

[54] GEOTHERMAL HEAT RECOVERY BY
MULTIPLE FLASHING

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1972, abandoned.

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[51] Int. Cl. **F01k 25/10; F03g 7/00**

[58] Field of Search **60/641, 655; 165/45**

[56] **References Cited**

UNITED STATES PATENTS

3,605,403 9/1971 Aikawa **60/26**

OTHER PUBLICATIONS

United Nations Conference on New Energy Sources
E/Conf. 35/G/41, Apr. 17, 1961; "Thermal Cycles for
Geothermal Sites" by Alf Hansen.
Geothermal Power, Vol. 226, No. 1, pgs. 70-77; Janu-
ary, 1972.

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[57] **ABSTRACT**

Hot fluid which may contain salts and other dissolved minerals as well as some fixed gases and especially hot water from a geothermal well is passed through successive flash chambers operating at progressively lower temperatures and pressures. Some of the flash chambers may operate below atmospheric pressure. The steam from each flash chamber is passed in heat exchange relationship with a working fluid to superheat the working fluid. The working fluid operating in a closed loop after being heated is expanded in a power extracting gas expansion device for the generation of power. The fixed gases or non-condensable gases are removed at the output of the highest temperature heat exchanger and released to the atmosphere or passed through a prime mover to recover additional power. The hot fluid at the output of each heat exchanger is either combined with the steam at the output of the next flash chamber and passed through the next heat exchanger or applied to the input of the next flash chamber in conjunction with the hot fluid that is not converted to steam from the preceding flash chamber.

