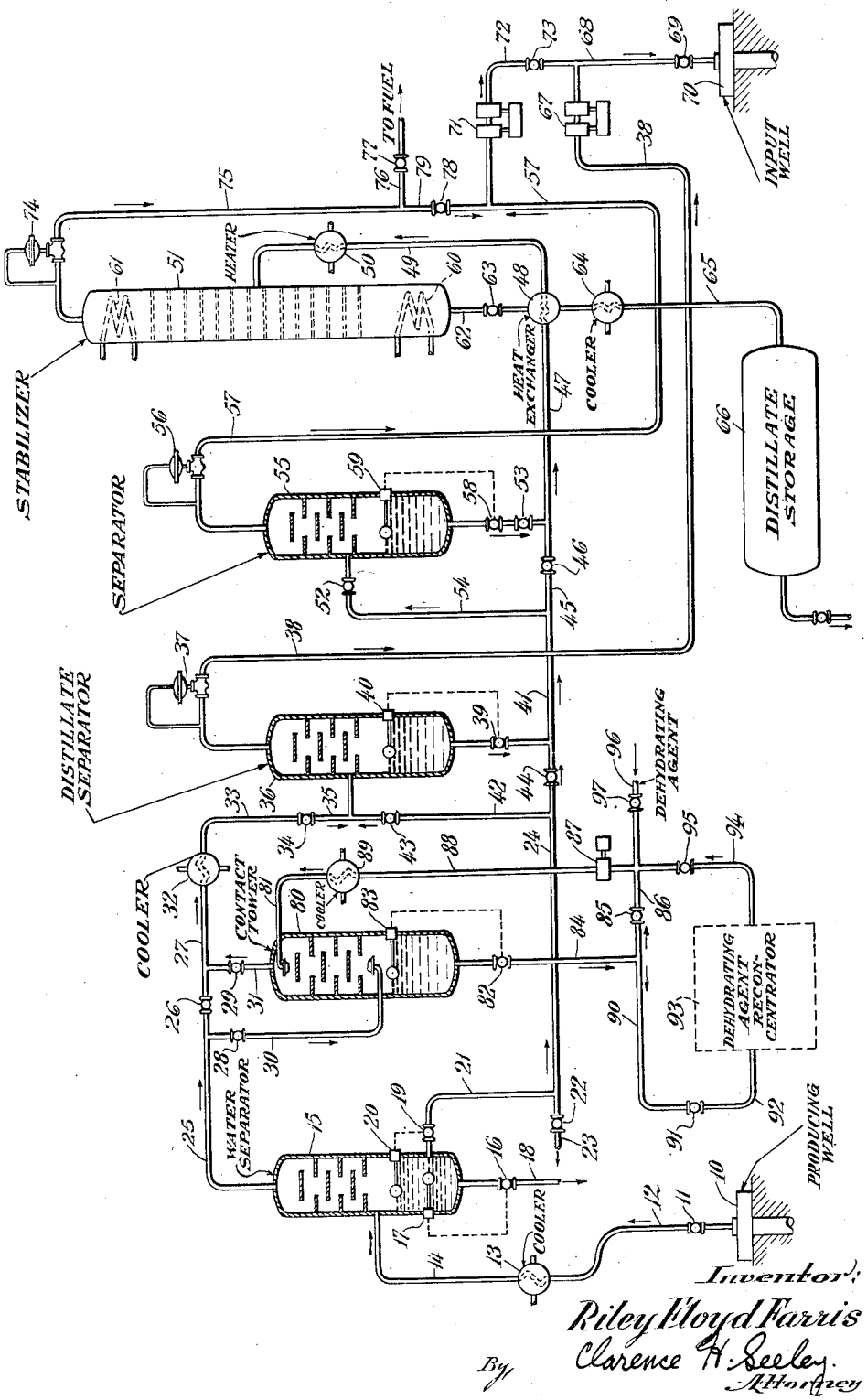
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RECOVERY OF LIQUID HYDROCARBONS FROM MOISTURE-CONTAINING WELL FLUIDS

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RECOVERY OF LIQUID HYDROCARBONS FROM MOISTURE-CONTAINING WELL FLUIDS

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This invention relates to the recovery of liquid hydrocarbons from well fluids and more particularly to improved methods and apparatus for economically recovering such hydrocarbons from the fluids produced by distillate wells which contain small quantities of moisture.

