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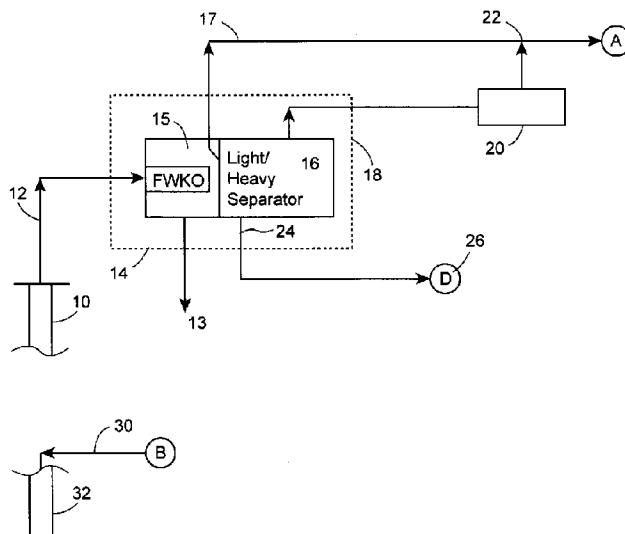
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(54) Titre : RECUPERATION DE SOLVANT DE FLUIDES DE PRODUCTION MELANGES ET SYSTEME EXECUTANT
LADITE RECUPERATION

(54) Title: RECOVERY OF SOLVENTS FROM MIXED PRODUCTION FLUIDS AND SYSTEM FOR DOING SAME



(57) **Abrégé/Abstract:**

A water separation system, including a bulk fluids separation vessel and a slop oil tank, for separating solvent from water produced from a solvent based in situ hydrocarbon extraction process. The bulk fluids separation vessel is configured to separate produced fluids into mixed water and light/heavy hydrocarbons. A first piping connection directs the light/heavy hydrocarbons to a downstream light/heavy separation stage. A second piping connection directs the mixed water downstream to a further water separation stage, which includes a skim tank. The skim tank permits the mixed water to separate into a lower density hydrocarbon rich stream and a higher density water stream. A third piping connection permits the slop oil tank to receive the lower density hydrocarbon rich stream. A fourth piping connection permits the slop oil tank to return at least a portion of the lower density hydrocarbon rich stream back to the bulk fluids separation vessel.

ABSTRACT OF THE DISCLOSURE

A water separation system, including a bulk fluids separation vessel and a slop oil tank, for separating solvent from water produced from a solvent based in situ hydrocarbon extraction process. The bulk fluids separation vessel is
5 configured to separate produced fluids into mixed water and light/heavy hydrocarbons. A first piping connection directs the light/heavy hydrocarbons to a downstream light/heavy separation stage. A second piping connection directs the mixed water downstream to a further water separation stage, which includes a skim tank. The skim tank permits the mixed water to separate into
10 a lower density hydrocarbon rich stream and a higher density water stream. A third piping connection permits the slop oil tank to receive the lower density hydrocarbon rich stream. A fourth piping connection permits the slop oil tank to return at least a portion of the lower density hydrocarbon rich stream back to the bulk fluids separation vessel.

**Title: RECOVERY OF SOLVENTS FROM MIXED PRODUCTION FLUIDS
AND SYSTEM FOR DOING SAME**

FIELD OF THE INVENTION

5 This invention relates to a hydrocarbon separation process and a system to perform such a process. In particular, this invention relates to a separation process in which one or more light hydrocarbon species, such as solvents, which may be present in mixed recovered production fluids from an in situ heavy oil or bitumen extraction process, can be separated from the other
10 recovered fluids such as water, other light hydrocarbons and heavy hydrocarbons, such as sales oil.

BACKGROUND OF THE INVENTION

 Environmentally acceptable extraction of hydrocarbons from the oil
15 sands remains a challenge. In situ techniques, such as SAGD, are being used but they come with a heavy carbon emission cost. As a result, other technologies for in situ extraction are being explored. One area that shows promise is the use of hydrocarbon based solvents in an in situ extraction process. Solvents offer the potential to reduce the extraction temperature as
20 compared to SAGD. Such reduced temperatures reduce the energy required to extract the hydrocarbons in place, resulting in much reduced carbon emissions for the recovery of an equivalent amount of resource through a solvent process as compared to, for example, SAGD.

 An example of such an in situ solvent based process is the **nsolve®**
25 gravity drainage process which uses condensing solvent within an underground extraction chamber to warm and dissolve the bitumen in place rather than using the high temperature and high pressure steam of SAGD to mobilize the bitumen. The more modest temperatures and pressures can result in significant potential energy savings as compared to conventional

SAGD with commensurate potential carbon emission reductions. Other solvent based technologies have also been proposed including combining solvent with steam and using solvent in conjunction with other sources of energy, such as RF energy. In all of these cases solvent is being injected into the oil bearing formation to help mobilize the bitumen so the bitumen can drain and be recovered with the produced fluids.

The hydrocarbon based solvents referred to here are generally lighter hydrocarbon species such as propane, butane and the like. Methane injection has also been proposed in certain processes, such as VAPEX, where it theoretically acts as a carrier gas or a displacement gas, but this process of injecting a mixed gas has not worked in practice. Rather than helping, methane may become a problem in the reservoir because it interferes with the mass and heat transfer of the solvent onto the bitumen at the extraction interface. However, some methane is usually naturally present in an underground gravity drainage extraction chamber dissolved in the in situ bitumen or hydrocarbons. Warming such hydrocarbons may result in methane as an off gas product from the hydrocarbons and so methane is likely to be produced as part of the mixed fluid production from a typical extraction. Any produced methane will need to be separated out from the solvent to maintain solvent purity before the solvent may be re-injected into the ground.

An in situ extraction process typically requires that the bitumen mobilizing material, whether it is solvent, steam, or even heat, be injected into or applied to the formation, generally into the oil bearing strata in an effort to make the bitumen mobile enough to drain through the formation. The oil rich zone or pay zone may be comprised of porous sand, rock or the like and may have heterogeneities such as clay lenses or the like. If the viscosity of the bitumen can be reduced enough the bitumen may be able to drain by gravity through the sand pack or porous parts of the formation. Then, the next step is to recover the draining liquids from the oil rich zone, for example through

production tubing located within or below an extraction zone. Gases may also be recovered either dissolved in the draining fluids or as a separate phase. One typical form of recovery is through the use of horizontal wells, in which an upper well is an injection well and a lower well is the production well. Water, naturally present or injected as steam, may also be recovered as part of the draining liquids. Artificial lift may be used to raise the production fluids to the surface.

The working fluid, such as solvent in the case of the **nsolv®**, process, may be injected in the upper injection well, interact with the bitumen so that the bitumen and such fluids drain down to the lower production well through an extraction chamber. While horizontal well pairs are common in these types of extractions there are many other forms of well configurations that can be used including one or more vertical wells alone or in combination with the one or more horizontal wells. The common element of all of these extractions is that a fluid mixture is recovered from the formation which includes some combination of off gases such as methane and carbon dioxide, some proportion of injected solvent gases such as methane, ethane, propane, butane or the like, and some combination of water and heavy hydrocarbons the latter of which may be separated from the other fluids to become sales oil. One or more of these fluids may be liquids or gases depending upon the temperature and pressure at any given point in the process.

