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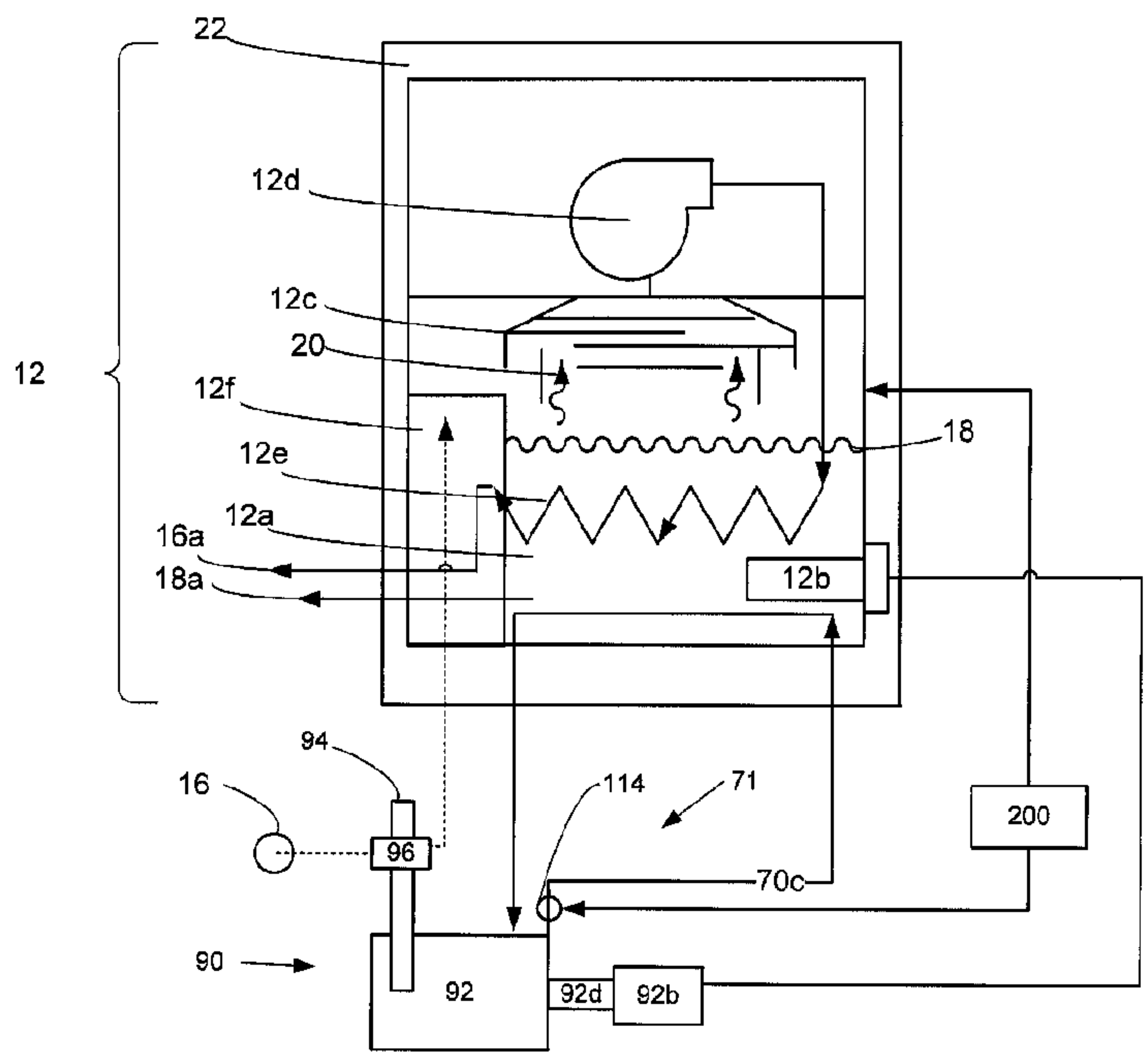
(54) Title: A LIQUID CONTAMINANT CONCENTRATOR APPARATUS AND METHOD OF USE

Figure 2



(57) Abrégé/Abstract:
The present invention pertains to methods, systems and apparatus that provide a cost effective means to concentrate raw water contaminants to reduce their disposal costs and/or for the use of the purified water through the use of recuperated prime energy normally lost to the environment. The present invention utilizes a novel method of capturing an increased amount of prime energy normally lost to the environment to support raw water liquid phase reduction processes utilizing known distillation processes. In the preferred embodiment, the energy recoupment may be derived from some or all of the electrical, mechanical and/or hydraulic equipment that is used to power and/or operate a Vapor Compression Distillation (VCD) system.

