. WALKER ET AL 2,284,112

METHOD OF TREATING WELL FLUIDS

Filed Aug. 12, 1938 5 Sheets-Sheet 1

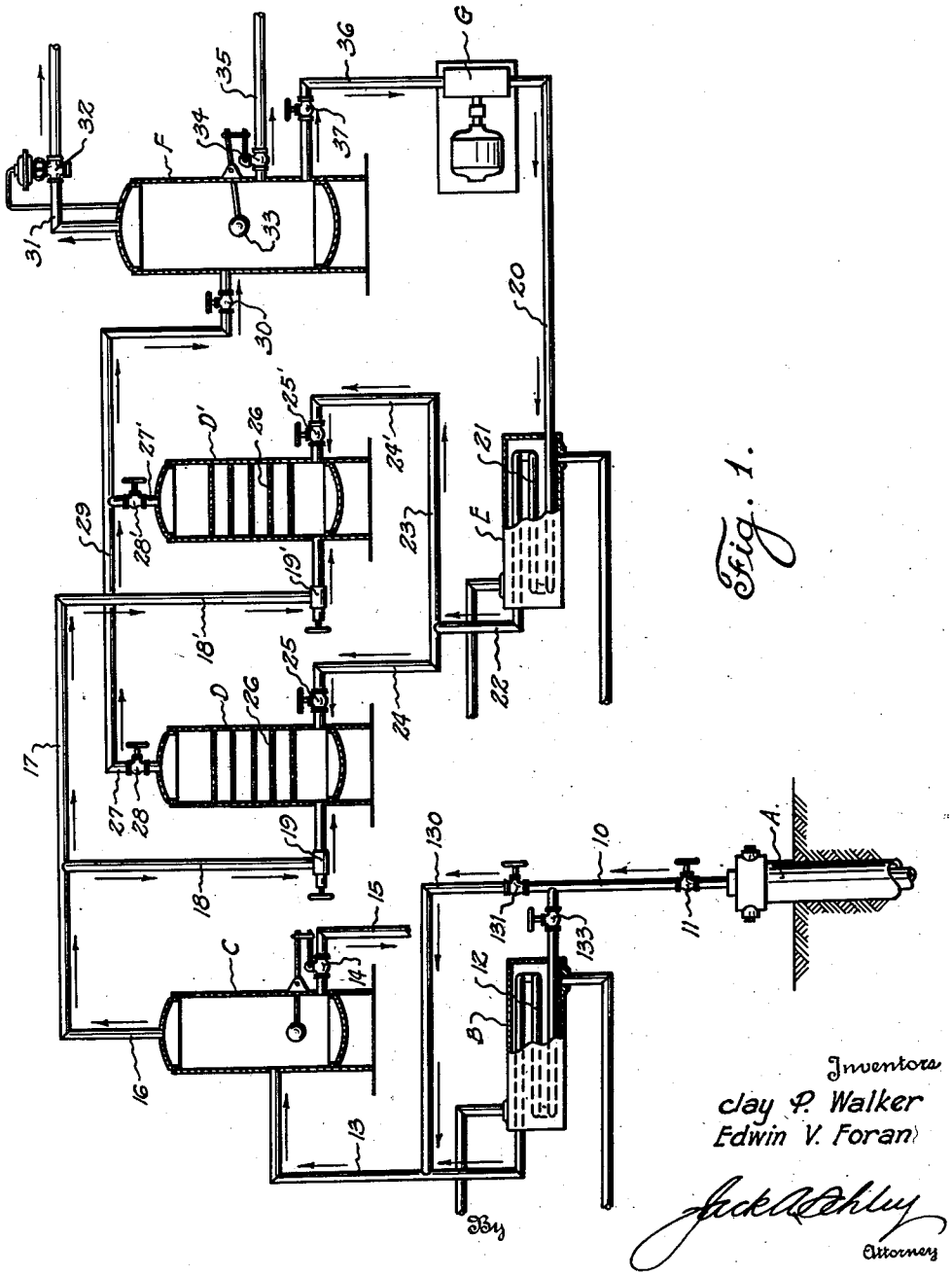

Fig. 1.

Inventors
Clay P. Walker
Edwin V. Foran

Jack A. Ashley
Attorney

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Filed Aug. 12, 1938 5 Sheets-Sheet 2

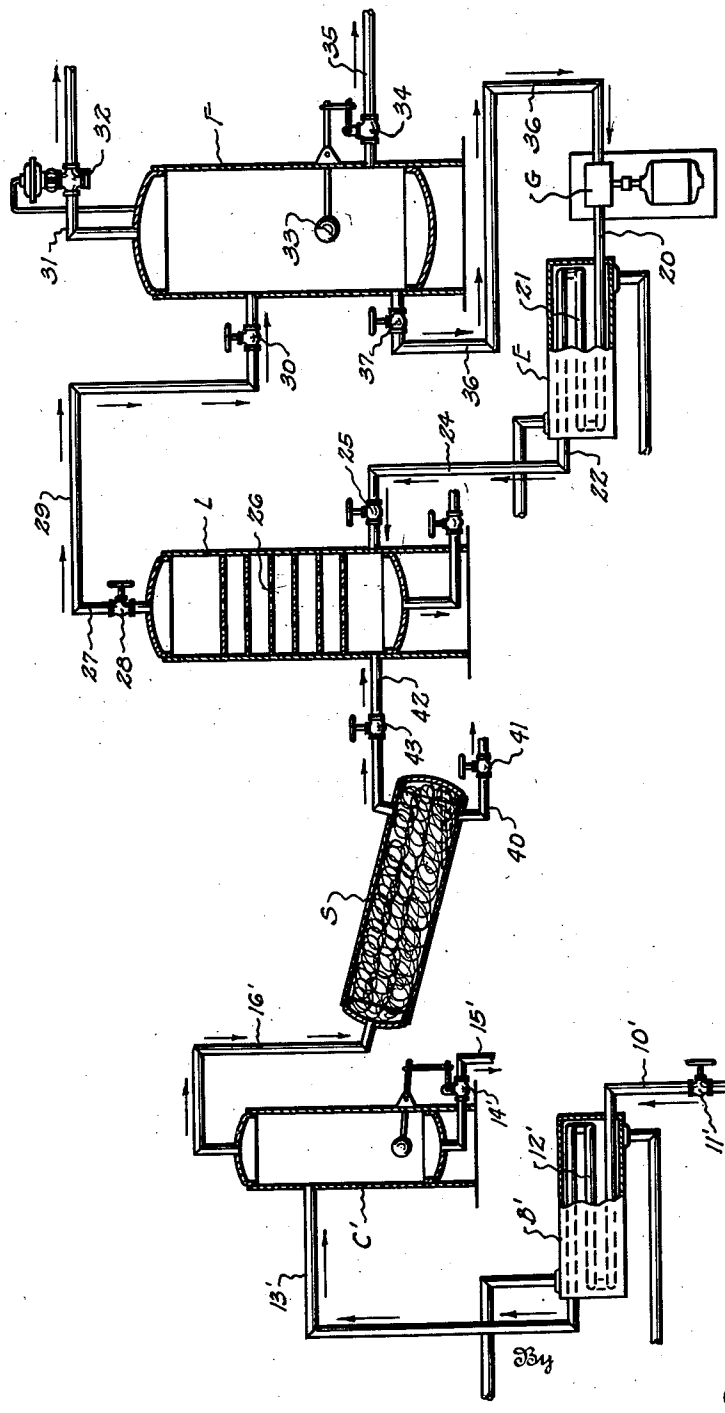

Fig. 2.