What is desired therefore is that when these mixed fluids (liquids and gases) reach the surface there is an ability to separate and in some cases purify these fluids into one or more species of these fluids. Typically the separation and purification of hydrocarbons is done with a distillation column and controlled cooling of the overhead gases to condense and concentrate the same. U.S. Patent 2,775,103 teaches such a hydrocarbon separation which includes a demethanizer column and an accumulator for removing gases such as ethane from other gaseous species such as methane and hydrogen. It also

relates to the recovery of propane where the same is used as a solvent for ethylene or ethane in the actual hydrocarbon separation process. In addition to the demethanizer there is provided an accumulator followed by a knock out drum.

5 However to make the system work this patent teaches that a great deal of refrigeration must be used. The feed temperature into the demethanizer column is minus 56 F (-49 degrees C). The overhead product is mixed with a propylene stream at minus 28 F (-33 degrees C) and the resulting mixture is cooled to minus 56 F (-49 degrees C). Then the mixture is passed through a
10 first heat exchanger and cooled to minus 82 F (-65 degrees C) and then through a second heat exchanger and cooled to minus 112 F (-80 degrees C) in a knock out drum. The patent teaches that a temperature as low as possible is preferred, to achieve a high quality separation.

 While this may separate out the ethane species as desired, it is very
15 energy intensive. For separating ethane out from small volumes this may not impose too significant an operating cost but for in situ solvent extractions of heavy oil or bitumen such as the **nsolv**® technology that involve large volumes of hydrocarbon solvent which is injected into the formation to condense, drain and then be recovered, purified and then re-injected the energy costs for
20 refrigeration could be overwhelming. This is because large volumes of solvent may be needed to mobilize the bitumen and will be co-produced with the bitumen. The solvent may need to be recovered in large volumes and then re-used to extract more bitumen. As such, a very refrigeration intensive separation process that uses up a great deal of energy and contributes to the
25 carbon footprint or cost of the process is not desirable.

 Canadian Patent application 2,777,966 describes a solvent injection plant for enhanced oil recovery that uses a distillation column to recover and purify the bulk of the solvent from produced bitumen. The invention also comprehends the use of a free water knock out vessel to separate water and

solids from the bitumen and at least one flash vessel stage for removing solvent as a vapour from the bitumen. In this configuration, additional flash vessel stages are required to minimize solvent loss to the bitumen stream and some solvent may be entrained in the water stream. For separating and
5 purifying large volumes of solvent, it is desirable to reduce solvent energy requirements and capital costs.

SUMMARY OF THE INVENTION

A process and system is desired which may be suitable for high volume
10 solvent recovery, purification, reuse and recycling for the in situ hydrocarbon extraction process such as the **nsolv®** condensing solvent extraction process. What is further desired is an energy efficient process to separate the various hydrocarbon solvent species out of a mixed production fluid in a surface facility so the solvent may be re-used and recycled back into the formation. Most
15 preferably such a separation will minimize solvent losses from the system and also allow the solvent to be purified so as to prevent solvent impurities from being injected into the formation and potentially interfering with any in situ mass transfer or heat transfer process within the formation. Such a separation process may preferably be tolerant to changes in feed composition over an
20 extraction period, may be able to handle large throughput volumes and may be more energy efficient.

The present invention is directed to various embodiments which may be able to efficiently separate the various hydrocarbon species to permit the desired solvent to be recirculated and the other components of the mixed fluid
25 production from the in situ process to be either sold or used for some other purpose such as for plant or other fuel. The present invention is also directed to various embodiments of exemplary systems or apparatuses to accomplish this. The present invention may provide for substantial recovery of the solvent or working fluid from the mixed fluids production extracted from the reservoir

to limit working fluids losses to sales oil or to the fuel gas stream, which losses would otherwise have to be made up with make-up solvent or working fluid. The present invention may further comprehend limiting a loss of working fluid or solvent in any waste water stream, for example, a separated produced
5 formation water stream. The present invention may be incorporated into a modular design which can be used in a variety of contexts and associated with a variety of processes where a feed stream originates within the formation and contains a mixture of hydrocarbons, including potentially large volumes of the injected solvent working fluid. The present invention may provide an efficient
10 method for separating various species which minimizes the energy required to do the separations and therefore to recover the working fluid in a cost effective manner. The present invention provides a separation process that may operate at much higher separation temperatures than the prior art while still achieving good separation results and thus may reduce the energy cooling
15 costs of the overall system. In part the present invention may provide that the cooling only be required at the end stage and even then that the coolest or lowest separation temperature may be in the range of -25 to 10 C for a working fluid consisting of propane for example. The present invention further provides that such cooling may only be applied to a small fraction of the recovered
20 fluids, as the majority of the separation and recovery of solvent can occur at even higher temperatures.

In a further aspect the present invention may provide an energy efficient method of recovering solvent that has been entrained in the separated bitumen stream or sales oil. This may have an added benefit that the vapour pressure
25 of the sales oil is reduced to facilitate safe and practical storage. The present invention may also provide in a preferred embodiment that the energy required for heating the streams for separation be recovered from other waste heat available from other process streams within the system, to lower total energy consumption.

According to one embodiment, the present invention provides a hydrocarbon separation system for separating produced fluids obtained from an in situ hydrocarbon extraction process, said separation system comprising:

5 a separation chamber having a liquid inlet, a vapour inlet, a bottom portion, and a top portion, said separation chamber being configured to separate inputs into bottom liquids and top vapours, said separation chamber having a bottom liquid outlet and a top vapour outlet,

a reboiler circuit to heat said bottom liquids to separate said liquids into purified solvent and a reboiler vapour fraction, wherein said purified solvent
10 may be reused in said in situ extraction and said reboiler vapours are recirculated back to said separation chamber; and

a multi-stage reflux circuit to receive said top vapours from said separation chamber, said multi-stage reflux circuit comprising at least:

(i) a first stage to receive and cool said top vapours to a first temperature
15 to condense a portion of said top vapours into a first reflux liquid, wherein said first reflux liquid is again passed through said separation chamber; and

(ii) a second stage to receive and cool said remaining top vapours from said first stage to condense at least a portion of said remaining top vapours into a recycle liquid at a second temperature, said second temperature being
20 lower than said first temperature, return said recycle liquid to said separation chamber and exhaust any non-condensing vapour as fuel;

and wherein the lowest temperature cooling is applied to the remaining top vapours from said first stage reflux drum.

In a further embodiment of the invention, the separation chamber may
25 be a distillation column or the like, where to enhance separation mass transfer the column may contain trays and/or packing to enhance vapour-liquid contact and may also rely on counter-current flow of the vapour and liquid streams to enhance mass transfer driving force.