In recent years, however, certain fields have been discovered from which the only products are natural gas and a relatively small amount of a volatile hydrocarbon mixture which is called distillate. Some wells have also been found which produce at a high gas-oil ratio relatively small amounts of heavy hydrocarbons such as those usually associated with the term "crude oil" together with the more volatile distillate.

My invention is concerned primarily with the recovery of distillate from distillate wells but also can be advantageously applied to wells of the latter type. These wells have many characteristics in common, including high pressure and high gas-oil ratio, and for purposes of simplicity both will be referred to herein as distillate wells and the products therefrom as distillates.

The reservoirs from which distillates are produced are invariably at high pressures and temperatures, for example 1500 to 4000 or more pounds per square inch and 125° F. to 250° F. or higher, and it is believed that in many cases the hydrocarbons therein exist in a single phase and that in others a portion of the heavy constituents is in a separate liquid phase which sometimes remains in the reservoir. The usual method of recovering distillate from a well fluid produced from such a reservoir is to reduce its pressure, for example by expansion through a valve, with or without auxiliary cooling, and then separate the precipitated liquid from the residual gas. It is now well understood that this precipitation or condensation upon reduction of pressure is due to the phenomenon known as retrograde condensation and that there is for every fluid composition and separator temperature a certain pressure at which the condensed liquid hydrocarbons contain a maximum yield of the desired relatively heavy distillate.

In carrying out operations of this type for the recovery of distillate hydrocarbons, it has been found in most instances that satisfactory performance of the recovery plant has been seriously impeded by the formation and deposition of natural gas hydrates in various portions thereof due to the natural presence of moisture in the well fluid being processed. Although natural gas hydrates are not completely understood, it may be said that they are solids having the general appearance of snow which form from water and natural gas constituents such as methane and ethane under superatmospheric pressures and at temperatures above the normal freezing point of water and below a temperature which is fairly definite for each pressure and fluid composition and which increases with increase in pressure. This temperature is hereinafter referred to as the "maximum temperature of hydrate formation," and for a typical distillate-containing well fluid composition may be for example, about 55–60° F. at 500 pounds per square inch, 65–70° F. at 1000 pounds per square inch, and 75–80° F. at 2000 pounds per square inch. Since the yield of liquid distillate obtained increases markedly as the temperature is lowered and the separator pressure employed is usually well in excess of 500 pounds per square inch, the problem of preventing hydrate formation is a very real one in distillate recovery systems, particularly those of the retrograde condensation type. It has been proposed to eliminate hydrate formation by injecting an antifreeze liquid such as a concentrated calcium chloride brine solution directly into the well fluid prior to cooling and expansion and then separating the distillate and antifreeze under retrograde condensation conditions from the residual gas, but this expedient is unduly expensive since it entails the absorption of all of the moisture from the well fluid, and consequently the reconcentration of a large volume of antifreeze liquid.

I have found that a large proportion of the water in a distillate-containing well fluid can be removed simply and economically by cooling the fluid to a temperature slightly above the maximum temperature of hydrate formation, and separating the condensed water therefrom prior to treatment of the fluid for the recovery of the liquid distillate hydrocarbons. By the selection of suitable conditions of water separation I am able to dispense entirely with the use of antifreeze or dehydrating agents in most cases, although under some conditions they may be desirable to reduce the water content still further. In the latter instances, however, reconcentration costs are kept extremely low.

It is an object of my invention to provide a novel and economical method of recovering valuable light liquid hydrocarbons from moisture-containing well fluids. Another object is to provide improved methods of removing water from high pressure distillate-containing well fluids. A further object is to provide novel apparatus which is particularly suitable for carrying out my improved methods of distillate recovery. Further objects and advantages of my invention will be apparent from the following detailed description thereof read in conjunction with the drawing, which represents schematically one form of apparatus suitable for distillate recovery according to my invention.