30 Claims, 5 Drawing Figures

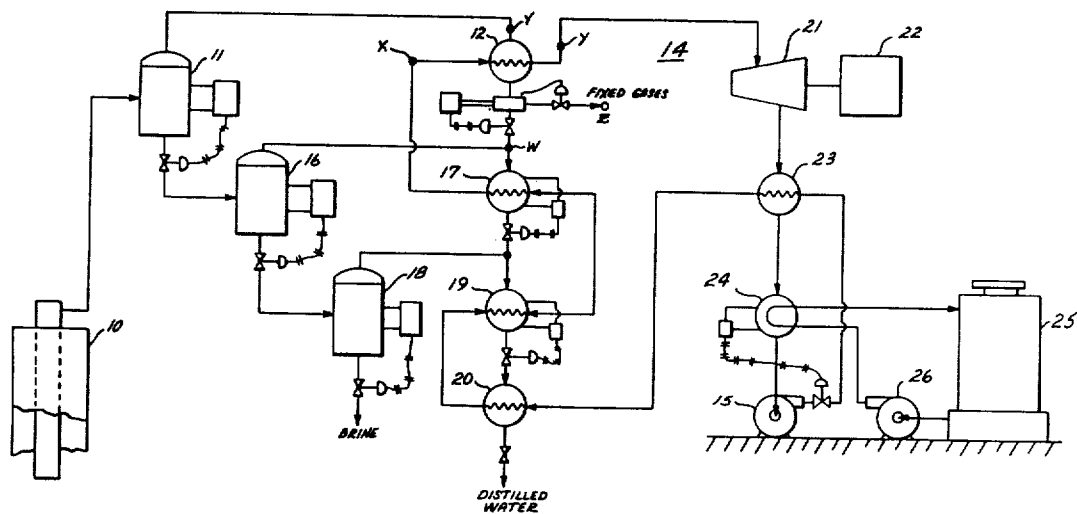


FIG. 1

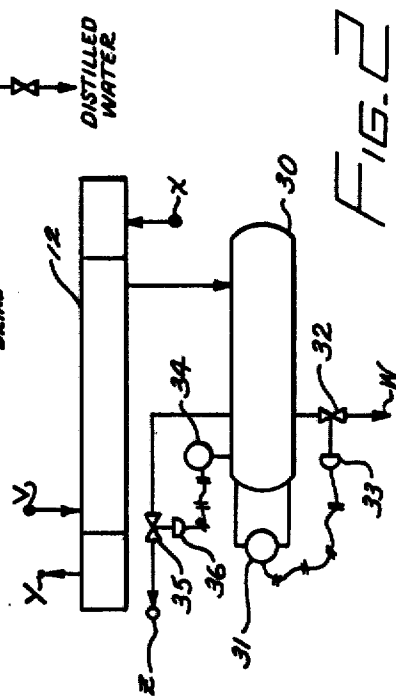
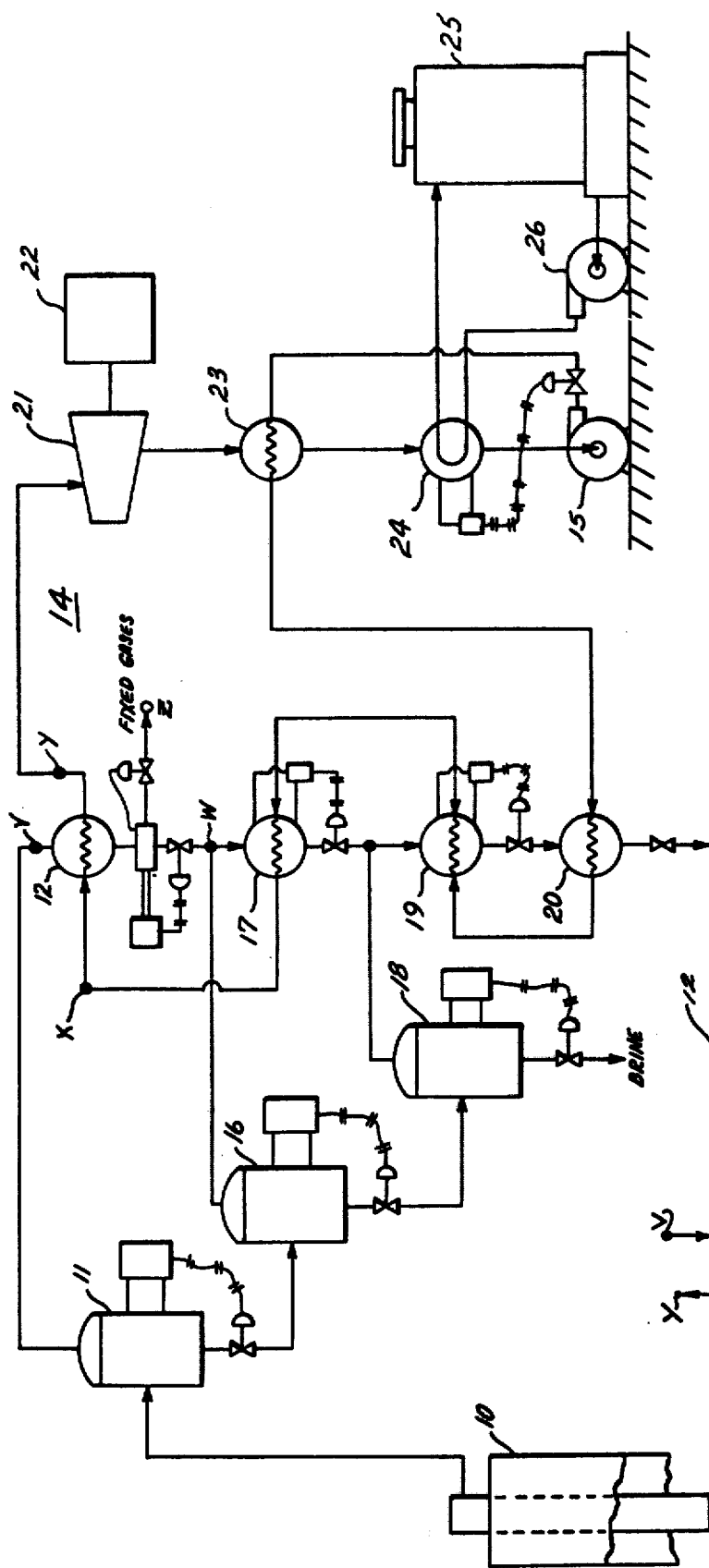