The present invention also comprehends a hydrocarbon separation

system for solvent recovery from separated hydrocarbons produced by means of a solvent based in situ hydrocarbon extraction process, said separation system comprising:

5 a separation chamber having a liquid inlet, a bottom portion, and a top portion, said separation chamber being configured to separate inputs into bottom liquids and top vapours, said separation chamber having at least one bottom liquid outlet and a top vapour outlet,

a reboiler circuit to heat a portion of said bottom liquids to reboiler vapours, wherein said reboiler vapours are recirculated back to heat said
10 separation chamber,

a reflux circuit to receive and condense said top vapours from said separation chamber into recovered solvent, and non-condensable gas, wherein a portion of said recovered solvent is returned to said separation chamber, while the remaining recovered solvent is directed to said in situ
15 extraction, and said non-condensable gas may be used for fuel,

a vapourizer for heating the recovered solvent to gas phase for injection; and

an oil cooler for final adjustment of the temperature of said purified oil for safe storage. Such a system may optionally include a first cross heat
20 exchanger, wherein the liquid flowing into said separation chamber is preheated while cooling the remaining bottoms liquid of said separation chamber to a first temperature, and /or

a second cross heat exchanger, wherein said bottoms liquid at said first temperature are cooled to a second temperature, which is lower than the first
25 temperature, producing purified sales oil, while preheating the recovered solvent from said reflux circuit,

The present invention may also comprehend a water separation system for further separating solvent from the water produced from a solvent based in situ hydrocarbon extraction process, said water separation system comprising:

a bulk fluids separation vessel having a separation zone, and being configured to separate mixed input fluids into mixed water and light/heavy hydrocarbons;

5 a piping connection to permit said light/heavy hydrocarbons to be sent to a downstream light/heavy separation;

a piping connection to permit the mixed water to be sent downstream to a further water separation stage, the further water separation stage including a skim tank that receives said mixed water from said vessel, said skim tank being sized and shaped to permit said mixed water to separate into a lower
10 density hydrocarbon rich stream and a higher density water stream;

a slop oil tank; and

a piping connection to permit a slop oil tank to receive said lower density hydrocarbon rich stream and a further piping connection from the slop oil tank to return at least a portion of said lower density hydrocarbon rich stream back
15 to said bulk fluids separation chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made, by way of example only, to preferred embodiments of the invention by reference to the following drawings in which:

20 Figure 1 is a schematic drawing of a first stage of a preferred solvent/bitumen separation sequence for separating a mixed fluid production into a bulk solvent stream, a product oil stream and a produced water stream according to a preferred embodiment of the present invention,

Figure 2 is a schematic view of a solvent recovery and purification
25 sequence for the bulk solvent stream, produced from the sequence of Figure 1, according to a preferred embodiment of the present invention,

Figure 3 is a schematic view of a solvent recovery process for the product oil stream, produced from the sequence of Figure 1, according to a preferred embodiment of the present invention; and

Figure 4 is a schematic view of a solvent recovery system for the produced water stream produced from the sequence of Figure 1, according to a preferred embodiment of the present invention,

5 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

Figure 1 shows a process flow schematic for processing a mixed fluid stream recovered from an underground formation and for separating the mixed fluid production into a bulk solvent stream, a product oil stream and a produced water stream. Thus Figure 1 provides context for the further separations shown in Figures 2, 3 and 4, which show preferred embodiments of the separation of working fluid or solvent from the three primary separation streams produced by the primary separation process of Figure 1. The bulk solvent stream may include lighter hydrocarbon species may be further separated into a purified working fluid, such as a solvent, and the other species which may include various non-condensables species. Such further non-condensable species may be used as fuel, for example, according to the present invention. One of the aspects of the present invention may be to recover a higher percentage of the working fluid at a lower energy cost from these product streams as described in more detail below.

20 Figure 1, which depicts a flow sheet which may be suitable, for example, for an **nsolv**® facility, shows a production well 10, which produces a mixed fluid stream 12. The primary constituents of the mixed fluids stream 12 are bitumen, formation water and solvent, but many other materials may also be present including light hydrocarbon species other than an identified working solvent species, solids and the like. The precise nature of the mixed fluid will vary, both as to the reservoir and over time depending upon what stage the extraction is at and how large the in situ extraction chamber has grown. The preferred solvent used for recovery may be selected according to the reservoir characteristics, such as native pressure, temperatures, depth, porosity and the

like, but for a preferred condensing solvent process such as the **nsolv®** technology the solvent may be propane, butane, pentane, ethane, COS, H₂S or the like. It will be understood that all of these solvents, and any others such as will be known to those skilled in the art and which may be useful in an in situ solvent extraction process for the extraction of hydrocarbons, are 5 comprehended by the present invention. The species selected for having the correct condensing characteristics for the reservoir (see Canadian Patent 2,591,354) may be called the working fluid. The term fluid as used herein comprehends both a gas or a liquid or both.

10 The primary production stream of mixed fluids 12 may be submitted to a primary separation stage identified by dashed box 14 which includes a primary water separation step, such as a free water knock out vessel or the like, to remove water and solid particulate shown at 13 from a light/heavy blend shown at 15, as will be understood by those skilled in the art.

15 The light/heavy blend 15 is forwarded to a light/heavy separator system 16, which in general has at least two output lines. By the term light/heavy, the hydrocarbons to be recovered are considered to be the heavy portion, while the solvent and any non-condensable species are considered to be the light portion. The light/heavy separator 16 may heat the mixed fluid light/heavy 20 blend 15 such that most of the working fluid and non-condensable species are vapourized to separate them from the remaining heavy oil or bitumen components (which collectively may be referred to as "sales oil").

25 The separator 16 has some output lines as shown. The first line 24 from the separator 16 is a sales oil line 26 through which the separated heavy fluids (which may also be called bitumen, product oil, or sales oil) may be sent for storage or for sales all through line 26, or for additional solvent recovery. It will be understood that in a preferred embodiment as described below, the heavy hydrocarbon fraction may be sent for further working fluid or solvent recovery. The mixed light fluids that are separated may comprise a high

pressure stream shown at 17, and a low pressure stream shown at 18. A compressor 20 may be provided to compress the low pressure stream 18 before it is added to the high pressure stream at 22 which together form a bulk solvent stream. The bulk solvent stream is then sent for further processing as shown at A. It is referred to as a bulk solvent stream since it is comprised mainly of solvent, but also includes noncondensables such as methane, carbon dioxide and the like. Additional output lines of intermediate pressure mixed solvent streams may also be generated depending on the number of separation stages employed and are thus comprehended by the present invention.

The light/heavy separator system 16 may also include a number of pumping, heat exchanger, and vessel stages as will be understood by those skilled in the art.

The liquid phase of the production stream 15 may be further pressurized with a booster pump and/or heated with a heat exchanger (not shown) to recover a portion of the working fluid or solvent as vapour at a pressure that is sufficiently high to feed subsequent purification stages without recompression.

Furthermore, a temperature and pressure of the first stage light/heavy separator may be selected, taking advantage of relative volatilities of dissolved impurities and the working fluid, so as to concentrate the impurities in the vapour output of the first stage, i.e. 17, thereby avoiding the purification requirement of working fluid liberated from heavy hydrocarbons in the downstream light/heavy separation stages, i.e. 18. Therefore, in one embodiment of the present invention, if the low pressure mixed solvent stream 18 is sufficiently low in impurities concentration, it may be combined directly with the downstream purified working fluid, 30.

Also shown on Figure 1 is a return line 30 which is returning purified solvent to the injection well 32.

Figure 2 shows an energy efficient solvent recovery system

according to the present invention. The system 110 includes a primary separation chamber 112, which may be for example, a deethanizer, and a source feed 114 for receiving the high pressure mixed light fluids line 22. As noted above a source for such a stream may be a primary separation stage
5 for an in situ extraction process using a condensing solvent as the working fluid, but the present invention comprehends that the energy efficient process may also be useful in other large volume through-put separation situations. The mixed lighter fluids or recovered fluids in the source feed 114 may contain a mixture of solvent and non-condensable (at reservoir extraction conditions)
10 species. Most preferably, any heavy hydrocarbons, such as sales oil, water and any other heavy species have already been removed. Prior to being fed into the chamber 112 there is shown a preliminary deethanizer feed drum 132 for separating the source feed 114 into liquids at 113 and gases at 115 as explained in more detail below.