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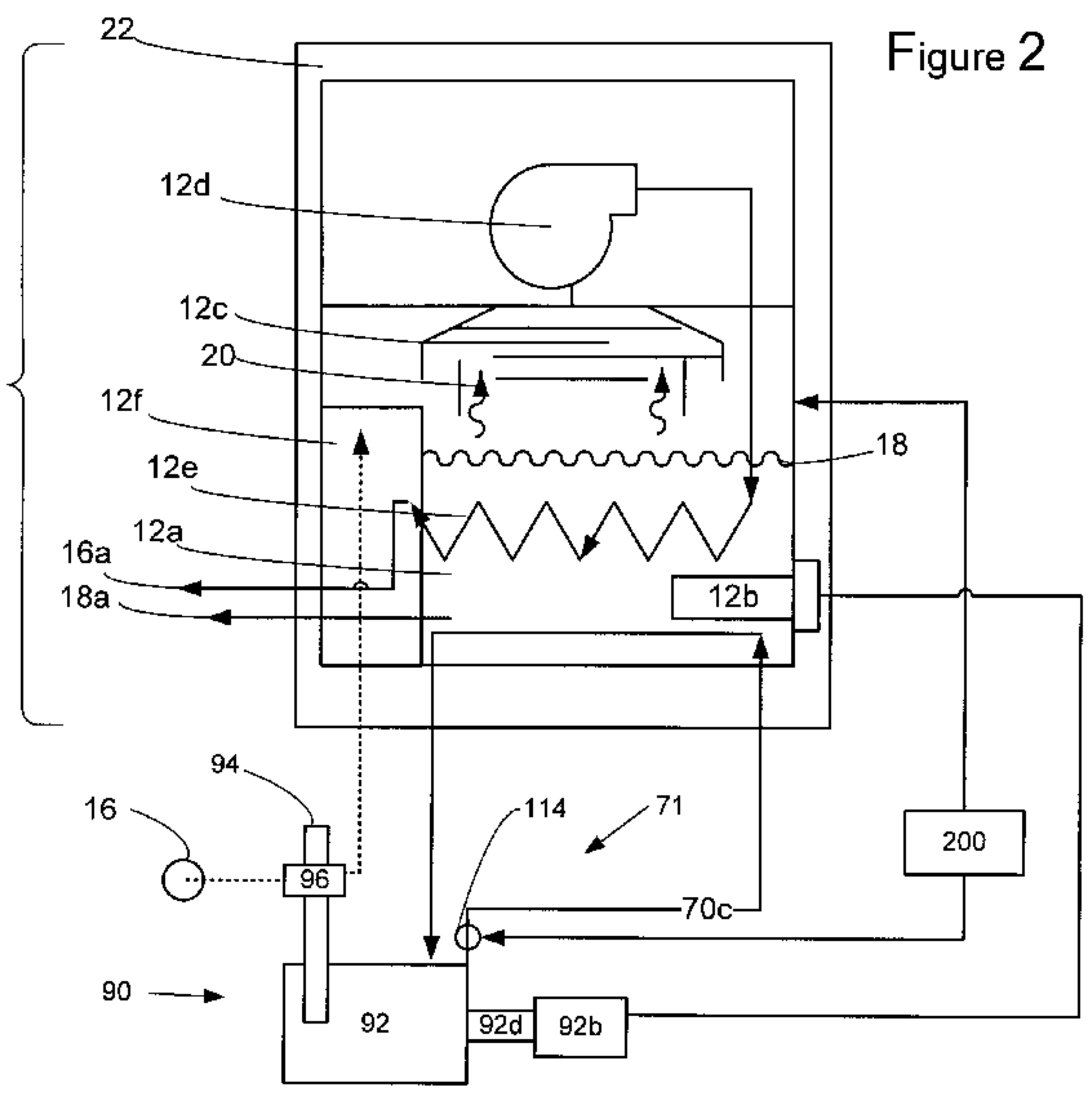


Figure 2

(57) Abstract: The present invention pertains to methods, systems and apparatus that provide a cost effective means to concentrate raw water contaminants to reduce their disposal costs and/or for the use of the purified water through the use of recuperated prime energy normally lost to the environment. The present invention utilizes a novel method of capturing an increased amount of prime energy normally lost to the environment to support raw water liquid phase reduction processes utilizing known distillation processes. In the preferred embodiment, the energy recoupment may be derived from some or all of the electrical, mechanical and/or hydraulic equipment that is used to power and/or operate a Vapor Compression Distillation (VCD) system.

A LIQUID CONTAMINANT CONCENTRATOR APPARATUS AND METHOD OF USE

RELATED APPLICATIONS

This application is related to and claims priority to United States provisional patent application 61/353,063 filed June 9, 2010 and incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to systems, methods of operation and apparatus for concentrating liquid contaminants to reduce their disposal costs and/or to make use of the purified water by utilizing a vapor compression distillation (VCD) system substantially sustained by recovered energy.

BACKGROUND OF THE INVENTION

Many water purification techniques and systems are well known for the removal of contaminants from water. Such techniques and systems include carbon filters, chlorination, pasteurization, deionization, distillation, and reverse osmosis. Many of these techniques have significant drawbacks in one way or another and are all affected by variations in the feed water quality with the exception of the distillation process.