FIG. 3

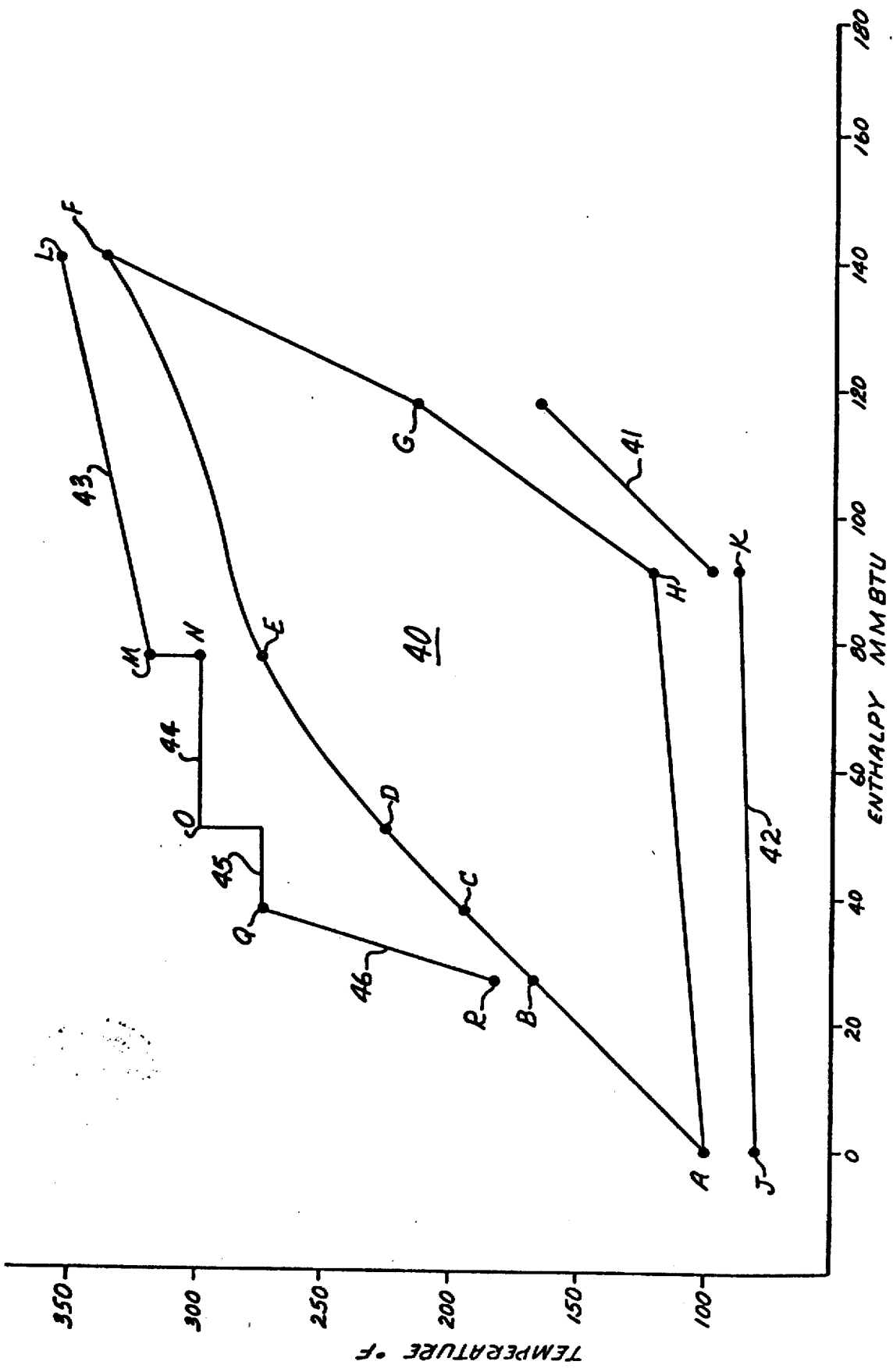


FIG. 4