15 It will be understood by those skilled in the art that each geological formation or reservoir will have its own unique characteristics such as temperature, pressure, porosity, water content and the like and so the preferred operating conditions for any given extraction can vary. Further, there are a number of different processes which can be used, one of which is the
20 **nsolv**® extraction process. Various working fluids can be used and the choice of working fluid will depend on the in situ conditions and the process. Two preferred working fluids for **nsolv**® are propane and butane, but other fluids may also be chosen depending upon the conditions. The term working fluid in this disclosure is intended to comprehend any fluid which can be used in an in
25 situ extraction process and which may be recovered in a mixed fluid production from the reservoir, and then needs to be separated from the other non-working fluids so it may be recovered, for example, for reuse. Thus, according to the present invention, there will be mixed production fluids recovered to surface which have the desired hydrocarbons as well as many other compounds and

the present invention is designed to separate and purify the same as may be desired for being able to utilize the recovered working fluids again. For example in an in situ solvent stimulation it is important to separate out the solvent and to obtain the desired purity specifications so that in some cases
5 the solvent can be reused in the formation to encourage more hydrocarbon recovery. Further, a more complete separation is desired to reduce solvent loss or waste in sales oil, in produced water or in the fuel gas stream – in other words a more complete separation leads to higher recovery and re-use of the working fluid with less waste and may be preferred.

10 In Figure 2 various terms are used by way of example only. For example, where the re-circulating solvent or working fluid is propane the system that is being operated may be a deethanizer. The column recovers a liquid propane solvent stream at the bottoms 120 – the lighter components (ethane, methane & lighter) are being removed off of the top 142 as a fuel gas
15 stream and this is defined as a deethanizer. If the column was designed to make a purified butane solvent product instead, components lighter than butane would be boiled off and the system would normally be referred to as a depropanizer. It will be understood that the present invention applies to many forms of solvent and the precise term for each part of the apparatus may vary
20 depending upon the nature of the species being separated that step. Therefore, the terms demethanizer, deethanizer and depropanizer are used herein by way of example only as the present invention comprehends the separation of various species depending upon the choice of the working fluid. More specifically, where the working fluid is propane or butane, a
25 demethanizer may be used.

In Figure 2, assuming the working fluid or solvent is propane, the deethanizer 112 includes a top tray 116 and a bottom tray 118. Bottom liquids are taken off below the bottom weir at 120 and the bottom liquids are sent to a reboiler 122. The reboiler 122 includes a weir 124 and the light fractions or

reboiler vapours are removed at 126 and recycled to the deethanizer 112 through inlet 128 and the reboiler liquids are removed at 130.

According to one embodiment of the invention, the reboiler liquids are a purified working fluid that may be vapourized and reused in the in situ
5 recovery process and may be, for example, nearly pure propane. The present invention comprehends other reboiler configurations can be used to provide heat input into the column but the one shown may provide reasonable results.

Coming off the top of the deethanizer is a line 142 which takes the top vapours to a deethanizer condenser 144. This condenser 144 may, for
10 example, be an air cooled condenser. Then the condensed material, which is referred to as a first reflux liquid, is fed into a reflux drum 146, through line 145. The liquids are drained through line 148 to a pump 150 and then back into the deethanizer at 152. The remaining vapours (or top gases) are taken off at 154 through line 156. At this point, 157, monoethylene glycol (MEG) may be added
15 as a desiccant to remove any residual water and prevent the formation of hydrates as the gases from the first reflux drum are cooled. The next step is to pass the first reflux fluids through a cross heat exchanger at 158, whereby the fluid stream is cooled through heat exchange contact with the recycle line 160 and the recycle line 160 is warmed by the first reflux fluids coming off the
20 reflux drum through line 156. MEG may be added as a desiccant to remove residual water and prevent the formation of hydrates as the gases from the cross heat exchanger 158 are cooled.

Next the remaining top vapours are passed through a trim condenser or overhead chiller 170 before entering a recycle drum 172. The temperature
25 in the recycle drum in the example of the working fluid or solvent being propane, may be in the range of about -25 to 10 degrees C and may be for example about 0 degrees C or even colder. A drain is provided from the recycle drum 172 at 174 to drain off the MEG desiccant. Then it can be passed through a regenerator 178 and reused by being re-injected into the process

either before or after the cross exchanger at 157, 180 or both. The MEG may be injected by means of an injection spray nozzle to atomize the MEG (for good mixing with the gas) and may be sprayed onto the inlet tube sheet of the cross exchanger and chiller. The MEG may be a liquid at the temperature of the recycle drum. The MEG may remain in the liquid phase during the chilling process. As the water is condensed from the vapour stream during the chilling process, it may be absorbed by the MEG. The MEG and water may form a homogeneous liquid phase that is heavier than the hydrocarbon liquid solvent to facilitate separation. The combination therefore may form a second liquid phase that settles out below the hydrocarbon phase by gravity. The MEG and water may then be withdrawn from a pipe 174 located at the bottom of the second reflux vessel where the MEG and water may be collected. Since the volume of MEG & water may be relatively small in comparison to the hydrocarbon liquid phase, an enlarged piece of pipe may be used at the bottom of this vessel to collect the MEG and water phase. An interface measurement device may be used to detect the hydrocarbon and MEG and water interface which accordingly allows the MEG and water to be preferentially removed.

As will be understood by those skilled in the art the MEG that is first injected into the exchangers may be referred to as a lean MEG and may be typically made of 80% MEG and 20% water. When the lean MEG comes in contact with the gas stream that is being cooled, it absorbs more water that is being condensed and may therefore contain more water. This may form a rich MEG stream which for example may now be 70% MEG and 30% water. The rich MEG must now be regenerated (or re-concentrated) back to the lean MEG conditions, so the water that was absorbed during chilling phase is to be removed. This may be done by a unit referred to as a MEG Regeneration unit 178, which for example may heat up the MEG solution to boil the desired amount of water off. As will be understood by those skilled in the art the exact proportions of water in the lean and rich MEG streams will vary from separation

to separation and that the foregoing percentages are by way of example only.

It can now be understood that the MEG is used to absorb any water that might be present in the remaining top gases from the reflux drum 146 to prevent such water from freezing or forming hydrates during the following cooling stages and thus impairing the free flow of fluids through the system 110.

It will also be appreciated by those skilled in the art that the MEG injection is just one way to inhibit the freezing of water in this gas stream or the formation of hydrates. Other methods include TEG Dehydration, molecular sieve dehydration, methanol injection, and the like which are also comprehended by the present invention, however MEG is preferred as it is believed to be more economic.

The non-condensing fractions from the recycle drum 172 are removed at 182 and may be used as fuel. These gases will primarily consist of nonworking fluids such as methane and ethane when for example the working solvent is propane. The recycle fluids can then be drained at 184, passed through recycle pump 186 and through line 160 to cross-heat exchanger 158. Eventually, line 160 joins mixed source feed line 114 and is thus sent back into the demethanizer feed drum 132 for recycling. In this way the present invention is able to capture significantly more of the in situ working fluid at higher separation temperatures thereby reducing the operating cost of the in situ stimulation due to refrigeration requirements and by avoiding losing working fluid from the gases being sent to be used a fuel or the like. For example, when the working fluid is propane, the present invention may recover at least 90% of the solvent and up to approximately 97.5% of the propane produced in the production fluids. In the case where the working fluid is butane the system and process may be able to recover at least 90% and up to approximately 99% of the butane working fluid for recycling back into the formation. In general, the present invention seeks to recover at least 90% of the solvent, preferably

at least 95% and most preferably over 97% of the solvent working fluid. As noted before, the higher the solvent recovery the lower the demand for make-up solvent.