As such, it can be both costly and/or inefficient to remove various contaminants including high total dissolved solids levels, organics, heavy metals, and pesticides from water using the known methods.

For example, reverse osmosis is a widely-used system that while effective under certain conditions is subject to a number of limitations. That is, reverse osmosis is generally wasteful of water insomuch as upwards of 50% of its intake stream may be discharged thus requiring several series of treatments to obtain desired separation levels. Furthermore, reverse osmosis may also only be able to manage a low maximum total dissolved solids intake stream, is limited by the risk of membrane tearing that allow contaminates to pass into the “clean” water supply unknown and by membrane fouling.

Carbon filters are also popular, however the filters and carbon must be replaced often and primarily only target chlorine, making them less effective in broad water contamination situations.

Other treatment techniques can be energy intensive and only well suited for centralized, large-scale water systems that require both a significant infrastructure and highly trained operators.

As a result, there has been a need for systems and methods to reliably produce clean water without regard to the water source and the degree of contamination of the water. Generally, there has also been a need for mobile, decentralized systems that are efficient in their mode of operation.

The use of Vapor Compression Distillation (VCD) systems to purify water is a well known process. Provided there is a reliable energy source, the use of VCD systems is an attractive way to purify water for a number of reasons including:

a) low energy cost per water volume purified;
b) high tolerance for high total dissolved solids levels;
c) absence of filters or other replaceable consumables; and,
d) low discharge percentage.

More specifically, in the oil and gas industry, processing raw surface water and processing fluids such as drilling mud and hydraulic fracturing fluids ("fraccing fluids") is a substantial and growing market as the use of formation fracturing techniques becomes more widespread particularly with the growth of shale gas development. As such, there is a need for more cost effective methods and systems to treat large quantities of raw and process water derived from such operations.

As discussed below, as VCD processes are generally considered less expensive to operate than standard distillation process, VCD systems are attractive for use in oilfield operations.

In a VCD system, the boiler and compressor/condenser of the VCD system recycle the heat energy necessary to turn the feed water to steam by continuously recovering and reusing the enthalpy of vaporization and the enthalpy of condensation. The VCD cycle has some losses attributed to systemic inefficiencies and product liquid discharges which require make-up heat to be supplied to maintain the process. In a typical VCD system, a portion of the make-up heat is provided by an electrical heating element(s) to sustain the system operation. While the VCD and/or its variant the Multi-Effect Distillation (MED) system are able to recycle 95% - 98% of the system energy, the remaining 2% - 5% make up energy requirements to sustain the distillation operation can be very expensive to generate at the operational throughput rates of many industrial processes.

For example, a review of past systems has revealed that a number of companies have developed various industrial VCD systems designed to process relatively large volumes of waste water. For example, companies such as Superstill Technologies, Inc. (US Patent 5,597,453 – Apparatus and method for Vapor Compression Distillation Device) and Aqua-Pure Ventures, Inc. (US Patent 6,375,803 – Mechanical Vapor Recompression Separation Process) provide descriptions of current state-of-the-art VCD processes that can be applied to the oil and gas water processing applications as well as a broad array of other consumer, commercial and industrial markets in general.

However these systems typically use electric heat to make up the 2%-5% of system heat loss over time which can represent a substantial cost when processing large volumes of contaminated raw water. By way of example, a VCD system processing 16 m^3/hr would require approximately 500 kW/hr to sustain its operation. Of that 500 kW/hr, 20% or 100 kW/hr is required in the form of electrical energy to operate the various pieces of electromechanical equipment necessary to operate the VCD process. The remaining 80% of the 500 kW/hr, or 400 kW/hr, is required in the form of heat energy to provide the approximate 2% make up heat energy necessary to sustain the VCD process at the 16 m^3/hr process rate. An engine/generator combination, required in remote and mobile operations of the oil and gas industry, and sized to power a VCD unit capable of processing 16 m^3/hr of raw water will consume approximately 135 liters/hr of diesel fuel or

3,247 liters/day. At a diesel fuel cost of $0.90/liter, the daily energy operating cost for the described VCD system to process 16 m^3/hr would be $2,923/day. Additional to the operational cost of fuel consumption is the environmental impact of these volumes of burned fossil fuels.