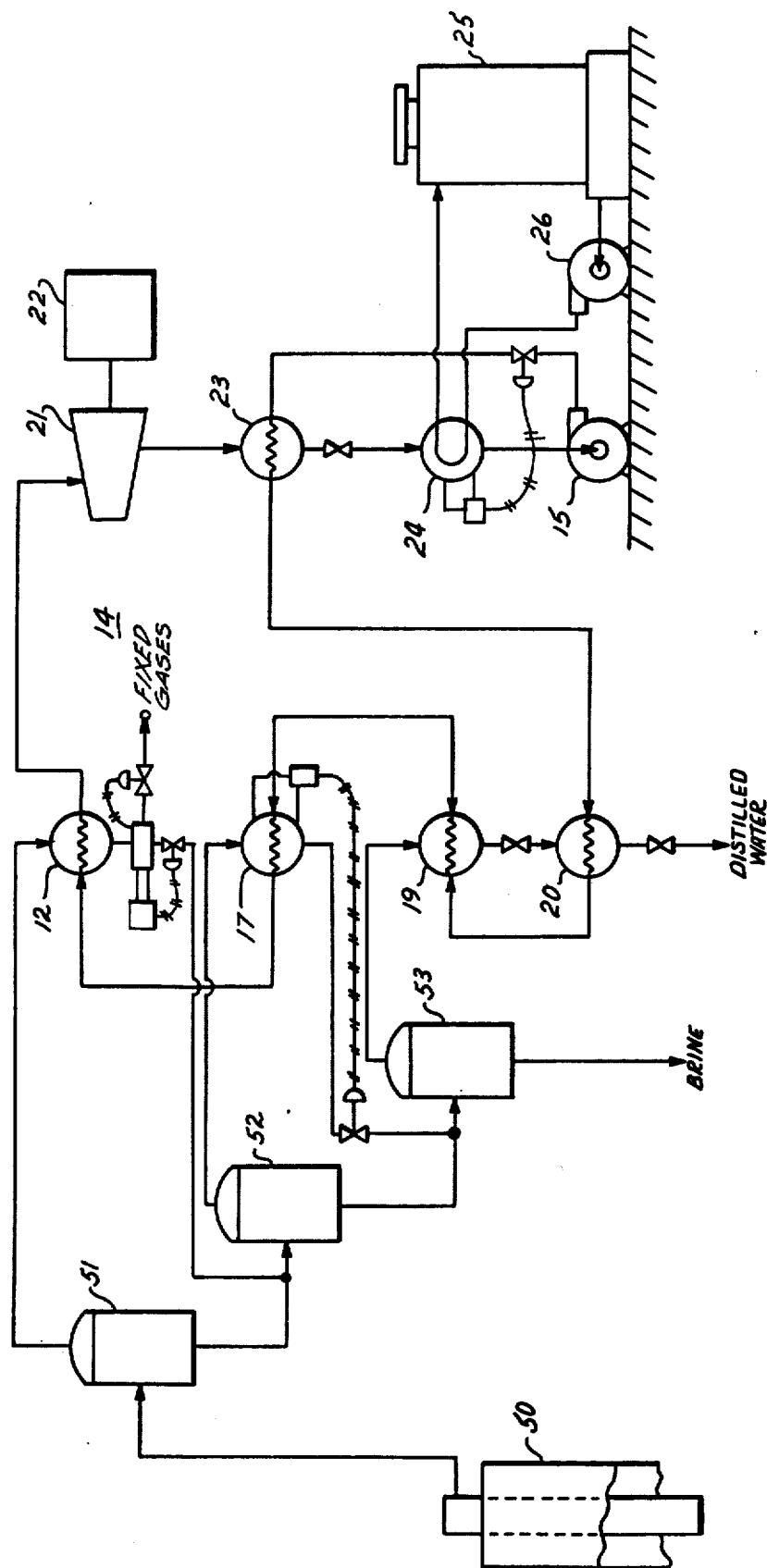
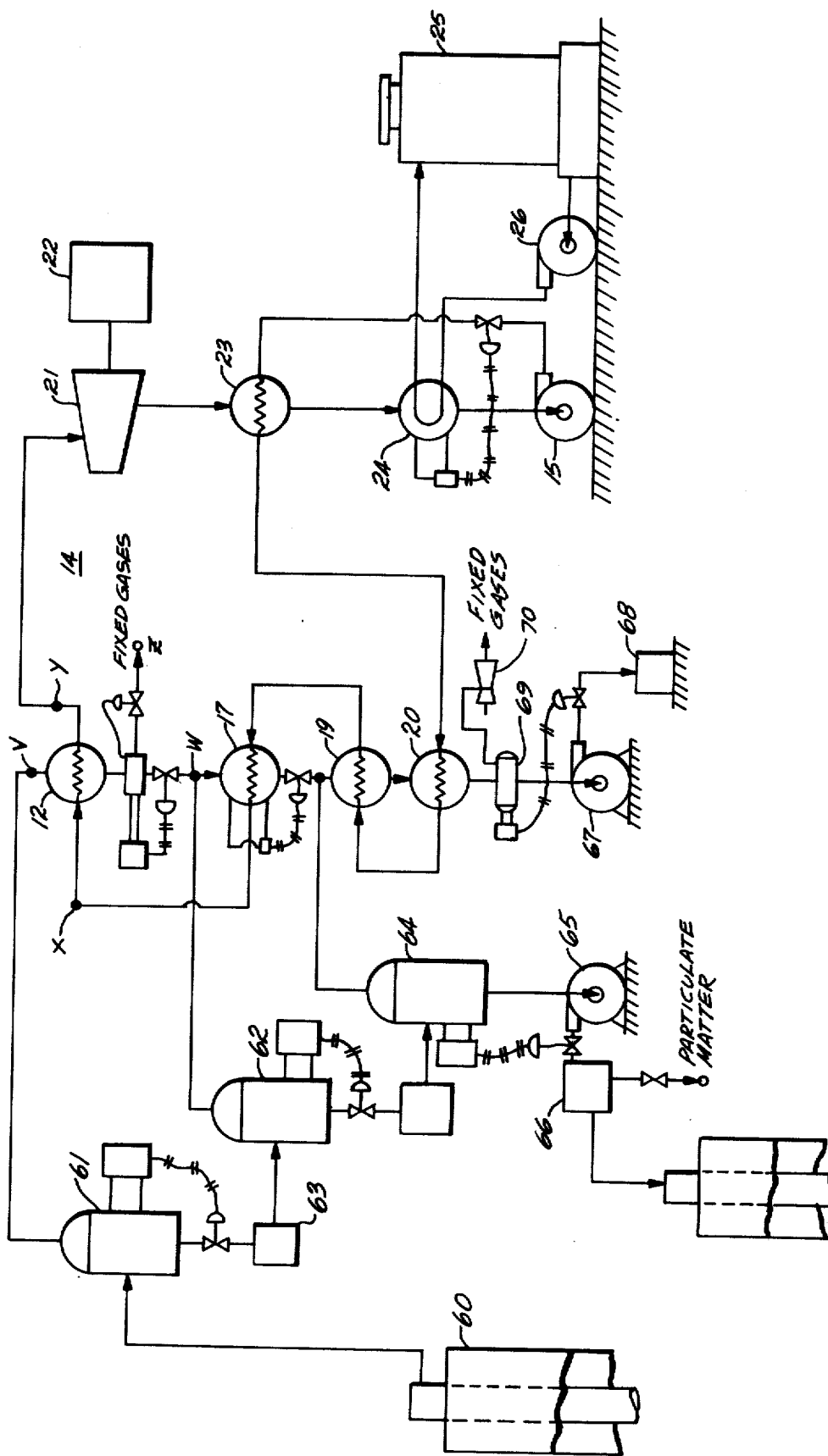