In one of its broadest aspects my invention comprises substantially cooling a moisture-containing well fluid produced at a high well head

pressure by a well of the distillate type to a temperature above the maximum temperature of hydrate formation of the fluid and separating water in the liquid state from the fluid and withdrawing it from the system prior to treatment of the latter for the recovery of valuable light liquid hydrocarbons. Generally speaking, well head pressures of distillate-type wells are in excess of 1500 pounds per square inch and it is preferred to carry out the cooling and water separation steps at pressures of the same order as the well head pressure, some pressure drop, of course, such as that resulting from the friction of the fluid in passing through heat exchanges, piping, etc. being unavoidable. The amount of water separated will depend upon several factors, one of the more important ones being the amount of cooling which is applied to the well fluid. Preferably the temperature of the fluid is reduced to a point just above, e. g. not more than about 25° F. above, the maximum temperature of hydrate formation for the particular fluid involved at the prevailing pressure. The lower portion of this range gives the best results, but in order to provide a factor of safety I prefer to cool the well fluid to a temperature not less than 5° F. above and not more than 15° F. above, the maximum temperature of hydrate formation. In this way most of the moisture in the well fluid as it is produced can be reduced to the liquid state and separated, and the residual moisture is in most cases insufficient to cause hydrate formation even upon further cooling.

The following example will serve to illustrate the degree of moisture removal obtainable according to my invention: The production from a distillate-type well in a Texas field contained approximately 0.95 barrel of water per million cubic feet of gas. The temperature at the bottom of the well was about 208° F. and the corresponding pressure was about 3100 pounds per square inch, while the well head temperature and pressure were about 134° F. and about 2700 pounds per square inch, respectively, when the production rate was 5,000,000 cubic feet per day. The maximum temperature of hydrate formation for this fluid was found to be about 83° F. at 2700 pounds per square inch. Cooling this well fluid to about 90° F. and separating the condensed water at about 2700 pounds per square inch results in the removal of approximately 90% of the moisture content.

The preliminary cooling step also causes the condensation of some liquid hydrocarbons, which separate out in the water seperator together with those present in the fluid in the liquid phase at the well head. These liquid hydrocarbons can be removed from the system together with the water or they can be handled separately in a manner which will be described in detail below.

Under some conditions, for example when extremely low temperatures are to be employed in the distillate separation operation, it may be desirable to dehydrate the fluid from which most of the water has been removed according to my invention. This can be done in any suitable manner including the use of adsorbents or liquid dehydrating agents. Alternatively normally gaseous antifreeze materials such as ammonia can be used. In any of these cases I am able to reduce the cost of such procedures by my preliminary cooling and water separation steps. One particularly advantageous method of carrying out an auxiliary dehydration is to contact the high pressure fluid after separation of water therefrom with a liquid dehydrating agent such as calcium chloride or other brine, glycerine, glycol, etc., and then separate the dehydrating agent containing absorbed water from the fluid prior to further processing for the recovery of distillate.

Further features and details of my invention can best be understood from the following description of a preferred embodiment thereof. Referring now to the drawing, a producing well 10 is shown which is of the distillate type as hereinabove described. The well fluid flowing therefrom at the well head will be at a relatively high pressure and temperature, for example, about 1500 to 4000 or more pounds per square inch and about 75° F. to 225° F., depending primarily upon the bottom hole temperature and pressure, the well fluid composition and the rate of production. This fluid passes through valve 11, which is normally wide open and therefore does not cause any substantial pressure reduction, and line 12 to cooler 13, in which it is substantially cooled to a temperature above the maximum temperature of hydrate formation of the fluid. The requisite cooling can be suitably obtained by indirect heat exchange with cold water or other cool streams which may be available, and preferably the cooling is sufficient to lower the temperature of the well fluid to a point above, but not more than about 25° F. above the maximum temperature of hydrate formation, the range from about 5° F. to 15° F. above the maximum temperature of hydrate formation being most desirable. The cooled fluid flows through line 14 into water separator 15.