Inventors
Clay P. Walker
Edwin V. Foran

Jack A. Ashley
Attorney

May 26, 1942. J. P. WALKER ET AL 2,284,112

METHOD OF TREATING WELL FLUIDS

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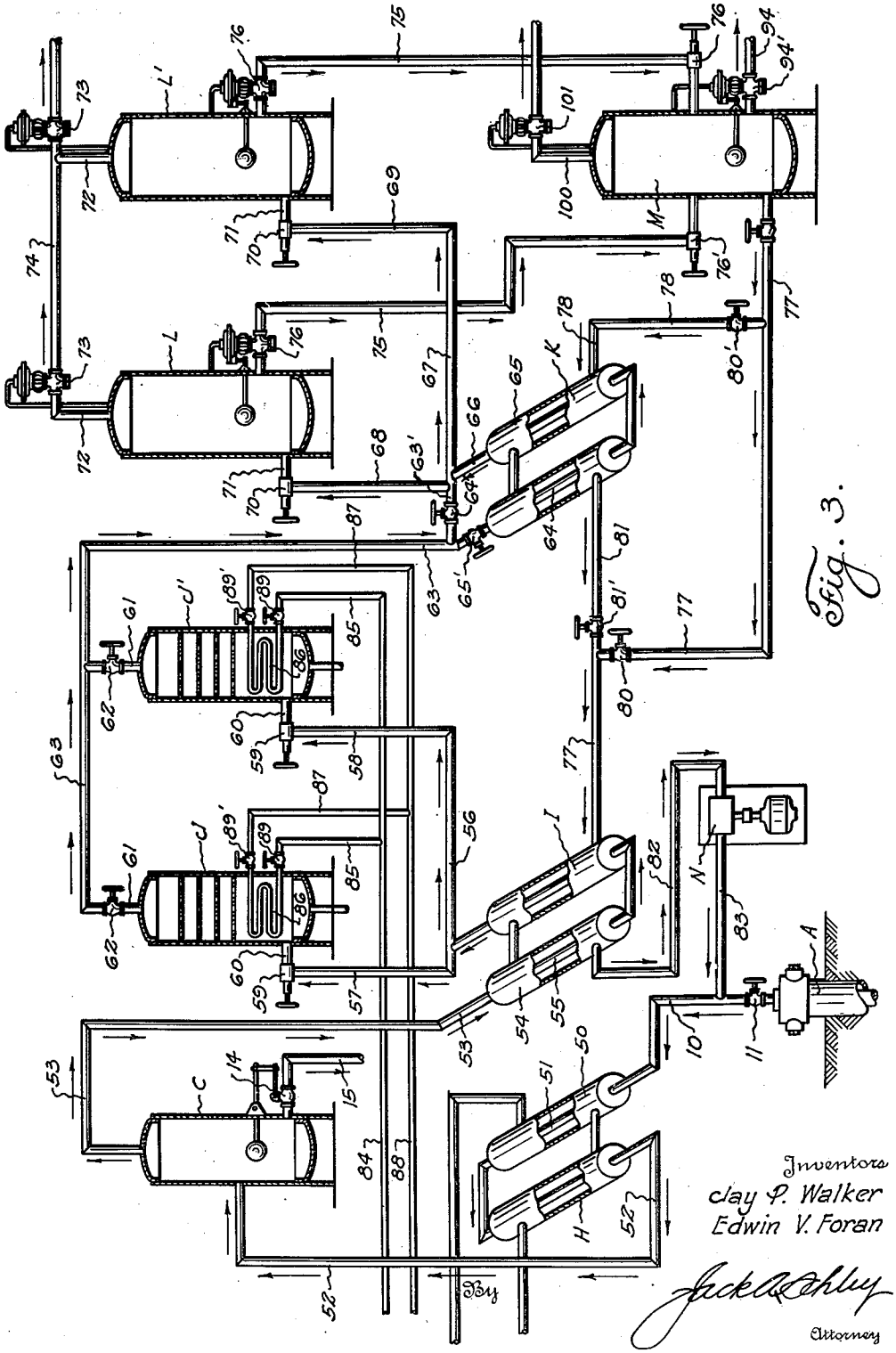

Fig. 3.

Inventors
Clay P. Walker
Edwin V. Foran

Jack A. Ashley
Attorney

May 26, 1942. J. P. WALKER ET AL 2,284,112

METHOD OF TREATING WELL FLUIDS

Filed Aug. 12, 1938 5 Sheets-Sheet 4

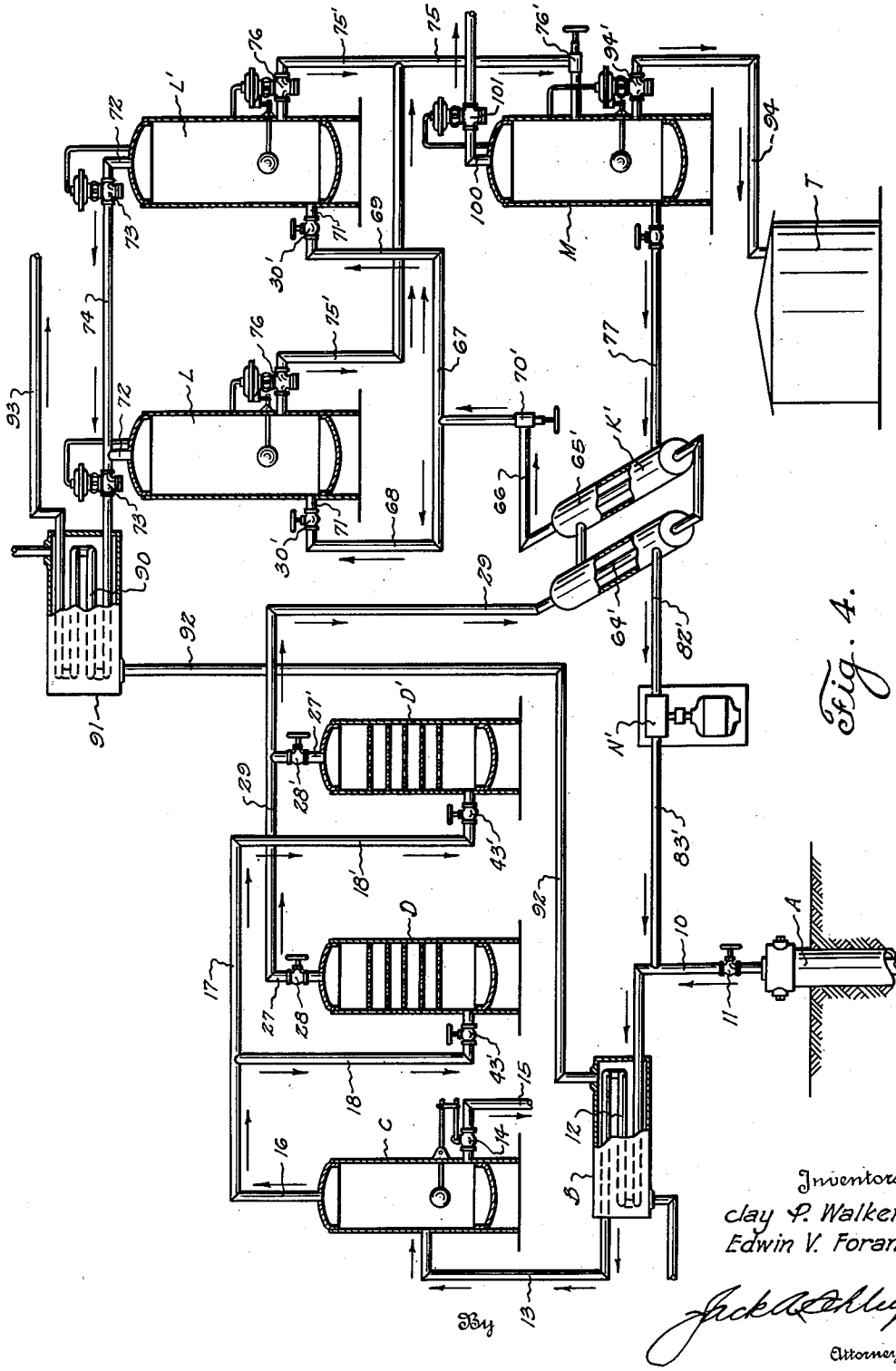

Fig. 4.