FIG. 5



1

GEOTHERMAL HEAT RECOVERY BY MULTIPLE FLASHING

RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 301,258 filed Oct. 26, 1972, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to extraction of useful energy from hot fluids which may contain salts and other dissolved minerals and more particularly to the recovery of such energy while eliminating scaling in the heat exchangers of the system.

It is known that the interior of the earth is a molten mass of rocks and is very hot. This geothermal heat energy may advantageously and efficiently be employed as a primary source of energy for the generation of power through fluid as a carrier. The fluid may appear as steam released from volcanic areas or hot water which is present in volcanic deposits and deep alluvial deposits that are porous enough to permit percolation of water to the deep hot zones. This fluid may have a temperature as high as 700°F. at a depth of 5,000 feet.

2. Description of the Prior Art

In areas where steam alone is produced, the steam may be used directly in turbines to drive generators to generate electricity. Where there is a mixture of steam and hot water, the steam may be separated in a flash chamber and then used in a steam turbine. However, the steam and the hot water generally contain corrosive materials that can cause destruction of the critical and expensive parts of the rotating machinery employed to convert the heat energy into mechanical and/or electrical energy.

As an efficient way of utilizing hot fluid which may contain salts and other dissolved minerals, especially hot fluids from a geothermal well, a working fluid may be superheated by passing the working fluid in heat exchange relationship with the hot fluid. The working fluid has a boiling point that is below the input temperature of the hot fluid and advantageously is given sufficient superheat to avoid condensation in a prime mover having at least 75% conversion efficiency. This method and apparatus for utilizing the hot fluid as a primary source of energy is disclosed in the copending application Ser. No. 301,056, filed Oct. 26, 1972, now abandoned, and represents an efficient way for generating power from hot fluids.

However, there are some hot fluids that contain such a degree of salts and other dissolved minerals that the above method may not be efficiently and economically useful over a long period of time. For example, it is known that the water from some of the geothermal wells in the Imperial Valley in California have more than 350,000 parts per million of dissolved solids which include salts and other minerals. The passage of this brine through a heat exchanger can result in the deposit of silica and other types of scale therein with a substantial decrease in the heat transfer efficiency within the heat exchanger and an increase in the pressure drop of the brine through the exchanger.

SUMMARY OF THE INVENTION

In accordance with this invention, the deposition of the minerals is substantially eliminated. A hot fluid that

2

may contain salts and other dissolved minerals and fixed gases is passed through successive flash chambers that are operated at progressively lower temperatures and pressures. The steam from each flash chamber is thereafter passed through a heat exchanger in heat exchange relationship with a working fluid. The working fluid is superheated as it passes through the heat exchangers and is subsequently expanded in a power extracting gas expansion device. The working fluid operates in a closed loop and is condensed after expansion and circulated through the closed loop. The hot fluid at the output of each heat exchanger may be combined at the input to the next lower temperature heat exchanger with the steam from the next lower temperature flash chamber for recovery of the heat remaining in the hot fluid. Advantageously, the working fluid is given sufficient superheat to avoid condensation in a prime mover having at least 75% conversion efficiency. For economical recovery of the heat from the superheated working fluid, the working fluid may also be selected such that the specific heat of the working fluid vapors is greater than 50% of the specific heat of the working fluid as a liquid over the same temperature range under the operating pressures of the process.

The working fluid circulates in a closed loop and for improved efficiency the heat remaining in the working fluid after expansion may be recovered by passing the working fluid at the output of the prime mover in heat exchange relationship with the working fluid as a liquid. The fixed gases or non-condensable gases that may be present in the hot fluid are carried through the highest temperature heat exchanger and are controllably removed from the hot fluid at the output of this heat exchanger while maintaining a constant ratio of steam to fixed gas to keep the heat exchanger and its associated fixed gas removing means from vapor locking. If there are sufficient fixed gases, the removed gases may be passed through a prime mover to produce additional power.

The hot fluid at the output of the last heat exchanger is substantially pure distilled water which may be recovered for subsequent use. The output of the lowest temperature flash chamber, other than the steam output, may be a high concentration brine that may be returned to the earth or retained for the removal of one or more of the minerals therein.

As an alternative to combining at the input to the next heat exchanger the steam from the associated flash chamber and the cooled hot fluid from the preceding heat exchanger, the cooled hot fluid from the heat exchanger may be applied to the input of the next flash chamber with the hot fluid from the preceding flash chamber.