The fluid entering separator 15 contains liquid material including not only water, but hydrocarbons as well, and the source of these liquids will be discussed briefly. It is well-known that the fluid pressure at the well head decreases as the rate of production increases, the pressure drop between well bottom and head ranging up to 1000 pounds per square inch or more at high rates of production and the temperature drop often being in the neighborhood of 50° F. to 150° F. In most cases such pressure and temperature drops will cause the condensation of some water and hydrocarbons as the well fluid flows upward through the tubing. Often hydrocarbon and/or aqueous material enters the base of the well in the liquid phase and this material is also contained in the well fluid as produced. Finally the temperature reduction in cooler 13 causes the further condensation of liquid hydrocarbons as well as water, so that considerable quantities of water and hydrocarbons in the liquid state are present in the fluid supplied to water separator 15.

Water separator 15 is therefore arranged so that the liquid water and hydrocarbons removed from the well fluid therein will settle to the bottom and stratify to form a lower aqueous layer and an upper hydrocarbon layer. The lower layer is withdrawn from the system through valve 16, which is controlled by liquid level control 17, and line 18, control 17 being equipped with a float having a density between that of water and that of the hydrocarbons in the upper layer. The hydrocarbon layer is withdrawn from separator 15 by means of valve 19 controlled by liquid level control 20 and line 21, and this material can also be removed from the system as a valuable product through valve 22 and line 23. However, the hydrocarbon fraction in line 21 is very "wild," i. e., it contains excessive amounts

of normally gaseous hydrocarbons such as methane and ethane, so that it is preferred to close valve 22 and pass it through line 24 for a further treatment within the system which will be described below.

The well fluid remaining in the vapor phase, which contains most of the desired liquid hydrocarbons but is now relatively free from water, is withdrawn from the upper portion of separator 15 through line 25 and flows through valve 26 and line 27 to the distillate recovery operation. In the form of my invention now being described valves 28 and 29 in branching lines 30 and 31 are closed and valve 26 is fully open so that the fluid in line 27 is still at a high pressure of the order of the well head pressure.

As stated above the desired distillate can be condensed by expanding the well fluid after the removal of water according to my invention. The expansion necessarily cools the fluid also due to the Joule-Thomson effect, and in some cases no auxiliary cooling will be required to obtain the desired temperature and pressure for the separation of distillate, but in others further cooling will be necessary and this is preferably done prior to expansion. The expansion step can be carried out using an expansion valve or orifice, or an expansion engine can be employed so that the well fluid does useful mechanical work, and the latter procedure is very advantageous since this type of expansion results in greatly increased cooling. For purposes of simplicity, however, ordinary cooling and expansion apparatus will be described, the fluid in line 27 being first cooled in cooler 32 and passed through line 33, expansion valve 34 and line 35 to distillate separator 36. Due to the removal of most of the water from the well fluid according to my invention, the formation of natural gas hydrates during these steps is substantially eliminated. The cool expanded fluid enters separator 36 at the pressure and temperature at which it is desired to separate distillate therefrom. Under most circumstances these will be in the range from about 500 to about 1500 pounds per square inch and from about −100° F. to about +50° F., but other conditions can be used.

Separator 36 is of type such that equilibrium between liquid and vapor phases is substantially reached, the pressure therein being controlled by valve 37 in residual gas line 38. The liquid hydrocarbon condensate settles to the bottom of separator 36 and is withdrawn by means of valve 39 controlled by liquid level control 40 and line 41 to the stabilization portion of the system. The hydrocarbon fraction in line 24 can be introduced into line 35 by means of line 42 and valve 43, or it can be passed directly into line 41 through valve 44. The former procedure is more advantageous since a slightly greater ultimate yield of stabilized distillate is obtained thereby.