As previously discussed the recycle fluids are passed through a cross
5 exchanger 158, to cool the incoming liquids and thus recover some of the energy used to cool them in the recycle drum 172.

By way of example consider a 30,000 BPD (barrels per day) **nsolv**® facility in which propane is being used as a solvent or working fluid. In a prior art process configuration, namely without the secondary reflux system of the
10 present invention, approximately 5,000hp of propane refrigeration is required. However with a two stage reflux system as illustrated in Figure 2 and described above, the propane refrigeration requirement may be reduced to about 300hp while at the same time achieving potentially about 10% more solvent recovery. In this sense the present invention may be considered to be more efficient than
15 the prior art one stage separation processes. Further the prior art one stage separation process would require so much additional energy, to achieve the very low temperatures required to achieve the further degree of separation that the energy cost of any such further cooling would make a comparable degree of separation uneconomic.

20 The present invention comprehends that a more (relative to a one stage separation) energy efficient and more complete separation may be achieved at 8 degrees C, however, lower temperatures are also comprehended such as 0 degrees C and even colder. A temperature range of between 10 degrees C and minus 25 degrees C is comprehended for the second condensation stage,
25 and the choice of temperature may be determined for example by a cost calculation having regard as well to the choice of working fluid. As will be understood by those skilled in the art the exact system configuration may be based on an estimate of the additional cost of the cooling energy required and the capital cost of the cooling equipment as compared to the value of the extra

solvent recovered. Of course the most preferred temperature will depend on the solvent or working fluid chosen. However, the present invention of a multi-stage separation system and method may provide a more complete separation at a higher temperature than the prior art one stage reflux systems.

5 By way of further non-limiting example, for a propane based extraction as noted above the approximately 97.5% of propane solvent may be recovered in the recycle liquid stream leaving the second reflux drum 160 from the first stage reflux drum vapour stream 156. For the butane based extraction it may be even higher at over 99%. Again, in the case where the working fluid or
10 solvent is propane, the main components exiting the deethanizer may be methane (about 2.5%), ethane (about 14.8%), propane (about 81.5%) & other (about 1.2%); the main components exiting the first reflux drum vapour line may be methane (about 9.9%), ethane (about 25.2%), propane (about 62.3%) & other (about 2.6%); as the gas is cooled the same components exist, but the
15 gas stream becomes lighter as the heavier components condense out first. The pressure in the first reflux drum may be, for example, about 1950 kPa(g).)

 The present invention comprehends that the form of the first cooling means could be air cooling, which is economic. Other suitable means could be water cooling or even high level refrigeration cooling, although both of these
20 alternatives would likely be less economic than the preferred air cooling.

 In this example the fluid components entering the cooling system prior to the second reflux drum may be methane (about 9.9%), ethane (about 25.2%), propane (about 62.3%) & other (about 2.6%); the main components of the liquid stream leaving the second reflux drum being sent back to the
25 deethanizer may be methane (about 7.2%), ethane (about 24.9%), propane (about 65.8%) & other (about 2.1%); the main components of gas stream leaving second reflux drum and being sent to fuel may be methane (about 43.9%), ethane (about 28.8%), propane (about 22.2%) & other (about 5.1%). Again, as the gas stream is cooled, it becomes progressively lighter; the

proportion of propane in the final gas stream being sent to fuel may therefore be lower – the flow rate of this stream may also be quite low so the mass of propane being sent to fuel is reduced or minimal. The pressure in the second reflux drum may be about 1881 kPa(g).)

5 The preferred external refrigeration system which may be utilized for the second reflux drum cooling application may be propane refrigeration, which may include a propane compressor, air cooled condenser and accumulator vessel to cool and recirculate the propane refrigerant.

10 Where the working solvent is also propane, the make-up propane solvent may be used to supplement or be added in place of an external refrigeration system. The make-up propane may be added as the underground extraction chamber grows. The make-up propane may be stored as a pressurized liquid (for example 875 kPa at 20°C for 100% propane) and may be also passed through the deethanizer to ensure its purity before being
15 injected. By first passing the make-up propane through the cross-exchanger 170, vapours entering the secondary reflux drum can be cooled to 0°C or even colder. Since propane has a high vapour pressure, as the pressure decreases, the make-up propane vapourizes, absorbing heat from the vapours entering the secondary reflux drum in the cross-exchanger. After the cross-exchanger,
20 the heated make-up propane may be sent to the solvent compressor 20, so that it can enter the deethanizer system with the flashed solvent vapour stream at 22 for purification. By using the make-up propane solvent in the overhead chiller, the load on the external refrigeration system is reduced and may even be eliminated, leading to equipment cost savings for the surface facility.

25 The present invention also comprehends other commercially available refrigeration systems could be used to achieve the same result provided that an external means for cooling the vapours is provided. In this regard, and again by way of example only, the vapour from the first reflux drum may be cooled from about 38 C to about 27 C; and the recycle liquid stream may be

heated from about 0 C to about 33 C.

It will be further understood that the present invention can be used for solvents, or working fluids, other than propane, which need to be recovered from a mixed produced fluid stream, such as butane, in which case the
5 operating conditions (temperature and pressure) would be adjusted accordingly and would differ from the values identified in the above non-limiting examples.

The two step process of the present invention may therefore provide for an energy efficient way of recovering the large volumes of recirculating solvent
10 from the fluids produced from the reservoir by an in situ extraction process. The deethanizer 110 can be operated at a fairly high temperature, as compared to the prior art, but one that may be low enough to cause the solvent to condense. Then the top gases can be further cooled in the reflux drum, for example for propane to about 38 C to cause a further condensation
15 to occur. The last stage, again for propane, includes a further temperature reduction, for example down to 0 degrees, but is only required for the remaining top gases from the reflux drum which are relatively small in volume as compared to the total working fluid throughput through the deethanizer. As a result, according to the present invention, the maximum cooling is only
20 applied to the smallest volume portion of the fluids separation. Further by means of the recycle loop with the cross current heat exchange as shown, the energy that was used to cool the fluids may be recovered to a certain extent.

In a further embodiment the second reflux stage may be replaced with an absorption column packed with a molecular sieve or the like, or the
25 absorption column may be added onto the end of the two stage separation according to the present invention to recover any even greater percentage of the working fluid as outlined above. In either case a column having hydrocarbon absorbing materials may be used to preferentially absorb certain hydrocarbon species and will be selected according to the working fluid being

used in the separation process. Just before or at the point where the absorbent has been fully charged, i.e. it cannot absorb any more working fluid, then it is necessary to isolate the unit from the process flow and remove the absorbed hydrocarbons, such as for example by heating the absorbent materials. Since this may involve a process interruption the present invention comprehends that two absorption units may be used in a side by side manner so one can be absorbing while the other is being heated and cleansed of any absorbed hydrocarbon species. Alternatively, a selective membrane module system may be used to separate remnants of the working fluid from one or more impurity species such as carbon dioxide. Thus, the present invention contemplates that the second separation step may not require a second reflux drum with cooling as described above. Thus in broad scope the present invention comprehends a solvent recovery which includes a two or more step separation process, where each subsequent step is applied to a smaller amount of fluid and can be done more efficiently than trying to achieve a one step separation on a much large volume of fluid.