To further increase the efficiency of the system, one or more flash chambers may be operated below atmospheric pressure, thereby permitting flashing at a lower temperature for more complete recovery of the heat energy in the hot fluid.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features and advantages of the present invention may be understood more fully and completely upon consideration of the following specification and drawing in which:

FIG. 1 is a process flow diagram for the extraction of useful energy from hot fluid in accordance with this invention;

FIG. 2 is a schematic diagram of the highest temperature heat exchanger and means for removing any fixed gases in the heating fluid;

FIG. 3 is a temperature enthalpy diagram for a typical power cycle of the working fluid with variations in temperature and enthalpy for the hot fluid and the cooling fluid set forth thereon;

FIG. 4 is a process flow diagram for an alternative process for the efficient recovery of heat for the generation of power in accordance with this invention; and

FIG. 5 is a process flow diagram for the process in accordance with this invention wherein flashing also takes place at subatmospheric pressures.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Geothermal heat and some waste heat may be efficiently converted to mechanical energy and finally electrical energy, as disclosed in the above-identified copending application by using hot water or steam or the combination to superheat a working fluid to a temperature to avoid condensation in a prime mover having at least 75% conversion efficiency.

There are many areas where hot fluid can be recovered from a geothermal well at a temperature up to approximately 450°F. or higher. In some areas, the hot fluid or brine will flow naturally to the surface; while, in others, pumping must be resorted to. In any event, the heat in the hot fluid can be recovered for the production of power. Additionally, there is considerable waste heat from oil refineries, atomic energy plants, etc. in the same temperature range as the fluid from a geothermal well that can be converted to useful power in accordance with this invention. By transferring heat from hot fluids, brine, and/or steam, such as may be recovered from a geothermal well, to a working fluid which has a low boiling point, such as isobutane, and expanding the vapors so produced through a prime mover, a large amount of the heat may be converted to useful power. The working fluid exhausting from the prime mover can be condensed and passed in heat exchange relationship with the fluid at the output of the prime mover to recover some of the heat remaining in the working fluid after expansion. The working fluid may be recycled in the system.

The hot fluid or brine, at a temperature from approximately 130°F. to 200°F., after passing in heat exchange relationship with the working fluid can be passed back into the earth or, alternatively, treated to recover valuable dissolved minerals. Where the hot fluid has salts and other dissolved minerals, such as exists with the water from geothermal wells in the Imperial Valley of California, scaling may occur by the adherence of salts or other dissolved minerals to the surfaces of the heat exchangers. This can greatly increase the pressure drop in the system and reduce the heat exchange transfer rate and substantially reduce the overall efficiency of the system.

In order to overcome these difficulties, the hot fluid which acts as a carrier from the primary source of energy, such as heat in the interior of the earth, is, in accordance with this invention, passed through successive flash chambers operating at progressively lower temperatures and pressures with the resultant gas or steam being passed in heat exchange relationship with a working fluid to superheat the working fluid. Subsequently, the superheated working fluid is expanded in

a power extracting gas expansion device for the production of useful power.

A process flow diagram for the efficient recovery of energy from fluid which may contain salts and/or other dissolved minerals therein is shown in FIG. 1. For purposes of illustration, it is assumed that the hot fluid is principally water from a geothermal well 10. The fluid may contain a large amount of salts and/or other dissolved minerals as is found in the fluid from geothermal wells in the Imperial Valley of California.

Typically, the geothermal well fluid at the surface has a temperature below 450°F. and for purposes of illustration it is assumed herein that the fluid has a temperature of 350°F. and contains a mixture of steam, fixed gases and water with dissolved salts and minerals therein. The hot fluid from the well 10 is passed through a first flash chamber 11, wherein steam is flashed off from the hot fluid. The steam from the flash chamber 11 is applied to a first heat exchanger 12 through which a working fluid passes in heat exchange relationship with the steam. The working fluid is circulated in a closed loop 14 by a pump 15. The working fluid is selected to have a boiling point below the input temperature of the hot fluid applied to the flash chambers and is given sufficient superheat in the heat exchangers to avoid condensation in a prime mover that has a 75% conversion efficiency.

Additionally, for the economical recovery of the heat from the vapors of the working fluid after expansion, the working fluid may be selected, as it is in this illustrative example, so that the specific heat as a vapor is greater than 50% of the specific heat as a liquid over the same temperature range under the operating pressures of the system. For geothermal fluid as the hot fluid and isobutane as the working fluid the input temperature of the working fluid to the power extracting gas expansion device will typically be around 320°F. and at a pressure of 450 psig or higher. For these input conditions the output conditions will typically be in the range of 100°F. to 250°F. and around 50 psig.