The distillate fraction in line 41 can be passed through line 45, valve 46, line 47, heat exchanger 48, line 49 and heater 50 to stabilizer 51 or some of the gases having an excessively high vapor pressure can be removed by flashing at a lower pressure prior to introduction into stabilizer 51. The latter procedure is usually preferable and can be accomplished by closing valve 46 and opening valves 52 and 53 whereupon the distillate in line 41 passes through line 54 and valve 52 into separator 55 which is maintained under a pressure controlled by back pressure control valve 56 in line 57 at some value less than that existing in separator 36, for instance 250 to 450 pounds per square inch. The remaining liquid is withdrawn from separator 55 through valve 58 which is controlled by liquid level control 59 and through valve 53 to line 47, whence it passes through heat exchanger 48 wherein its temperature is raised by indirect heat exchange with hot stabilized distillate from stabilizer 51. Supplemental heat is added if necessary by means of heater 50.

Stabilizer 51 can be of conventional design and is preferably operated at about 200 to 400 pounds per square inch, for instance 350 pounds per square inch. Heat is applied to the bottom of the stabilizer by means of heating coil 60 and reflux is provided for example by means of dephlegmating coil 61. The stabilized distillate passes from the tower bottom through line 62, valve 63, heat exchanger 48, cooler 64 and line 65 to distillate storage tank 66. While I have shown stabilizer 51 as my preferred means of producing distillate of a quality meeting specifications, the same product can be obtained although with lower yields by further stages of expansion and separation in a manner well known in the art, and this procedure is also contemplated as an alternative method.

The residual gas from distillate separator 36 in line 38 is preferably compressed by means of compressor 67 to a pressure which allows its reinjection into the same or another producing formation through line 68, valve 69 and input well 70. Recycling in this manner greatly increases the total yield of liquid hydrocarbons recoverable from a producing formation and its advantages are now universally recognized. Generally speaking, it will be desirable to recompress and reinject the gas from separator 55 and this can be done by means of compressor 71 which raises the pressure of gas from line 57 and delivers it to line 68 through line 72 and valve 73. The overhead from stabilizer 51 is withdrawn through pressure control valve 74 and line 75 and can be withdrawn for fuel or any other suitable purpose through line 76 and valve 77. Alternatively the gas in line 75 can be reinjected by closing valve 77 and opening valve 78 in line 79 or the gas in line 57 can be withdrawn from the system through lines 79 and 76 by closing valve 73 while keeping valves 77 and 78 open.

It is apparent from the above that I have described a simple and efficient system for recovering distillate from moisture-containing well fluids according to my invention which substantially eliminates the problem of hydrate formation under most conditions. As explained above, however, it may be desirable under certain circumstances to carry out a separate dehydration operation on the well fluid after the removal of most of the water therefrom, and the drawing includes apparatus for accomplishing this in a preferred manner.

In this modification valve 26 is closed and valves 28 and 29 opened, so that the fluid in line 25 removed from the upper portion of water separator 15 flows through line 30 into the lower portion of contact tower 80, which can suitably be of the bubble plate type. A liquid dehydrating agent, such as concentrated calcium chloride brine, glycerine, glycol, etc., or mixtures thereof, is supplied to the upper portion of tower 80 by means of line 81 and flows down the tower countercurrent to the ascending fluid, thus removing a substantial part of the

remaining moisture therefrom. By suitable regulation of the dehydrating agent concentration, ratio of dehydrating agent to well fluid, etc., any desired amount of moisture removal can be achieved. Dehydrating agent collects in the bottom of tower 80 and is withdrawn through valve 82, which is controlled by liquid level control 83, and line 84, from which all or a portion of it can be returned to line 81 by means of valve 85, line 86, pump 87, line 88 and cooler 89. Cooler 89 may not be necessary in some cases but is advantageous when the dehydrating agent would otherwise be at a temperature above that of the well fluid in tower 80, for instance when reconcentrated dehydrating agent is used. All or a part of the dehydrating agent in line 84 can also be directed by means of line 90, valve 91 and line 92 into reconcentrator 93, which can be of conventional design and is therefore not shown in detail. The reconcentrated dehydrating agent passes through line 94 and valve 95 to pump 87 for recirculation. Fresh dehydrating agent to fill the system and for make-up is supplied through line 96 and valve 97.