Inventors
Clay P. Walker.
Edwin V. Foran

By Jack A. Ashley
Attorney

May 26, 1942. J. P. WALKER ET AL 2,284,112

METHOD OF TREATING WELL FLUIDS

Filed Aug. 12, 1938 5 Sheets-Sheet 5

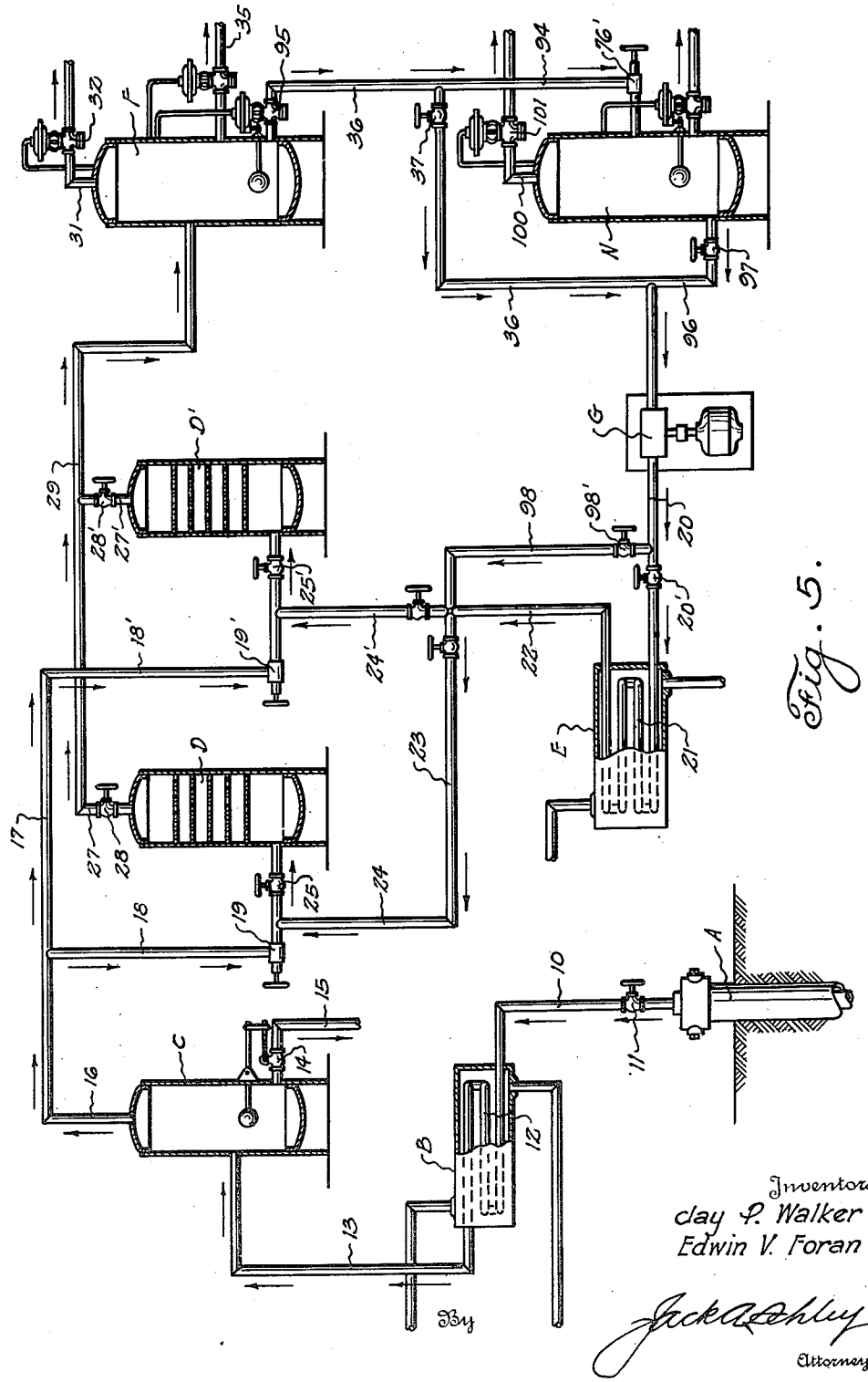

Fig. 5.

Inventors
Clay P. Walker
Edwin V. Foran

Jack A. Ashley
Attorney

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UNITED STATES PATENT OFFICE

2,284,112

METHOD OF TREATING WELL FLUIDS

Jay P. Walker, Tulsa, Okla., and Edwin V. Foran, San Antonio, Tex., assignors to Eureka Process Corporation, Tulsa, Okla., a corporation of Delaware

Application August 12, 1938, Serial No. 224,468

8 Claims. (Cl. 62—175.5)

This invention relates to new and useful improvements in methods of treating well fluids.

The invention has to do with the dehydration of well fluids of the character set forth in our Letters Patent No. 2,080,351, issued May 11, 1937.

The gaseous contents of so-called high pressure reservoirs generally include water vapors as well as various hydrocarbon vapors. The occurrence of water in the vapor phase, under high pressures in general, follows the same physical laws which control the occurrence of the various hydrocarbons in the vapor phase, under high pressure.

When the condition arises within the well flow stream under which gas hydrates are formed, they generally tend to freeze by adhering to the inner walls of the transmission lines or pipes and build up concentrically in such a manner as to ultimately entirely clog, or otherwise obstruct the flow of the well fluids through the pipes or system through which the well fluids are conducted. This formation of hydrates may take place at various temperatures depending upon the pressures prevailing under the different conditions of flow; and in general the higher the pressure, the higher the temperature at which these hydrates will form.

In the event that prior to the formation of hydrates, the water or its elements, through additional condensation, is reduced in its relative quantity in the flow stream with respect to the other hydrocarbons, it will require somewhat proportionately longer periods of time for the hydrates to form and obstruct, or otherwise clog, the flow stream as compared to the time required when no forced or induced condensation, or withdrawal of the water or its elements, is affected, prior to the formation of the hydrates. It, therefore, becomes desirable either to reduce or avoid the formation of hydrates in the flow stream by extracting from the flow stream as completely as possible, within economical limits, as much of the water and its elements as is possible; or following dehydration to produce gas hydrates under controlled conditions and at selected points which coupled with alternate flow apparatus, will avoid shutting down the plant.

One of the means by which water and its elements in the flow stream may be extracted from the vapor phase, as well as from its free liquid phase, is accomplished by a change in temperature, the degree of magnitude of the change in temperature depending upon the pressure conditions existing in the flow stream. In the event that hydrates are already existent in the flow stream at its junction with the well head, or in advance of this junction, it may be necessary to change the temperature upward for the purpose of converting the already formed hydrates to the liquid phase under which condition the water and its elements as a free liquid may be extracted. The formation of gas hydrates may be substantially avoided by reducing the pressure, which causes cooling of the flow stream, resulting in condensation of water vapor; but care must be taken to maintain temperatures at all times above the temperature at which hydrates will form. On the contrary by reducing the pressure and cooling sufficiently, the formation of hydrates at selected points may be controlled, and clogging of the system thus avoided.