The brine or fluid remaining in the flash chamber 11 is passed to a second flash chamber 16 operating at a lower temperature and pressure than the flash chamber 11. The steam from flash chamber 16 is coupled to a second heat exchanger 17 in which the working fluid is passed in heat exchange relationship with this steam. The fluid at the output of heat exchanger 12, which is advantageously a liquid as a result of a condensing heat transfer mode in heat exchanger 12, is combined with the steam at the output of flash chamber 16 at the input to heat exchanger 17 for the removal of some of the heat remaining in this fluid. The brine or fluid, which may contain salts and other dissolved minerals, remaining in flash chamber 16 is passed to a subsequent flash chamber 18 operating at a still lower temperature and pressure than the flash chamber 16. The steam from flash chamber 18 is applied to a heat exchanger 19 through which the working fluid passes in heat exchange relationship with the steam. The still hot liquid at the output of heat exchanger 17 is combined with the steam from flash chamber 18 at the input of heat exchanger 19 for the removal of some of the heat remaining in this fluid.

Additionally, heat exchanger 20, which may represent one or more heat exchangers, may be included for the passage of the fluid therethrough for the removal of any heat that remains in the fluid and for the complete

condensation of the fluid. The resultant output of relatively pure distilled water may either be returned to the earth with the brine or recovered for some useful purpose. The working fluid flows in heat exchange relationship with the fluid in heat exchanger 20.

Even though three flash chambers and four heat exchangers are shown in the process flow diagram of FIG. 1, it is of course recognized that this is only illustrative and a fewer number or greater number of each may be employed as required.

The working fluid in the closed loop 14, after being superheated in passing through the heat exchangers 12, 17, 19 and 20, is expanded in a power extracting gas expansion device, such as a turbine 21, representatively shown in FIG. 1. The turbine 21 may drive a utilization means, such as generator 22 for the generation of electricity. The expanded gas at the output of turbine 21 may be passed in heat exchange relationship with the working fluid as a liquid in a heat exchanger 23 at the output of turbine 21. Advantageously some of the heat remaining in the working fluid at the output of the turbine 21 is transferred to the working fluid as a liquid, which greatly increases the efficiency of the system. Although exchanger 23 materially increases the efficiency of the process, the process can be operated by passing the vapors from prime mover 21 directly to a condenser 24 and passing the working fluid directly from pump 15 to exchanger 20. This method of operation will materially increase the heat load on cooling tower 25 and the water rate through condenser 24.

The working fluid at the output of the heat exchanger 23 as a vapor is passed through a condenser 24 where any remaining superheat is removed and the working fluid is condensed. The cooling fluid, such as water from a cooling tower 25 is circulated by a pump 26 through the condenser 24 for condensing the working fluid. The cooling tower may advantageously be operated at atmospheric conditions.

In addition to the possibility of salts and other dissolved minerals in the hot fluid, fixed gases such as carbon dioxide may be present in the hot fluid. These fixed gases will pass with the steam from flash chamber 11 into the heat exchanger 12. These fixed gases may be removed from the hot fluid by apparatus, representatively shown in FIG. 2.

The apparatus shown in FIG. 2 is connected to the terminals V, W, X, Y, and Z, set forth on the process flow diagram of FIG. 1. The steam from flash chamber 11 is applied to terminal V and enters the heat exchanger 12 at the left end thereof. The working fluid is applied to terminal X and enters the right or colder end of the heat exchanger 12 and passes from the right to the left through the heat exchanger in heat exchange relationship with the steam that is passed from the left to the right through the heat exchanger. The heated working fluid exits from the left end of the heat exchanger 12 and appears at terminal Y. The steam, with any fixed gases carried thereby, passes into a separation chamber 30 coupled to the output of the heat exchanger 12. The hot fluid with the fixed gases entering the chamber 30 is primarily a liquid which may have a small amount of steam therein. Attached to the chamber 30 is a liquid level controller 31 which senses the level of the liquid within the chamber and controls a valve 32 through a motor 33. The control may be done electrically or pneumatically, or by some other means. As a consequence of the liquid level controller 31 con-

trolling the valve 32, a selected level of liquid is maintained in the chamber 30.

A temperature controller 34 is also connected to the chamber 30 for sensing the temperature within the chamber. The temperature controller controls a valve 35 through a motor 36 for controlling the rate of flow of the fixed gases and remaining steam from the chamber 30. The temperature controller 34 maintains a selected constant ratio of steam to fixed gas in the chamber 30 and keeps the chamber from vapor locking, a condition that would exist if the fixed gases were not eliminated. The temperature within the chamber 30 goes down as the proportion of fixed gas increases. The temperature controller 34 sensing the decrease in temperature, opens the valve 35 further to remove more fixed gas. If there is sufficient fixed gases in the hot fluid from whatever source is employed, such as the geothermal well 10, these gases may be passed through output terminal Z through an appropriate prime mover to produce additional power. Otherwise the gases may just be released to the atmosphere.