As is also known, when a fossil fuel is combusted within an internal combustion engine, approximately one-third of the combustion energy is converted to electricity while the remaining approximately two-thirds of the combustion energy is lost to the atmosphere as radiated and exhaust heat. Therefore, for a given mobile VCD system that requires 500 kW/hr of electrical energy to sustain its operation, an appropriately sized engine/generator system must generate this electricity as a byproduct of the fuel combustion process. The engine/generator system must therefore, as is commonly known, burn approximately three times the required electricity energy in fossil fuels due to the inefficiencies of the process by which heat energy is converted to electrical energy. Practically this relationship therefore requires a 500 kW/hr electricity demand requiring 1,500 kW/hr of fossil fuel combustion energy. Of the 500 kW/hr energy required to sustain a VCD system processing 16m^3/hr of raw water, 20% [or 100 kW/hr] is required as electrical energy and 80% [or 400kW/hr] is required in the form of heat energy. To generate the 400kW/hr of heat energy, the engine/generator system must combust approximately 1,200 kW/hr of fossil fuels. As a result of this configuration and inefficiency, 800 kW/hr of available heat energy is not only wasted in terms of fuel cost but also discharges larger volumes of combustion contaminates into the environment than necessary. Accordingly, there is also an environmental need to reduce this carbon footprint as well as an economic need to reduce the operational cost of this process.

Further still, the generated 400 kW/hr in electrical energy must then be converted into resistance based heat energy to be usable as the makeup heat for sustaining the VCD system evaporation process.

Another system as described by Kamen (US Patent 7,340,879 - "Locally Powered Water Distillation System") describes a system that teaches reducing the capital cost of water purification by providing VCD systems that operate with electricity created from various forms of consumable fuels. In this regard, Kamen teaches the use of a thermal cycle engine, such as an external combustion sterling type engine to power an electrical generator to be used within a distributed network of electrical generating utilities for producing electricity for power generation purposes and the electrical power to operate a VCD water generator coincidentally. Kamen provides a combined electrical power and water purification system that requires a combustible fuel source and a water source to produce purified water suitable for human consumption. The fuels sources for the Kamen system can be any combination of hydrocarbons, coal, wood, dried dung or any type of material or chemical reaction that would combust or react to generate a sufficiently high temperature heat necessary to power the thermal cycle engine of the system which in turn generated electricity to power the VCD. In the Kamen system, the Sterling engine converts heat energy from burning combustibles to electrical energy used directly to power the coupled VCD systems electrically driven components.

Thus, there is a need for a VCD system that can reduce the fuel consumption required to operate VCD systems, particularly in industrial processes where due to the scale of the operations, the operational and fuel costs are significant.

SUMMARY OF THE INVENTION

The invention provides novel methods and apparatus to improve economics, reduce operational costs, provide a smaller environmental footprint and generate a greater throughput or conversely a energy system as a function of a given energy source necessary to power a typical VCD system for processing raw and/or process water.

In accordance with a first embodiment, a water purification system is provided, the system comprising: an electrically operable vapor compression distillation (VCD) type system for distilling input water to produce clean output water, the VCD type system including a VCD sump for containing and heating the input water; and, a heating module (HM) in heat exchange contact with the VCD sump for supplying heat to the VCD sump for heating the input water wherein the HM includes a VCD heat exchanger within the VCD sump for transferring heat from a hot fluid to the VCD sump.

In one embodiment, the HM is an internal combustion engine (ICE) having a cooling fluid circulation system and the cooling fluid circulation system is connected to the VCD heat exchanger.

In another embodiment, the system includes a second heat exchanger operatively connected between the cooling fluid circulation system and VCD heat exchanger.

In another embodiment, the system includes an exhaust system heat exchanger operatively connected to an exhaust system of the ICE, the exhaust system heat exchanger for pre-heating input water prior to introducing the input water into the VCD sump.

In yet another embodiment, the system includes an exhaust system heat exchanger operatively connected to an exhaust system of the ICE, the exhaust system heat exchanger for pre-heating input water prior to introducing the input water into the VCD sump and for contacting the input water for scrubbing ICE exhaust gas.

In another embodiment, the system includes a control system operatively connected to the HM and VCD type system for monitoring temperatures within the HM and VCD sump to control the flow of hot fluid from the HM to the VCD sump.

In one embodiment, the system includes a generator operatively connected to the ICE to provide electrical energy to VCD systems including a VCD compressor and VCD circulating pumps. The VCD system may also include an electrically operated immersion heater within the VCD sump for providing heating power to the VCD sump during VCD system start-up.

In another aspect, the invention provides a method of operating a vapor compression distillation (VCD) type system having a VCD sump comprising the step of: providing hot fluid heat to the VCD sump by a hot fluid in heat exchange contact with the VCD sump. The method may also include the step of heating the hot fluid within an engine block cooling fluid circulation system within an internal combustion engine (ICE) and contacting the hot fluid within the VCD sump and/or the step of pre-heating input water for the VCD using heat from the ICE.

In one embodiment, heat for pre-heating the input water is derived from the engine block of the ICE and/or derived from an exhaust system of the ICE.

In another aspect, the invention may also include the step of contacting the input water with ICE exhaust to effect scrubbing of ICE exhaust and pre-heating of the input water prior to introducing the input water to the VCD sump.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is described with reference to the drawings in which:

Figure 1 is a generalized schematic illustration of a prior art VCD system powered by an electrical power source;

Figure 2 is a schematic illustration of one embodiment of the invention; and,

Figure 3 is a schematic illustration of an internal combustion engine heat exchange system configured to a VCD system in accordance with one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The invention is described with reference to the figures. In the context of this description, it is understood that different vapor compression distillation (VCD) systems, including Mechanical Vapor Compression (MVC) and Multi-Effect Distillation systems, can be utilized within the scope of the invention and that the following description of the general principles of operation of a VCD is not meant to be limiting.