These gas hydrates assume a crystalline formation and their accumulation leads to clogging or stoppage of the flow. The accumulations are usually most predominate at points in the transmission lines or system where the direction of flow is changed. However, where a body of liquid is accumulated in the line of flow of the well fluids the gas hydrates may accumulate to such an extent as to cause freezing and defeat further flow or adequate separation of liquids and gas. Such an occurrence would cause the shutting down of a gas or liquid recovery plant.

While thawing out the frozen area would permit the resumption of flow and operation, the evil would not be cured unless alternate apparatus was employed. In a closed cycle system, or one in which the recovered liquid was recirculated in the well stream or used as a reflux, the trouble would be exaggerated. Any free water or water vapor condensate which gets into the transmission line or system will almost without exception cause freezing if the temperature is sufficiently low and the requisite hydrocarbons are present.

In the processing of a well stream flowing from a sub-surface reservoir in which condensable hydrocarbon vapors occur under high temperatures and at high pressures, it is often found necessary to greatly reduce the temperature to increase the recovery of hydrocarbon liquids from such vapors. The critical degree of temperatures at which gas hydrates form varies according to the components of the hydrocarbon vapors and the pressures under which they are produced. Thus if the gaseous fluids or vapors being processed produce hydrates, because of their water content, at relatively high degrees Fahrenheit, under high pressures, the clogging or freezing

will occur much more rapidly. Where pressures are maintained in the range of retrograde condensation, it is highly desirable to dehydrate as well as to control the formation of gas hydrates under such high pressures. Pressures may enter the retrograde range at from 600 pounds to 1500 pounds per square inch, according to the particular components of the well stream being processed; and such range may run through several thousand pounds per square inch.

One object of the invention is to provide an improved method for dehydrating a flowing well stream which is more or less gaseous and includes water vapors, as well as hydrocarbons, likely to cause the formation and accumulation of gas hydrates; and which stream may also include free water and hydrocarbon liquids.

A further object of the invention is to provide an improved method of treating a well stream to delete, as near as is possible thereunder, a maximum of water content as a preliminary step to the recovery of liquefiable fractions, flowing from the well predominately in vapor phase, by admixing with the said well stream, preferably in relatively large quantities, recovered self-liquids or their equivalents as a reflux or liquefaction medium, whereby the formation and accumulation of gas hydrates is controlled and either minimized or accentuated as the steps may require.

A further object of the invention is to provide a method for treating well streams, usually flowing from the well under temperatures considerably greater than those at which the stream is processed and which stream is ordinarily predominately gaseous and has free water or water vapors, or both, entrained therein; which method involves reducing the flowing pressure of the well stream, if necessary, and cooling said stream within a range of temperatures and at pressures above those at which gas hydrates will form, which temperatures must not be in excess of those existing at the source of the well stream, whereby the water vapors may be condensed and removed from the well stream, thus preventing the formation of gas hydrates in the system.

Another object of the invention is to provide a method wherein the well stream, after its pressure is reduced and its temperature is lowered to the proper degree, as above stated, is passed through a preliminary separation step to cause the water condensation and free water to drop out of the flowing well stream which is more generally gaseous, but which may include some liquid hydrocarbons, whereby the collected water may be drawn off and prevented from getting into the processing system to form gas hydrates therein.

An important object of the invention is to provide an improved dehydration method wherein the well stream is first cooled to cause the condensation of the more aqueous vapors and the condensate precipitated as free water; the residual well stream then being carried through a pressure reduction step to further reduce the temperature to a point where gas hydrates will be formed and the water vapors substantially extracted, so that the stream is reduced to approximately a hydrocarbon fluid which will permit it to be further processed with minimum interference from gas hydrates.

Another important object of the invention is to provide in the method an alternate and complementary step so that when the flow of the stream is seriously impaired or cut off by the formation of hydrates during the step of preforming gas hydrates, the flow of the stream may be shifted to another channel and the step of forming gas hydrates carried out while the apparatus first used is being thawed out.

Still another object of the invention is to admix with the well stream a cooled reflux hydrocarbon liquid which has been recovered from the well stream, or otherwise obtained, at such temperatures and in such quantities as to liquefy and precipitate desirable liquefiable fractions flowing in the well stream and recover such fractions in agglomeration with the reflux, during the gas hydrate forming step, and subsequently separating the hydrocarbon liquids from the gas of said well stream and utilizing a portion of the recovered liquids as the reflux medium; all steps being performed under high pressures.

A further object of the invention is to provide at a suitable point in the method an additional step, which however, may be omitted, whereby the gaseous well stream after passing through one or more dehydrating steps, is scrubbed or filtered, or is passed through water absorbing material, whereby a further reduction of the water content of the well stream is extracted and collected.

An important object of the invention is to provide a method for dehydrating gaseous well fluids which includes the steps of extracting the water vapors by condensing and then admixing with the residual gaseous fluid a quantity of hydrocarbon liquid reflux, previously extracted from the well fluid or otherwise obtained, whereby the induced formation and accumulation of gas hydrates is controlled, and more continuous operation is assured.

An important object of the invention is to provide an improved method wherein cooling of the gaseous well stream, together with reduction of the pressures thereof, may be carried out at different stages in the process of recovering liquids from gaseous fluids, the cooling being performed after or between pressure reductions, or both, and before or after the introduction of the reflux into the well stream or both.

Constructions designed to carry out the invention will be hereinafter described, together with other features of the invention.

The invention will be more readily understood from a reading of the following specification and by reference to the accompanying drawings, in which examples of the invention are shown, and wherein:

Figure 1 shows in diagram form an apparatus for carrying out the method,

Figure 2 is a diagram of an apparatus for performing a modification of the method, and

Figures 3, 4 and 5 are each diagrams showing other forms of apparatuses for performing the method in its various ramifications.

In the drawings (Fig. 1), the letter A indicates a flowing well producing a gaseous fluid which is conducted through a pipe designated by the numeral 10. The pipe may include a valve or choke 11, whereby the pressure of the fluid flowing from the well through the pipe may be reduced.

The pipe 10 is connected to the coil 12 of a cooling unit or heat exchanger B which may be of any suitable construction. An ammonia cooler and a water cooler have been used with good results, but any method of cooling may be employed. It is important to reduce the temperature of the gaseous fluid in order to condense the water vapors, but care must be taken not to low-

er the temperature below a degree, which will cause the formation of gas hydrates. As an illustration it was found that where a certain gaseous fluid was flowed at a temperature of approximately 120° F., and under a pressure of approximately 1,600 pounds, the temperature could be lowered to about 66° F., without inducing the formation of gas hydrates.

After the gaseous fluid or well stream is cooled in the coil 12 of the cooler B, it is conducted through a pipe 13 to the intermediate section of an upright separating tank C. While passing through the coil 12 and flowing to the separator, a large portion of the water vapors will condense and enter the separator as water, also some free water, not in vaporous form, will flow from the well. There will be some further condensing of the water vapors in the separator.

Water in the separator C will collect in the bottom thereof and when reaching the necessary level, will cause the valve 14 in a pipe 15, leading from the bottom of the separator, to open and discharge the water therefrom. The gaseous fluid in the upper portion of the separator C will still have entrained therein, water vapors, a portion of which are not condensable at the prevailing temperature and pressure. The gaseous fluid is conducted from the top of the separator C through a pipe 16.