Figure 3 shows an energy efficient solvent recovery unit (SRU) applied to the bitumen stream 26 according to a further aspect of the present invention. The unit consists of a multistage distillation column 210, reflux drum 212, reboiler 214 and condenser 216 to further purify the separated heavy fluids or product oil 26 while recovering solvent that has been entrained. As will be understood by those skilled in the art, the distillation column may have stages established by internal trays or packing. The top stage vapour outlet 218 of the distillation column 210 is condensed at 216 and sent through the reflux drum 212. The vapour from the reflux drum 212 is non-condensable gas 220 which may be used as a fuel gas in the plant, for example. The liquid 221 from the reflux drum 212 is recovered solvent, which is preheated in a solvent preheater 224, which may be a cross heat exchanger, and vapourized at 226 for solvent injection 30. A portion 228 of the bottoms liquid of the distillation column 210

is sent to the reboiler 214, which heats the distillation column by recirculating vapourized bottoms liquid. The remaining bottoms liquid is purified product oil which is sent to a cross heat exchanger or separated oil preheater 230 to preheat the incoming bitumen 26, while pre-cooling the purified product oil to a first temperature. The purified product oil may then be cooled to a second temperature, which is lower than the first temperature in the solvent preheater 224. A final adjustment of the purified product oil temperature may be done in a product oil cooler 230 for tighter control of the vapour pressure and solvent content in the final sales oil. As previously stated, depending upon the nature of the working fluid, the present invention comprehends that the separation facility may include a number of separation stages, at appropriate interstage fluid pressure and/or temperature, it may employ parallel streams in some or all of the stages, and may adjust the number of cross heat exchangers to maximize the energy efficiency and cost efficiency of the process as shown in Figure 3.

By way of example, consider a 10,000 BPD oil **nsolv**® facility in which butane is being used as a solvent or working fluid. In a prior art process configuration, three stages of parallel flash vessels are used for light/heavy separation, without the solvent recovery unit of the present invention. The total energy requirement of the system is about 30 MW, accounting for both heating duty and electrical power. To achieve the same total solvent recovery according to the present invention, by using the solvent recovery unit in place of the two downstream flash vessels, the total energy requirement is also about 30 MW, however it requires about 30% less electrical power than the prior art configuration. This results in overall energy cost savings since electrical power is more expensive than heating duty, which may be provided by waste heat or fuel recovered at the plant. .

Figure 4 shows a mixed fluid separation system, according to a further aspect of the present invention, which minimizes the hydrocarbon loss to the

produced water 13 of the circuit described by Figure 1. For ease of understanding the free water knock out vessel (FWKO) 12 is shown together with the mixed water stream 13 and the light heavy hydrocarbon stream 15. The FWKO may include a water/hydrocarbon interface level control 202, using
5 a nucleonic based density profiler along the separation zone of the FWKO, which may also have the appropriate vessel baffles and siphon breaking with piping 294 and flow control valve 296 to discourage hydrocarbon entrainment in the water outlet stream, as will be understood by those skilled in the art. The mixed water 13 may be collected in a skim tank 300, which is sized and shaped
10 to permit the mixed water to separate including providing for a sufficient height and sufficient residence time for separation of the high density phase from the low density phase for the design flow rate. The high density phase is separated water, which may be sent to disposal or further treatment as needed. The low density phase contains recovered floatable hydrocarbons 306, which are
15 skimmed off the top of the skim tank and may be sent to a slop oil tank 308. From the slop oil tank 308, at least a portion of the recovered hydrocarbons are sent back to the FWKO at 310. The present invention comprehends the operator may select the skim tank size and hydrocarbon recycle rates 310 to maximize separation efficiency.

20 In one embodiment of the present invention, the skim tank 300 may be replaced by one or more hydrocyclones. As will now be understood this requires the fluids in the FWKO to have enough residence time to be able to provide a steady feed rate for the hydrocyclones.

While the foregoing description describes preferred embodiments of the
25 invention it will be understood that variations are comprehended by the present invention. Some of these variations have been discussed above and others will be apparent to those skilled in the art as falling within the broad scope of the claims appended hereto. For example, various working fluids can be recovered according to the present invention, and may require different

temperatures and different concentrations than provided in the non-limiting example above, depending upon the nature of the recovered fluids.

**THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:**

1. A water separation system for separating solvent from water produced
5 from a solvent based in situ hydrocarbon extraction process, said water
separation system comprising:
- a bulk fluids separation vessel having a separation zone, and being
configured to separate mixed input fluids into mixed water and light/heavy
hydrocarbons;
 - 10 a first piping connection to permit said light/heavy hydrocarbons to be
sent to a downstream light/heavy separation stage;
 - a second piping connection to permit the mixed water to be sent
downstream to a further water separation stage, the further water separation
stage including a skim tank that receives said mixed water from said vessel,
15 said skim tank being sized and shaped to permit said mixed water to separate
into a lower density hydrocarbon rich stream and a higher density water
stream;
 - a slop oil tank;
 - a third piping connection to permit said slop oil tank to receive said lower
20 density hydrocarbon rich stream; and
 - a fourth piping connection to permit said slop oil tank to return at least
a portion of said lower density hydrocarbon rich stream back to said bulk fluids
separation vessel.
- 25 2. A separation facility for separating a mixed fluid stream produced from
an underground formation by means of an in situ solvent based hydrocarbon
extraction process into separate process streams, said separation facility
comprising:
- a first separation stage configured to separate said produced mixed

fluids into at least a mixed water process stream and a heavy and light hydrocarbon process stream;

5 a second separation stage configured to separate said heavy and light hydrocarbon process stream into a heavy hydrocarbon process stream and a bulk light hydrocarbon process stream;

a bulk light hydrocarbon separation stage configured to separate said solvent from said bulk light hydrocarbon process stream;

10 a mixed water separation stage configured to separate said mixed water process stream into a lower density mixed hydrocarbon rich process stream and a higher density water process stream; and

a final hydrocarbon separation stage configured to separate at least some residual light hydrocarbons from said heavy hydrocarbon process stream.

15 3. The separation facility of claim 2, wherein said final hydrocarbon separation stage is configured to produce sales oil.

20 4. The separation facility of claim 3, wherein said final hydrocarbon separation stage is further configured to vapour pressure adjust said sales oil to facilitate safe storage.

5. The separation facility of claim 2, wherein said solvent separated from said bulk light hydrocarbon process stream, by said bulk light hydrocarbon separation stage, is suitable for re-use in the in situ solvent extraction process.

25 6. The separation facility of claim 2, wherein said residual light hydrocarbons separated from said heavy hydrocarbon process stream, by said final hydrocarbon separation stage, are suitable for re-use in the in situ solvent extraction process.

7. The separation facility of claim 2, wherein said lower density mixed hydrocarbon rich process stream separated from said mixed water process stream, by said mixed water separation stage, is suitable for re-use in said in situ base solvent extraction process.

8. The separation facility of claim 5, wherein said separated solvent is suitable for said re-use in the in situ solvent extraction process without further purification.