As shown in Figure 1, a generalized prior art VCD system 12 is described in which input water 16 is heated in reservoir or sump 12a by an electrical heater 12b to create steam which is passed through a steam compressor 12d, reservoir heat exchanger 12e and heat exchanger 12f to create distilled, clean water 16a, and waste concentrate 18a.

As described and shown in Figure 2, in accordance with the invention, the VCD system includes a reservoir or sump 12a, electrical water heating system 12b, steam compressor 12d, reservoir heat exchanger 12e and input water heat exchanger 12f together with an alternate heat source 90 to create distilled, clean water 16a, and waste concentrate 18.

In operation, input water 16 is delivered to the input water heat exchanger 12f where the input water is warmed by clean water outflow 16a and waste water concentrate 18a. The input water 16 is delivered to reservoir 12a to be further heated within the reservoir 12a primarily by compressed steam via reservoir heat exchanger 12e and top off heat provided by water heating system 90. Generally, the temperature within the reservoir is controlled so as to effect boiling and steam generation above fluid level 18. Generated steam 20 is collected by vapor compressor 12d and waste water concentrate 18a is discharged through intake heat exchanger 12f.

As noted, compressor 12d is operated to compress steam 20. The compressed steam passes through reservoir heat exchanger 12e where the steam is condensed whilst providing input heat to the reservoir 12a and the reservoir water. Distilled and clean water 16a is collected from the system.

In accordance with the invention as shown in Figures 2 and 3, heat from an external source (particularly an internal combustion engine 92) is used to provide the necessary makeup heat for the VCD system thereby obviating or reducing the need for an electrical heating system. As shown, a diesel engine 92 is equipped with a cooling fluid circulation system 71 that utilizes the heat from the cooling fluid 70 of the diesel engine that is used directly as the makeup heat source within the VCD. In this embodiment as shown in Figure 2, heated cooling fluid being circulated through the engine block of the diesel engine is directly connected to the sump 12a of the VCD so as to provide make-up heat.

In an alternate embodiment, as shown in Figure 3, the heat from the cooling fluid may be directed to the VCD through a heat exchanger 93. Importantly, in each embodiment using the engine block cooling fluid, the circulation is such that after the cooling fluid leaves the VCD or the heat exchanger 93, it passes through the engine radiator 70a prior to reentering the engine block. This allows the cooling fluid to enter and exit the engine block at a fairly consistent and predictable temperature, so as to not damage the engine, regardless of what is happening with the VCD or exchanger 93.

In a further embodiment, the diesel engine 92 may also be used as a means to preheat the input water 16 entering the VCD by contacting the input water 16 with the heat from the diesel engine including the exhaust stack and/or the engine block or heat exchanger 96.

In another embodiment, the exhaust from the diesel engine is contacted with the water 16 entering the VCD to both scrub the diesel exhaust and to preheat the input water.

Generally, upon start-up of the VCD system 12, the diesel engine will usually provide rotary input power 92d to a generator 92b to produce electrical power to heating element 40 to heat the input water within the sump 12a to boiling temperatures to initiate the evaporation process. The generator will also sustain the power requirements of a VCD's compressor and various pumps. However, in some embodiments, heat to initiate the evaporation process may be derived solely from the heat recovered from the internal combustion engine cooling fluid, or in combination with an electric element, as described above.

As the system reaches temperature, the compressor 12d is activated to compress water vapor created within the evaporator which in turn provides heat to the heat exchanger in the sump allowing for the exchange of latent heat of condensation and vaporization. Thus, as the system reaches steady-state, the amount of on-going heat required by the immersion heater is reduced (if used at all) and the makeup heat is provided solely by the engine block heat exchange fluid 70c.

In other embodiments, the configuration of the heat exchangers with respect to the VCD system can be varied. In one embodiment, as shown in Figure 3, a diesel engine is shown having a known liquid cooling system 70 with radiator 70a and radiator fan 70b in which engine cooling fluid 70c is circulated to dissipate heat from the normal operation of the diesel engine. As shown, the cooling system may be configured directly to the VCD to provide heat directly to the sump 12a such that the radiator 70a is initially bypassed to direct the fluid to the exchanger 93 before being directed to radiator 70a for final cooling prior to reentering the engine block 92. Thus, the cooling fluid is circulated directly to the VCD system so as to transfer heat to the VCD. In this embodiment, appropriate valves such as valve 95a is provided to effect initial radiator bypass under the control of controller 200. As noted above, an optional heat exchanger 93 may also be utilized.