The pipe 16 connects with a manifold pipe 17 from which branch pipes 18 and 18' extend. The pipe 18 is connected with a tank D, which we have named a "liquedenser" for reasons which will be hereinafter self-evident. The pipe 18' is connected with a second liquedenser D'. The tanks or liquedensers D and D' are substantially duplicates and are intended to be used alternately. The pipe 18 includes a choke 19 or suitable pressure reducing valve; while the pipe 18' includes a choke 19' or valve. When one choke is open the other is closed.

By regulating the choke the reduction in pressure may be controlled. The degree of pressure reduction will depend to a large extent upon the reactions of the well stream, as some components apparently cause the formation of gas hydrates for a given pressure at higher temperatures than others. As it is the purpose of this phase of the invention to intentionally form gas hydrates in the liquedenser, the choke will be adjusted to cause sufficient pressure reduction to accomplish this result at the desired temperatures and pressures.

As has been well known in the oil and gas producing industry, even prior to 1936, reducing the pressure of a high pressure gaseous well stream, such as flows from a distillate reservoir, will produce retrograde condensation when such pressure reduction occurs within certain limits, below which continued pressure reduction would re-vaporize such condensates or liquefiable fractions. The base of such range is generally accepted as around 700#, but the upper limits have not been definitely established. As an example, when the pressure is reduced on the surface of the ground from 1600# to 1000#, not only will there be condensation due to retrograde condensation, but there will also be natural cooling and the amount of liquefiable components condensed will, in the absence of counter-acting forces, be amplified. The condensation may be still further increased by artificial cooling or refrigeration while still maintaining the pressure of the flowing stream within the retrograde condensation range. These were well established laws at the time above referred to.

A heat exchanger or cooler E similar to the exchanger B is provided and the reflux hydrocarbon liquid is supplied thereto through a pipe 20, connected to its coil 21. A pipe 22 leads from the coil to a manifold pipe 23; while branch pipes 24 and 24' lead therefrom to the liquedensers D and D' respectively and includes cut-off valves 25 and 25'. The temperature at which the reflux liquid is introduced into the liquedenser will have much to do with the formation of gas hydrates, so only a slight reduction in the flowing pressure of the well stream, may be required. As an instance where the stream is flowing at 1600 pounds pressure, as hereinbefore recited, it may only be necessary to reduce such pressure to about 1400 pounds. Considerable time will be required to form the gas hydrates, otherwise no profitable recovery of liquid hydrocarbons could be obtained. As explained in our Letters Patent No. 2,080,351, the cool liquefaction reflux causes precipitation of liquefiable fractions in the well stream. The quantity of the reflux introduced largely controls the agglomeration while the temperature controls, in a great measure, the recovery.

Where the pressure has been reduced to 1400 pounds, a temperature of approximately 60° F. has been attained and this has caused precipitation of water by forming gas hydrates, being below the degree F., at which gas hydrates form at the prevailing pressure. The temperature in the liquedenser may go even lower, as with many gaseous fluids, greater liquid recovery may be effected at temperatures of 40 degrees F. or lower. However, the lower the temperature, the more certain hydrates are to form and in economical practice it may be more profitable to maintain these lower temperatures.

Each liquedenser may have suitable perforated baffles 26 therein, or it may be otherwise constructed to carry out the process. The steps performed in the liquedenser are substantially the same as in the tank C of our aforesaid Letters Patent. It will be noted that the reflux pipe 24 enters near the bottom so as to give the liquid full opportunity to admix with the well stream, as the latter flows upwardly in the liquedenser.

Pipes 27 and 27' including valves 28 and 28' extend from the tops of the liquedensers and connect with a manifold pipe 29 which leads to a separator F. When the liquedenser D is in operation the choke 19 and the valves 25 and 28 are open, while the choke 19' and valves 25' and 28' are closed, thus cutting the liquedenser D' out of operation. Several hours or more than a day may be required for the liquedenser D to become sufficiently obstructed to necessitate shifting the flow to the alternate liquedenser D'. In such an event the choke and valves which were open before the flow was shifted are closed and the choke 19' and valves 25' and 28' which were closed, are opened, thereby bringing the liquedenser D' into operation and shutting off the liquedenser D which may then be thawed out in any suitable manner. This arrangement obviates any interruption in the operation of the plant.

The pipe 29 leading to the separator has a valve 30 and enters the separator at about mid-height. The reflux liquefaction liquid will thoroughly admix with the well fluids while flowing upwardly therewith through the liquedenser D or D'. The said admixing of the liquid with the

well fluids will cause a liquefaction and precipitation of the liquefiable fractions which are in vaporous form, by its intimate or surficial contact therewith, thus making it possible to increase the recovery of the liquefiable fractions from the well fluids.

Ordinarily, the primary well stream of these distillate type wells is substantially composed of free gases not subject to appreciable liquefaction under high pressures, fractions in vaporous form which are liquefiable, and other fractions in the liquid phase. These components prevail in a state in which the liquid phase fractions are highly dispersed or atomized and form a more or less homogeneous mixture with the gases and liquefiable vaporous fractions.

In the process of admixing, a major change in the character of the well stream fluids takes place in the form of an increased liquid content which results in a unification of the highly atomized or dispersed liquid particles in the primary well stream fluids with the more massive liquid particles of the liquefaction liquid. During this step, in which the unification of the atomized and more massive liquid particles takes place, the resultant liquid and gas admixture is prepared for separation, which is efficiently accomplished due to the fact that the atomized or highly dispersed particles have united or combined with the more massive liquid particles of the medium. During the process of admixture any cooling of the fluids which may take place will further increase the recovery of liquefiable fractions from the combined fluids. The fluids enriched by the liquefaction liquid flow from the tank D, under substantially high pressure, out through the pipe 29. This stream flowing through the pipe 29 has a much greater liquid content or liquid to gas ratio than the well stream as it flows from the well and enters the high pressure separator F, preferably at midheight, wherein separation of the liquids from the gas takes place.

The well stream or fluids having been prepared for separation prior to their entrance into this separator F will readily yield to separation therein, the liquids descending to the lower portion and the gases rising and passing out through a pipe 31 having a valve 32 connected therein for controlling the pressure in said separator. The recovered liquids are accumulated in the separator and when they reach a discharge level the float 33 will be raised and the valve 34 opened, whereby said liquids will flow out through a pipe 35 to the stock tanks or other disposal (not shown). The gas which escapes through the pipe 31 will be under high pressure because after passing through choke 19, the only pressure reduction will be that incidental to the flow. This gas is suitable for commercial uses or due to its high pressure may be economically returned to a sub-surface reservoir.

A pipe 36 including a valve 37 extends from the separator F at a point much lower than the pipe 35, for conducting the liquefaction liquid to a pump G which discharges into the pipe 20. The lower location of the pipe 36 assures a constant supply of reflux liquid, as hereinbefore described.

It is pointed out that by regulating the operation of the pump G the quantity and rate of introduction of the liquefaction liquid into either the tank D or D' may be controlled. At some stages in the practice of the method, it may be desirable to employ more or less quantities of liquefaction liquid in order to procure the most efficient recovery of liquefiable fractions. Thus, the provision of an ample supply of the liquefying liquid is most desirable and, of course, such liquid may best be used after the separation of the gases therefrom, and after adequate cooling.

In some instances it may be possible to eliminate the cooler B and therefore a by pass pipe 130 including a hand valve 131 is connected with the pipes 10 and 13. A hand valve 133 is connected in the pipe 10 between the cooler and the joint with the pipe 130. When the valve 133 is closed and the valve 131 is opened the cooler will be cut out.