Many details which have been omitted in the above description have not been given in order to simplify the description, but such details, for instance the construction and operation of the apparatus according to my invention for any particular well fluid or fluids, the use of available plant streams for cooling or heating by indirect heat exchange, etc., can be easily supplied by those skilled in the art. I contemplate also as a part of my invention all modifications within the spirit thereof, such as the use of high pressure absorption or other methods for the recovery of distillate from the relatively dry well fluid, the substitution of two separators for the water separator 15, or of a mixer-separator system for contact tower 80. By high pressure absorption I mean the contacting of the well fluid at a relatively high pressure, for example 1000 pounds per square inch or more and preferably in excess of 1500 pounds per square inch, with a liquid absorption medium less volatile than the distillate to be recovered, and separation of the enriched absorption medium from the residual gas. In many cases the absorption step can be carried out without first reducing the pressure on the relatively dry well fluid, but further cooling is almost always advantageous.

It is obvious that the fluid from a plurality of distillate wells can be combined and the distillate recovered therefrom accordingto my invention in the same manner as hereinabove described for the fluid from a single well, and that a plurality of input wells can likewise be used.

While I have described my invention in connection with certain embodiments thereof, it is to be understood that these are by way of illustration and not by way of limitation, and that I do not means to be bound thereby but only by the appended claims in which I have defined my invention.

I claim:

1. Apparatus for recovering liquid hydrocarbons from a moisture-containing fluid produced by a well of the distillate type at a high well head pressure comprising means for cooling said fluid at high pressure, a high pressure separator, means for introducing said cooled fluid into said separator, means for removing condensed water from said separator and withdrawing the same from the system, independent means for removing liquid hydrocarbons and vapor phase material from said separator, means for reducing the pressure of said vapor phase material, a second separator, means for introducing said material after pressure reduction and said liquid hydrocarbons into said second separator and means for removing a liquid hydrocarbon fraction and a residual gas from said second separator.

2. The method of recovering liquid hydrocarbons from a fluid produced by a well of the distillate type at a high well head pressure and containing substantial amounts of water which comprises substantially cooling said fluid to a temperature above the maximum temperature of hydrate formation of said fluid, whereby a major portion of the water in said fluid is condensed, introducing said cooled fluid into a separating zone, removing a stream consisting essentially of liquid water from said separating zone and from the system, separately removing a gas stream consisting essentially of hydrocarbons from said separating zone, contacting said separated gas stream at a pressure in excess of 1000 pounds per square inch with a liquid absorption medium less volatile than the liquid hydrocarbons to be recovered, and separating the enriched absorption medium from the residual gas.

3. The method of claim 2 wherein said fluid is cooled to a temperature not more than 25° F. above the maximum temperature of hydrate formation of said fluid.

4. The method of recovering liquid hydrocarbons from a fluid produced by a well of the distillate type at a high well head pressure and containing substantial amounts of water which comprises substantially cooling said fluid to a temperature above the maximum temperature of hydrate formation of said fluid, whereby a major portion of the water in said fluid is condensed, introducing said cooled fluid into a separating zone, removing a stream consisting essentially of liquid water from said separating zone and from the system, separately removing a gas stream consisting essentially of hydrocarbons from said separating zone, contacting said separated gas stream with a liquid dehydrating agent to remove further quantities of water therefrom, separating said dehydrating agent from the further dehydrated gas stream, and recovering liquid hydrocarbons from said further dehydrated gas stream.

5. The method of claim 4 wherein said liquid dehydrating agent comprises a concentrated aqueous calcium chloride solution.

6. The method of claim 4 wherein the step of recovering liquid hydrocarbons includes contacting said further dehydrated gas stream at a pressure in excess of 1000 pounds per square inch with a liquid absorption medium less volatile than the liquid hydrocarbons to be recovered, and separating the enriched absorption medium from the residual gas.

7. The method of claim 4 wherein the step of recovering liquid hydrocarbons includes expanding said further dehydrated gas stream whereby liquid hydrocarbons are condensed therefrom by virtue of the retrograde condensation effect, and separating said liquid hydrocarbons from the residual gas.

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