The controller 200 monitors the energy requirements needed for makeup heat in the VCD sump 12a. If the engine block is supplying more heat energy than is required by the VCD, the control system will interact with appropriate valves to redirect the engine block cooling fluid to the engine radiator thereby bypassing the exchanger 93 and/or the sump. Then when the VCD requires additional heat energy the controller will again redirect the engine cooling fluid back into the heat exchanger. The controller may also control the flow rate of the engine block cooling fluid and/or the sump heating fluid. By controlling, for example, the flow rate of VCD sump heating fluid relative to the flow rate and temperature of the engine cooling fluid, the controller can control the temperature at which the VCD heating fluid exits exchanger 93 and enters the VCD sump. The same flow control can be used with reference to exchanger 96.

Similarly, the controller can also monitor the performance and operation of a heat exchanger 96, 93 as may be applicable.

In addition, system control is provided by appropriate sensors and valves within the VCD that provide feedback to a controller 200 that monitors various parameters in the system including temperatures, pressures and flow-rates to ensure efficient operation of the system.

Benefits

The operation of the present invention provides the benefits of increased heat energy management that can reduce each of the capital, operational and maintenance costs of a VCD system while improving the throughput for a given energy level.

Importantly, in the system as described above, each of the engine block and/or the engine exhaust pipe, the enables the system to recuperate the heat energy normally given off into the atmosphere wherein the recuperated heat energy is utilized for the initiation and sustaining energy needs for operating the VCD system. As such, the heat recovery is such that the VCD can produce comparatively greater volumes of product water more economically than prior art systems, or conversely, the system of the present invention can substantially reduce the required size of the prime energy system and reduce the amount of consumable fuel necessary to produce a given volume of product water by over 60%.

For example, in the context of the system described above, rather than consuming 1,500 kW/hr in fuel (thereby losing 1,000 kW/hr in heat energy to the atmosphere) to power a VCD system, the present invention can reduce the engine/generator size from a 500kW/hr capacity to a 200 kW/hr engine/generator capacity to process the same 16 m^3/hr rate. A 200 kW/hr engine/generator set has the 100kW/hr in the form of electricity required (actually double this is available) to operate the VCD electro-mechanical equipment and recuperates 400 kW/hr in direct heat energy (normally lost to the atmosphere) and applies to provide the makeup heat energy required to sustain the VCD operations.

Therefore, a system of the present invention, utilizing a 200kW/hr engine/gen, would consume only 54 liters/hr (1,309 liters/day) as compared to a prior art system requiring 135 liters/hr (3,247 liters/day) to accomplish the same 16 m^3/hr throughput. This energy savings translates in to 1,938 liters/day (fuel saved) at $0.90/liter of diesel fuel which equals $1,744/day cost saving. This is a daily fuel cost savings of 60%.

A further benefit of the present invention lies is the ability, in one embodiment, of the engine exhaust heat recovery sub-system to scrub the diesel exhaust gasses for greenhouse gasses and polluting particulate thereby reducing the comparative carbon footprint when compared to the prior art VCD systems. In this case, heat exchanger 96 may be configured such that exhaust gas directly contacts raw water to provide a scrubbing effect as described in co-pending patent application (PCT/CA2010/001440 and incorporated herein by reference). Alternatively, for a given amount of water processed, less fuel is needed resulting in overall less emissions into the environment.

In summary, the benefits of the present invention provide a meaningful increase in the economics and a reduction of the environmental footprint when processing raw and process water particularly in oilfield operations such as hydraulic fracturing operations, oilfield drilling operations and the processing of heavy oil produced water ponds and lakes. Specifically when applied to oil and gas drilling operations, the present invention can process high volumes of drilling fluids and accumulated lease surface water to reduce the liquid phase of such water to concentrate the water contaminants for improved collection, reuse and/or disposal processing.

Although the preferred embodiments of the methods and systems of the present invention have been illustrated in the accompanying drawings and described in the foregoing specification, it is understood that the invention is not limited to the embodiments disclosed, but is capable of numerous rearrangements, modifications and substitutions without departing from the spirit of the invention as set forth herein.

CLAIMS

1. A water purification system comprising:
   an electrically operable vapor compression distillation (VCD) type system for distilling input water to produce clean output water, the VCD type system including a VCD sump for containing and heating the input water;
   a heating module (HM) in heat exchange contact with the VCD sump for supplying heat to the VCD sump for heating the input water wherein the HM includes a VCD heat exchanger within the VCD sump for transferring heat from a hot fluid to the VCD sump.

2. The water purification system as in claim 1 wherein the HM is an internal combustion engine (ICE) having a cooling fluid circulation system and the cooling fluid circulation system is connected to the VCD heat exchanger.

3. The water purification system as in claim 2 wherein a second heat exchanger is operatively connected between the cooling fluid circulation system and VCD heat exchanger.

4. The water purification system as in any one of claims 2-3 further comprising an exhaust system heat exchanger operatively connected to an exhaust system of the ICE, the exhaust system heat exchanger for pre-heating input water prior to introducing the input water into the VCD sump.