In Figure 2 we have shown another form in which it is the purpose to avoid the forming of hydrates or reduce them to a minimum. The letter A' indicates a flowing well producing a gaseous fluid which is conducted through a pipe designated by the numeral 10'. The pipe may include a valve or choke 11', whereby the pressure of the fluid flowing from the well through the pipe may be reduced.

The pipe 10' is connected to the coil 12' of a cooling unit or heat exchanger B' which may be of any suitable construction. An ammonia cooler and a water cooler have been used with good results, but any method of cooling may be employed. It is important to reduce the temperature of the gaseous fluid in order to condense the water vapors, but care must be taken not to lower the temperature below a degree, which will cause the formation of gas hydrates. As an illustration it was found that where the gas fluid was flowed at a temperature of approximately 110° F., and under a pressure of approximately 1,300 pounds, the temperature could be lowered to about 61° F., without inducing the formation of gas hydrates.

After the gaseous fluid or well stream is cooled in the coil 12' of the cooler B', it is conducted through a pipe 13' to the intermediate section of an upright separating tank C'. While passing through the coil 12' and flowing to the separator, a large portion of the water vapors will condense and enter the separator as water, also some free water, not in vaporous form will flow from the well. There will be some further condensing of the water vapors in the separator.

Free water in the separator C' will collect in the bottom thereof and when reaching the necessary level, will cause the valve 14' in a pipe 15', leading from the bottom of the separator, to open and discharge the water therefrom. The gaseous fluid in the upper portion of the separator C' will still have entrained therein, more or less water vapors, a portion of which are not condensable at the prevailing temperatures. The gas fluid is conducted from the top of the separator C' through a pipe 16', to a scrubber S.

The scrubber may be of any suitable type and may include one or more drums or barrels. For the purpose of illustration, one such drum is shown but frequently two or more such drums are used. The drum may be disposed at an incline, the pipe 16' entering the center of the head at the upper end. The drum is filled with fibrous material, such as wood excelsior or hay, as is the common term in the oil fields. At the lower end, a water discharge pipe 40 leads from the bottom of the drum and includes a hand valve 41, although an automatic valve may be used. A pipe 42 leads from the top of the drum at the lower end for conducting the dehydrated gaseous fluid therefrom.

The drum being filled with fibrous material,

it is obvious that the gaseous fluid may flow through such material. The quantity of material is usually sufficient and in such conglomeration or compactness, as to thoroughly scrub or filter the fluid. By contact with this material additional water will be scrubbed out or absorbed. The water extracted in the scrubber S will settle to the lower end of the drum and from time to time, may be drawn off. Sufficient travel path must be provided to obtain the desired dehydration, and this will control the length, size and number of drums. The separator C' and the drum S constitute a dehydrator and by their use, one of the major steps of the method is performed. However, any apparatus, of which there are several, may be used for this purpose.

The pipe **42** conducts the dehydrated gaseous fluid from the drum to an upright tank L which is known as a "liquedenser." A valve **43** may be connected in the pipe **42**, where it is desired to reduce the flowing pressure of the gaseous stream. The apparatus which is illustrated beyond the liquedenser L, is set forth in our Letters Patent No. 2,080,351, issued May 11, 1937, but the invention is not to be limited to such an apparatus.

The pipe **42** enters the liquedenser L at one side near the bottom. Under operating conditions the liquid in the liquedenser is carried above the inlet from the pipe **42**, and therefore, the influent is discharged into a body of hydrocarbon liquids. As a rule, difficulties arising from freezing occur in the processing apparatus. Freezing or formation of hydrates at the bottom of the liquedenser or at points beyond, would cause clogging and eventually stoppage, necessitating shutting down the plant.

Gas hydrates are crystalline compounds which resemble ordinary snow. They gradually build up inside turns, in valves, or at any irregularities in the system, packing in the form of opaque ice. Experiments have shown that gas hydrates are formed by hydrocarbons in the presence of water vapors throughout a broad range of high pressures. The formation of gas hydrates in gaseous fluids seems to depend primarily upon the pressure, temperature and composition of the gas-water vapor mixture. It is said that the combination of certain gases with water, forming hydrates at elevated pressures and to temperatures above the normal freezing point of water, is a phenomenon that has in more recent years been generally recognized by the gas industry.

So far as is known, water vapor is the only component of the gas stream that can be controlled on a practical basis. However, the complete removal of the moisture in the gaseous fluid will, of course, eliminate the possibility of hydrates forming. It is believed that it is not necessary that the gas be entirely free from water vapor since these hydrates cannot form until the dew point of the gas is reached; therefore it is desirable to maintain a temperature above a critical point, under prevailing pressures.

It is sometimes essential to the proper recovery of liquefiable hydrocarbons from the gaseous fluid, that the reflux body of liquid in the liquedenser L have a temperature which may be many degrees Fahrenheit lower than the temperature of the influent as it enters said liquedenser. Under these conditions liquefiable fractions are precipitated and agglomerated with the reflux liquid.

This reflux liquid must have a temperature low enough to bring the contents of the liquedenser down to a low degree to produce a satisfactory recovery. It is found with some gaseous fluids that desirable recovery is had at 40 degrees F., and in such instances the reflux liquid is cooled to, and introduced into the liquedenser at 40 degrees F. or less. However, the well stream flowing into the liquedenser L must be maintained at a degree F. above the critical temperature at which hydrates will form in the presence of water vapor, unless substantially all of the moisture has been previously extracted.

While certain fundamental steps are necessary to the method there are many ramifications. To say which apparatus or which embodiment of the method is preferable, would be difficult, if not impossible, because of the various producing conditions which exist. Several apparatuses are illustrated herein, but many others may be evolved in carrying out the method.

In Figure 3 a form is shown, wherein the reflux is used as a cooling medium. The flow stream pipe **10** leads from the well A and includes the choke or regulating valve **11**, the same as in Figure 1. A water cooler H is provided and includes a plurality of cylindrical water jackets **50** through which a coil **51** extends. One end of the coil is connected to the flow stream pipe **10**, while the other end is connected to a pipe **52**. The pipe **52** leads to the water knockout C, as in Figure 1, and a pipe **53** extends from the latter. A second cooler I similar to the cooler H includes a plurality of cooling jackets **54** and a coil **55** connected at one end to the pipe **53**. The well stream flowing through the coil **51** of the cooler H from the pipe **10** is cooled so that the free water and water condensates are dropped out in the knockout C. The gaseous well stream flowing out through the pipe **53** is again cooled while passing through the coil **55**.

A manifold pipe **56** leads from the coil **55** and risers **57** and **58** extend upwardly from said pipe. At the upper end of each riser is a choke **59** from which horizontal pipes **60** extend. One of the pipes **60** is connected to a liquedenser J, while the other is connected to a liquedenser J', somewhat the same as in Figure 1. Only one of the chokes is open at a time, except perhaps for a short period when the shift is being made from one liquedenser to the other. Discharge pipes **61** including cut off valves **62** lead from the liquedensers and conduct the flow stream to a manifold pipe **63** which is connected to one end of a cooling coil **64** extending through jackets **65** of a cooler K. A discharge pipe **66** leads from the coil to a manifold pipe **67** from which risers **68** and **69** extend upwardly, each riser having a choke valve **70** at its upper end from which a horizontal pipe **71** extends. One of the pipes **71** is connected to a separator L, while the other pipe **71** is connected to a separator L'. Only one of the separators is used at a time and the chokes may be eliminated and ordinary hand valves substituted. In case it was not desired to use its cooler K a valve **64'** in a by pass pipe **63'** can be opened and a valve **65'** in the pipe **63** closed.