9. The separation facility of claim 2, configured to use said separated bulk light hydrocarbon stream as fuel.

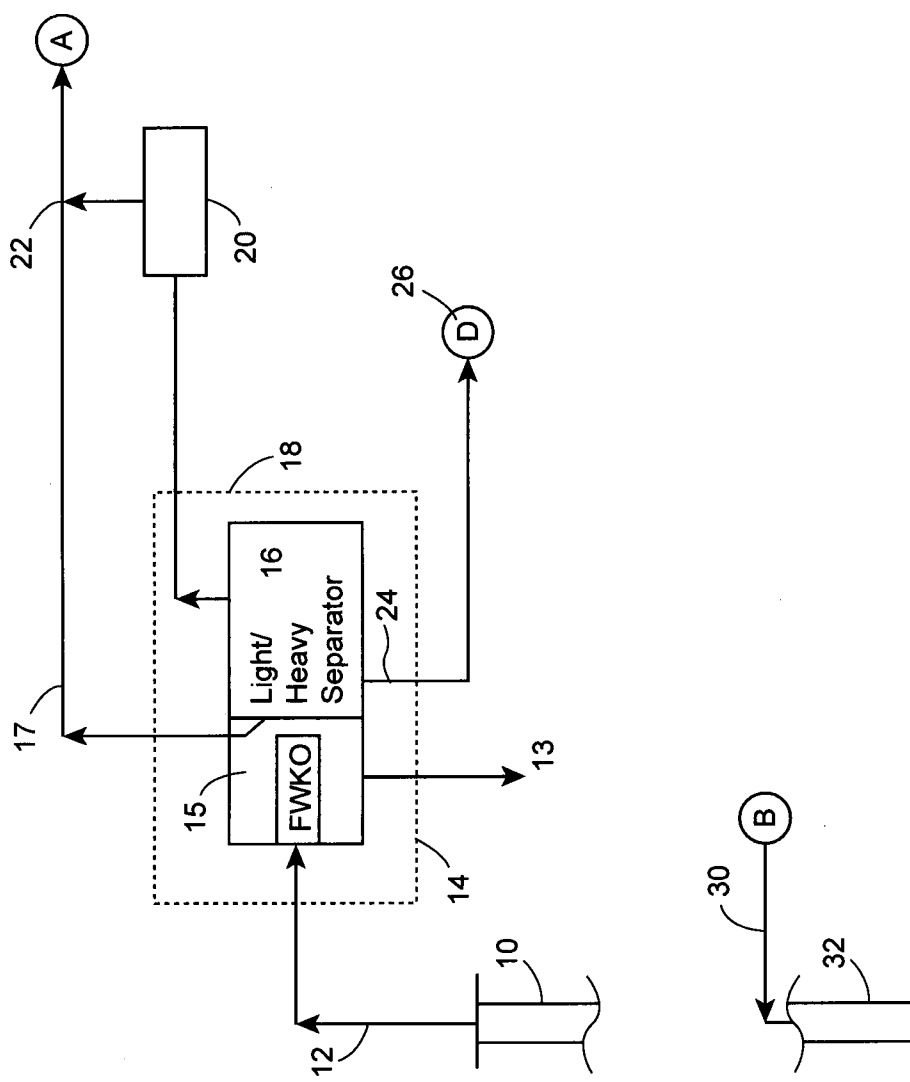


Figure 1