5. The water purification system as in any one of claims 2-3 further comprising an exhaust system heat exchanger operatively connected to an exhaust system of the ICE, the exhaust system heat exchanger for pre-heating input water prior to introducing the input water into the VCD sump and for contacting the input water for scrubbing ICE exhaust gas.

6. The water purification system as in any one of claims 1-5 further comprising a control system operatively connected to the HM and VCD type system for monitoring temperatures within the HM and VCD sump to control the flow of hot fluid from the HM to the VCD sump.

7. The water purification system as in any one of claims 2-6 further comprising a generator operatively connected to the ICE to provide electrical energy to VCD systems including a VCD compressor and VCD circulating pumps.

8. The water purification system as in any one of claims 1-7 wherein the VCD system includes an electrically operated immersion heater within the VCD sump for providing heating power to the VCD sump during VCD system start-up.

9. A method of operating a vapor compression distillation (VCD) type system having a VCD sump comprising the step of: providing hot fluid heat to the VCD sump by a hot fluid in heat exchange contact with the VCD sump.

10. The method as in claim 9 further comprising the step of heating the hot fluid within an engine block cooling fluid circulation system within an internal combustion engine (ICE) and contacting the hot fluid within the VCD sump.

11. The method as in claim 10 further comprising the step of pre-heating input water for the VCD using heat from the ICE.

12. The method as in claim 11 wherein heat for pre-heating the input water is derived from the engine block of the ICE.

13. The method as in claim 11 wherein heat for pre-heating the input water is derived from an exhaust system of the ICE.

14. The method as in claim 13 further comprising the step of contacting the input water with ICE exhaust to effect scrubbing of ICE exhaust and pre-heating of the input water prior to introducing the input water to the VCD sump.