Gas pipes **72** lead from the tops of the separators and include diaphragm regulating or pressure reducing valves **73**, or any other suitable valve. These pipes connect with a manifold pipe **74** which conducts the residual gas to

the compressor or other point of disposition. Discharge pipes 75 including diaphragm operated oil valves 76, or other valves suitable for the purpose, lead from the separators to a flash tank M. The liquid may be discharged from the separators at high pressures such as 1,000 to 1,400 pounds or higher, per square inch. The diaphragm operated valves 76 act to lower the pressure, but it is necessary to use a choke of some sort in order to control the pressure at which the separated liquid enters the flash tank. In each pipe 75 a choke 76' may be connected, one of which can be closed when the other is open. By means of these chokes the pressure of the liquid entering the flash tank may be reduced to any desirable pressure above atmospheric. The gas which in solution in the liquid is present in considerable amounts and when flashed off is conducted from the tank by a pipe 100 which has a diaphragm pressure reducing valve 101 or other suitable valve connected therein. This gas may be used for any suitable purpose. This sudden reduction in pressure will greatly reduce the temperature of the residual liquid. For instance, if the liquid entered the tank at 1,200 pounds pressure at 47° F., and it was flashed down to 50 pounds, its temperature might be lowered to approximately 28° F. These temperatures are subject to variation according to the components of the liquids.

A pipe 77 leads from the flash tank M to one of the jackets 54 of the cooler I, whereby the cold reflux is conveyed thereto. A branch pipe 78 extends from the pipe 77 to one of the jackets 65 of the cooler K. By this arrangement the cold reflux is used as a cooling medium for the flow stream. Either of the coolers I or K may be used, individually. The pipe 77 includes a hand valve 80 and the pipe 78 has a hand valve 80' connected therein. A discharge pipe 81 leads from the cooler K to the pipe 77 adjacent the cooler I, whereby the cold reflux which passes through cooler K is exhausted through the cooler I. The pipe 81 includes a valve 81' which is closed when the valve 80' is closed. When the valve 80 is closed and the valves 80' and 81' are open the reflux will flow from pipe 77 through pipe 78 to the cooler K and thence by pipes 81 to pipe 77 and cooler I; but when valves 80' and 81' are closed and valve 80 is opened, cold reflux will flow only to cooler I.

A return pipe 82 leads from the cooler I to the reflux pump N, whereby the pressure of the reflux liquid is raised so that it may be injected into the flow stream at the desired point. A reflux supply pipe 83 leads from the pump. This pipe may connect to the flow stream conductor at any point in advance of the liquedensers or could be connected directly thereinto. We have shown the pipe 83 connected to the pipe 10 in advance of the cooler H. After the reflux passes through the coolers I and K, its temperature, owing to heat exchange with the flow stream, will be somewhat raised. In stepping the pressure of the reflux liquid from the flash tank pressure up to the operating pressure, its temperature will not be appreciably raised. By injecting it into the flow stream in advance of the first cooler and subsequently cooling the stream, very good results will be had. The reflux will be given ample opportunity to admix with the gaseous well stream and begin its co-action therewith, early in the process.

The apparatus shown in Figure 3 is exceedingly flexible. The cooling may be more readily controlled and applied at the point desired. The pressure reductions may be carried out as desired and temperatures thus controlled. Flashing is much less expensive than cooling with ammonia coils or other artificial means and it eliminates freezing in the ammonia coils. By using two separators alternately, and reducing the pressure at the separator, any water vapors remaining in the stream leaving the densifier may be converted into gas hydrates, and when one separator freezes up, the other separator may be used.

When one of the liquedensers freezes up it is shut off and the flow stream is directed into the other liquedenser. This is also the case with the separators L and L'. In Figure 3, we have shown means for thawing out the frozen tank and it may be applied to any of the tanks shown in the other apparatuses. Of course, any means of thawing may be used and if the temperature of the atmosphere surrounding the frozen tank is high enough, no other thawing means may be needed.

Hot water, from a suitable source, is supplied through a pipe 84 which connects by means of branch pipes 85 with coils 86 in the bottoms of the liquedensers J and J'. As the freezing generally occurs at the bottom of the tank, the hot water coil is most effective at this point. The return water from the coils is carried off through branch pipes 87 to a return pipe 88. Hand valves 89 and 89' are connected in the pipes 85 and 87, respectively, whereby steam may be supplied to either liquedenser. Application of the coils to the separators L and L' has not been shown.

The operation of the apparatus shown in Figure 3 is much the same as in Figure 1. The gaseous stream flows from the well A through the pipe 10 to the cooler H. If necessary the flowing pressure of the stream is reduced by the valve 11. The stream continues its flow through the pipe 52 to the water knockout C where the free water and condensates are dropped out. The gaseous stream leaving the knockout by way of the pipe 52 may be substantially free from water, but may still have entrained sufficient water vapors to form gas hydrates. The stream flows on through the coil 55 of the cooler I, in which its temperature is brought down to the desired degree F. The cooled stream is discharged into the pipe 56.

The choke valve 59 of the liquedenser J is opened, the choke valve of the liquedenser J' being closed. The cold gaseous stream will now flow up the riser 57, through the choke 59 and pipe 60 into the liquedenser J, wherein the recovery process is carried out, as hereinbefore described. The cooling of the stream while passing through the cooler I and the pressure reduction effected by the choke, brings the temperature of the stream down approximately the degree F. at which gas hydrates form; however, this low temperature promotes recovery of the liquefiable fractions. This step of purposely causing the formation of gas hydrates in the liquedenser, as hereinbefore pointed out, is usually sufficient to accomplish adequate dehydration. The cooling between the water knockout and the liquedenser may be profitable in some instances because it is not necessary to choke the stream to such an extent as in Figure 1, and therefore, a higher pressure may be carried in the liquedenser; however the cooler may be omitted if desired.

The cooling of the stream in the cooler I is

usually sufficient. The stream escaping through the pipe 61 into the pipe 63, may be conducted directly to the pipe 67 by way of the by-pass pipe 63', when the valve 64' is opened and the valve 65' is closed. If it is desired to use the cooler K the valve 64' is closed and the valve 65' is opened. The stream flowing from the pipe 63 through the cooler K is again cooled in passing through the coil 64. This cooled stream is discharged into the pipe 66 and 67 from which it flows up the riser 68, through the choke 70 and pipe 71, into the separator L. The cooler K may be found sufficient and in such event the choke 70 may be omitted.

Where the stream is cooled and choked at the liquedensers, or choked alone, it may be found expedient not to lower the temperature at this point, to as low a degree F., as in Figure 1, where there is neither cooling of the stream flowing from the liquedenser nor choking at the separator. In the apparatus shown in Figure 3, there is a two-step formation of gas hydrates at two selected points; either of which might be used alone. It is manifest that numerous adjustments and manipulations are practical within the teaching of this phase of the method.

While it would be possible to take off some of the recovered liquids from the separator, the separated gas having been discharged, it is preferable to conduct all of the liquid through the pipe 75 to the flash tank M. By means of the valve 76 the flow of the liquid is regulated and by use of the choke 76' the pressure is reduced several hundred pounds. This sudden pressure reduction or flashing will drop the temperature sufficiently so that additional cooling of the reflux liquid, which is drawn off through the pipe 77 will usually not be necessary. The remainder of the recovered liquid which is not used for the reflux, is drawn off from the flash tank for storage or other disposition by means of a pipe 94 including a valve 94'. In flashing the liquid, gas in solution will be liberated in the tank and this gas may be taken off as described.