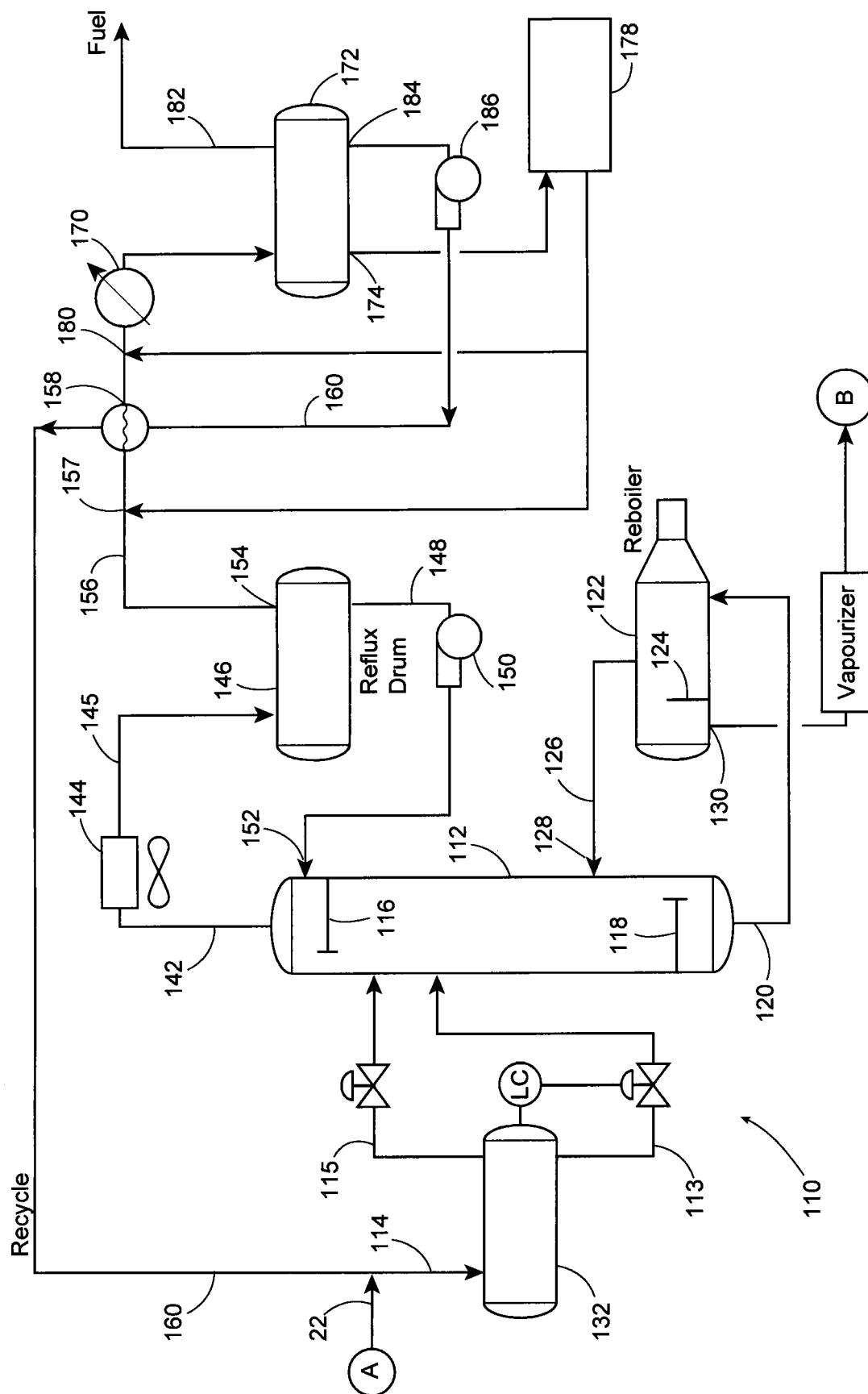


Figure 2

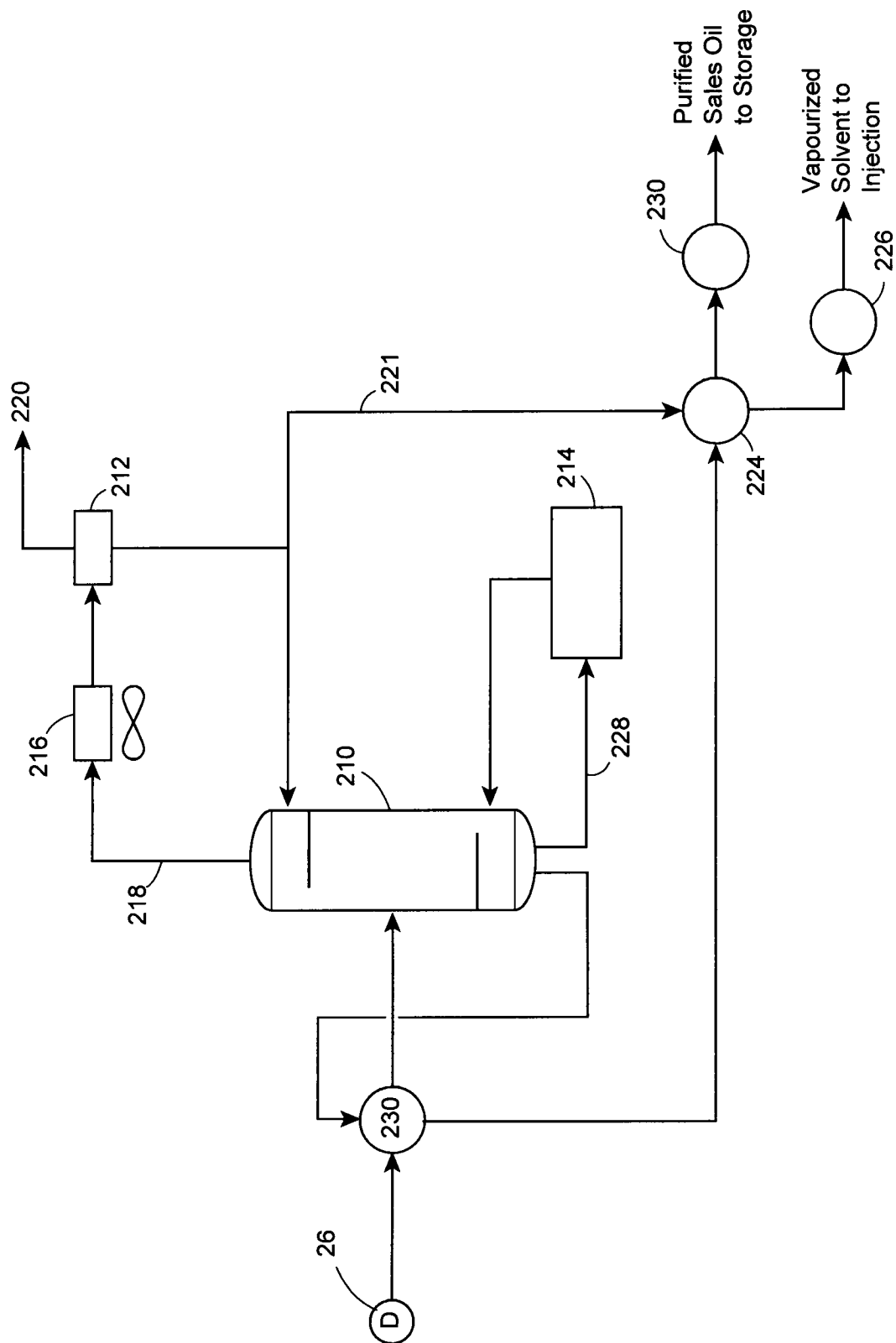


Figure 3

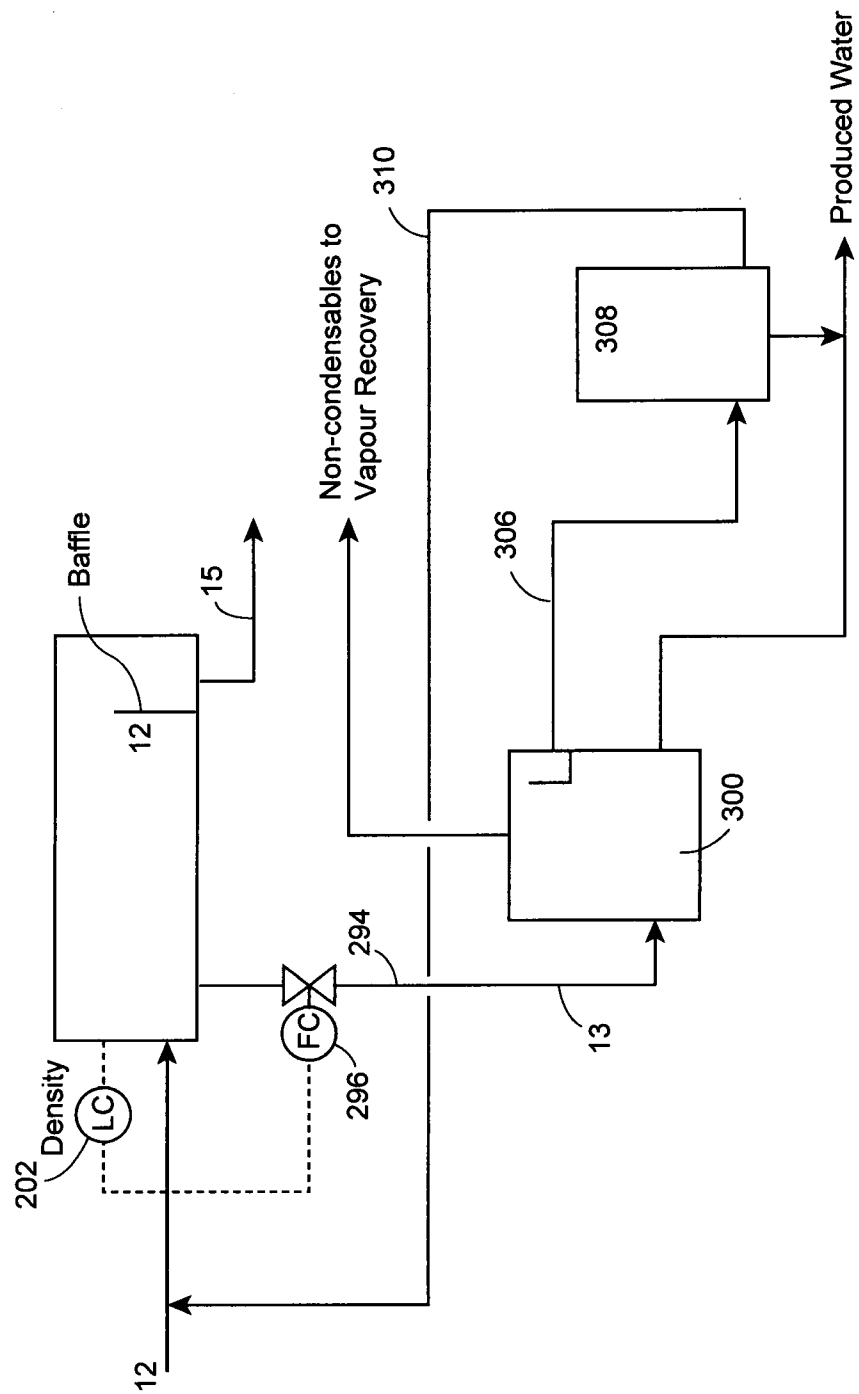


Figure 4