Figure 1

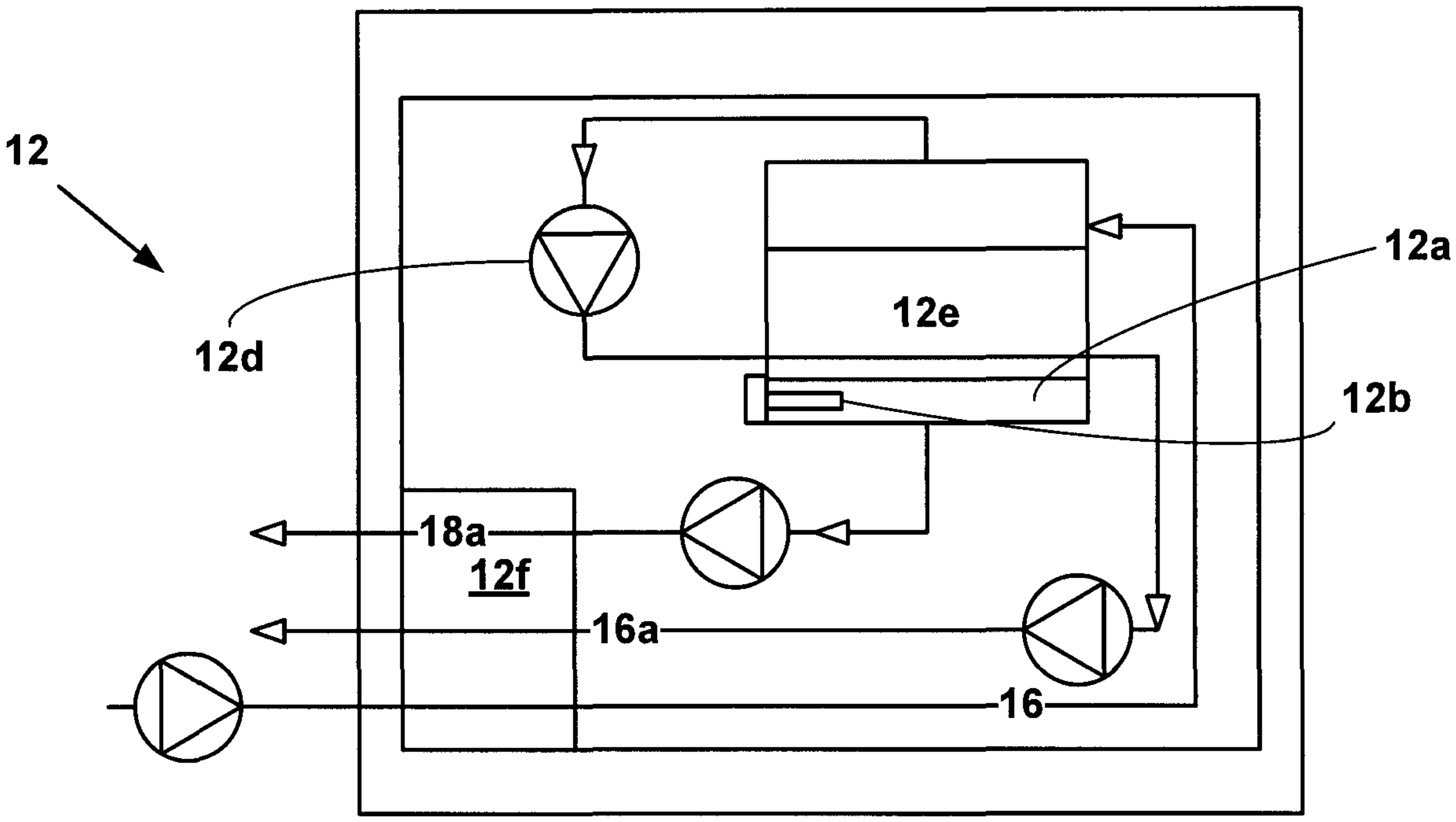
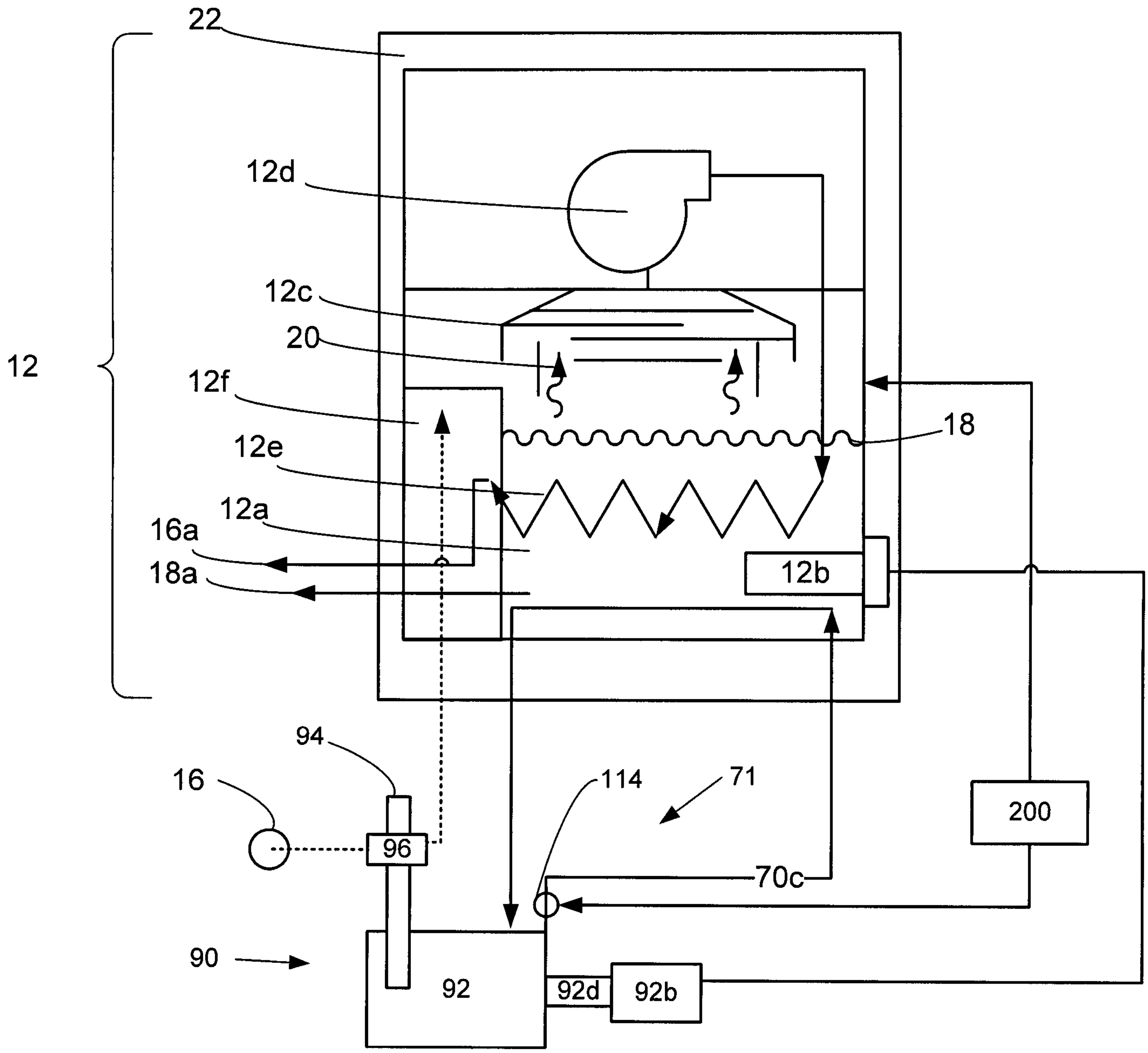


Figure 2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12d
12c
20
12
12f
18
12e
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12b
18a
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114
71
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96
70c
90
92
92d
92b

Figure 3