The apparatus shown in Figure 4 has features in common with both Figures 1 and 3 and the same reference letters and numerals are used, where the parts are substantially the same. The well A is connected with the coil 12 of the cooler B by the pipe 10 which includes the valve 11, and the pipe 13 leads from the cooling coil to the water knockout C from which the pipe 16 extends. The densifiers D and D' are connected with the manifold pipe 17 by branch pipes 18 and 18' which include hand valves 43', so either densifier may be shut off. The chokes 19 and 19' are omitted, but, of course, could be used. Discharge pipes 27 and 27' lead from the liquedensers and include the valves 28 and 28'. These pipes are connected with a manifold pipe 29.

The pipe 29 is connected with the coil 64' of a cooler K' having a jacket 65'. It will be noted that there is substantially no pressure drop between the valve 11 at the well and the cooler and without the use of chokes there is no induced formation of gas hydrates in the liquedensers. The cooled flow stream discharges from the coil 64' into a pipe 66 in which a choke 70' is connected. The pipe 66 connects with a manifold pipe 67 from which risers 68 and 69 extend upwardly and connect with pipes 71 leading to the separators L and L'; the chokes 70 being omitted, and the single choke 70' serving in place thereof, however, hand valves 30' are connected in the pipes 71.

Where the pressure of the flow stream is 1,600 pounds and it reaches the cooler K' at a temperature of about 70° F., it will emerge from said cooler at about the same pressure but with a temperature of about 60° F. The choke may be set to reduce the pressure and cause a further pressure drop. Gas from the separators escapes through the pipes 72 to the pipe 74 which in turn connects with a heat exchanger coil 90, whereby the temperature of the gas is raised and the water flowing through the jacket 91 is lowered. This cooled water is conducted by a pipe 92 to the coil 12. A gas discharge pipe 93 leads from the coil 90. This portion of the apparatus may be applied to any of those shown herein.

The recovered liquids are carried from the separators by pipes 75' which connect with a pipe 75 leading to the flash tank M. The pipe 94 leads from the flash tank to a stock tank T, but other disposition of the liquid may be made. The cold reflux from the flash tank is carried off by a pipe 77 which connects with the jacket 65' of the cooler K'. A flow pipe 82' leads from the jacket to a pump N' from which a supply pipe 83' leads to the flow stream pipe 10.

Figure 5 illustrates an apparatus which is substantially the same as that shown in Figure 1, except that the flash tank N is used and the reflux cooled thereby. Also the cooler E is arranged so that the cool reflux liquid may be passed therearound, thus making it possible to use the cooler or not to use it, as may be desired. In case it was not desired to flash off such a quantity of gas as to reduce the pressure to a low point and thus cool the reflux to a low degree F.; the temperature of the reflux discharged from the flash tank could be further lowered by passing it through the cooler E.

The pipe 36 is arranged to lead to the pump G and a diaphragm operated oil valve 95 is connected in the pipe adjacent the separator F., like the valve 76 of Figures 3 and 4. A branch pipe 94 extends from the pipe 36 to the flash tank N and the choke valve 76', as in Figures 3 and 4, is connected in the pipe 94 adjacent said tank. The cut-off hand valve 37 is connected in the pipe 36 adjacent, but beyond, the joint with the pipe 94. A discharge pipe 96 including a hand valve 97 extends from the tank N to the pipe 36 for conducting the cold reflux from the tank. By closing the valve 37 the flash tank may be used and by opening the valve 37 and closing valves 76' and 97, the liquid may be passed around the tank through the pipe 36.

A branch pipe 98 including a valve 98' extends from the pipe 20 to the manifold pipe 23. The liquid discharged from the pump G may flow through the pipe 20 to the cooler E or it may be conducted around said cooler by closing a valve 20' connected in the pipe 20 beyond the pipe 98 and flowing it through the pipe 98 leading from the discharge of said pump. The pipe 22 leading from the cooler E connects with the manifold pipe 23 to which the pipe 98 also connects. The pipes 24 and 24' are connected in the pipes 18 and 18' between the chokes and the densifiers and the valves 25 and 25' are moved to the pipes 18 and 18' between the densifiers and the reflux connections. With this form either extraneous or flash cooling may be used, or both if desired.

In the various forms shown and described the liquids and gas are separated in the separators F, L and L' and it is within the scope of the invention to make whatever disposition of the

recovered liquids as is desired. Where flashing is employed it is not necessary that all of the recovered liquids be conducted to the flash tank, although this is the preferable method. The cooling of the well stream flowing from the well, or prior to the introduction of the precooled reflux, or prior to reducing the pressure of the well stream to cool it may be omitted where conditions do not require such cooling. Any cooling step may be omitted where the temperatures can otherwise be obtained. The step of knocking out the free water and water condensates may be omitted.

The various valves, 18, 18', 30, 30', 43, 43', 59 and 70, may all be used for pressure reduction; in fact, any valve which is adjustable by having its cut-off member movable toward and from a seat may be used for reducing pressure, as is well known in this art, ordinary hand valves frequently being used for this purpose. The point at which pressure reduction is carried out in the method covered by this invention is subject to variation as will be evident from an examination of Figure 1, wherein the choke 18 is placed in advance of the liquedenser D, and Figure 3 wherein the choke 70 is placed in advance of the separator L. Where the pressure of the gaseous stream is reduced through a valve and the flow directed into a separator, there will be separation and expansion, and a refrigerating effect will be had in the separator which will cool both the uncondensed gas and the liquids.

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

1. The method of recovering liquefiable hydrocarbon constituents from distillate type of wells which includes, flowing the gaseous stream from the well at a pressure within the range of retrograde condensation, extracting free water from said stream while maintaining the flowing pressure of the stream within said range, controlling the formation of gas hydrates in said flowing stream and changing the course of flow of said stream before hydrate formation stops flow of the stream, cooling the stream to condense liquefiable hydrocarbon constituents therein while maintaining the pressure within said range, and separating uncondensed gas from the liquids at a pressure within the range of retrograde condensation.

2. The method set forth in claim 1 with the step of cooling the flowing stream prior to extracting water therefrom to condense water vapors therein and increase the extraction of water therefrom.

3. The method of recovering liquefiable hydrocarbon constituents from distillate type of wells which includes, flowing the gaseous stream from the well at a pressure within the range of retrograde condensation, extracting free water from said stream, then admixing with said stream a liquefaction liquid, flowing the admixed fluids concurrently to condense and precipitate liquefiable hydrocarbon components in said stream at a pressure within the range of retrograde condensation, controlling the formation of gas hydrates and shifting the flow of the admixed stream prior to complete stoppage of said flow of the formation of gas hydrates while maintaining the pressure of the flowing stream within the range of retrograde condensation, and separating the uncondensed gas from the liquids at a pressure within the range of retrograde condensation.

4. The method set forth in claim 3 wherein the control of the formation of gas hydrates is accomplished by reducing the temperature of the flowing stream to cause such formation.

5. The method set forth in claim 3 with the step of recycling a portion of the recovered liquids as the liquefaction liquid.

6. The method set forth in claim 3 with the steps of recycling a portion of the recovered liquids as the liquefaction liquid and cooling said liquid prior to admixing it with the flowing stream.

7. The method set forth in claim 3 with the step of cooling the stream prior to admixing the liquefaction liquid therewith.

8. The method set forth in claim 3 wherein the formation of gas hydrates is controlled by reducing the pressure only within the pressure range of retrograde condensation.

JAY P. WALKER.
EDWIN V. FORAN.