In one illustrative example, hot fluid from a geothermal well having a surface temperature of 356°F. and containing some degree of fixed gases and salts and other dissolved minerals and a working fluid of a mixture of isobutane and isopentane in the molal ratio of 4 isobutane to 1 isopentane in the process and apparatus illustrated by the process flow diagram of FIG. 1 results in the temperature enthalpy diagram of FIG. 3. Flash chamber 11 is operated at a temperature of 356°F. and 130 psig. Flash chamber 16 is operated at a temperature of 300°F. and 52 psig, and flash chamber 18 is operated at a temperature of 275°F. and 30 psig. As a typical example, 127,400 lbs/hr of steam is produced in flash chamber 11 with 11,100 lbs/hr. of non-condensable or fixed gases being present therein. 48,000 lbs/hr of steam is produced at the output of flash chamber 16 at 300°F. and 19,850 lbs/hr is produced at the output of flash chamber 18 at 275°F. If 7,400 lbs/hr of steam is removed with the 11,100 lbs/hr of fixed gases at the output of heat exchanger 12, then 187,850 lbs/hr of distilled water will appear at the output of heat exchanger 20. With 1,049,000 pounds per hour of mixed hydrocarbons, such as the 4 to 1 molal ration of isobutane to isopentane as the working fluid, the working fluid has the following temperatures and pressures in the closed loop 14.

The working fluid at the output of pump 15 has a temperature of 100°F. at a pressure of 515 psig. The temperature of the working fluid at the output of heat exchanger 23 is 168°F., at the output of heat exchanger 20 is 196°F., at the output of heat exchanger 19 is 226°F., at the output of heat exchanger 17 is 276°F., and at the output of heat exchanger 12 is 340°F. and has sufficient superheat to avoid condensation in a prime mover that has at least a 75% conversion efficiency. Thus, the working fluid at the input to turbine 21 has a temperature of 340°F. and a pressure of 485 psig, with a 30 psig drop in the pipes and heat exchangers. In expanding in the turbine 21, the temperature and pressure of the working fluid reduces to 216°F. and 48 psig respectively. The temperature of the working fluid is further reduced to 123°F. in passing through heat exchanger 23 in heat exchange relationship with the working fluid as a liquid. The temperature of the working fluid is subsequently reduced in the condenser 24 to 100°F. by water from a cooling tower entering at

80°F. and exiting at 90°F. The cooling tower 25 and pump 26 provides 31,090 gallons of water per minute through condenser 24.

Now referring to FIG. 3, the power cycle 40 for the working fluid results from the process in accordance with the present invention operating under the above temperatures and pressures. The working fluid gives up approximately 26,000,000 BTU's of superheat as represented by curve 41, in heating the working fluid as a liquid in heat exchanger 23. The temperature of the working fluid progresses between points A and B along the power cycle 40 in the heat exchanger 23. The working fluid is further heated to point C in heat exchanger 20, to point D in heat exchanger 19, to point E in heat exchanger 17, and point F in heat exchanger 12. The working fluid gives up energy between points F and G in passing through the turbine 21. The working fluid gives up heat in the heat exchanger 23 between points G and H and is de-superheated and condensed in condenser 24 between points H and A. The cooling fluid from the cooling tower 25 increases in temperature and absorbs heat, as represented by curve 42 between points J and K thereof. The hot fluid which is converted to steam in the flash chambers 11, 16, and 18, gives up heat along the curves 43, 44, 45, and 46 of FIG. 3. The steam with the fixed gases from flash chamber 11 in passing from points L and M on curve 43 decreases in temperature because of the presence of the fixed gases. The presence of the fixed gases in the steam going into heat exchanger 12 reduces the condensation temperature due to the partial pressure effect of these fixed gases. Thus, curve 43 differs from curves 44 and 45 because of the assumed presence of these gases in the above ratio. Advantageously, the steam in each heat exchanger 12, 17, and 19 operates in a condensing heat transfer mode and exits from the heat exchangers as a liquid. The combined steam from flash chamber 17 and the fluid at the output of heat exchanger 12 transfers heat to the working fluid along curve 44 between points N and O. The combined steam from flash chamber 18 and fluid at the output of heat exchanger 17 transfer heat to the working fluid in heat exchanger 19 along the curve 45 between points P and Q. The heat remaining in the fluid is transferred to the working fluid in heat exchanger 20 along curve 46 between points Q and R.

In this system, with geothermal well water as the hot fluid and mixed hydrocarbons as the working fluid produces the power cycle 40, set forth in FIG. 3. Typical turbines and generators can in accordance with this invention efficiently generate 11,500 kilowatt hours of electrical power or more than 15,400 horsepower. The working fluid is selected to be compatible with the hot fluid and temperatures and pressures of the system are selected to produce the greatest efficiency with practical equipment while considering available materials and costs.

As an alternative to the process of the apparatus representatively shown by the process diagram of FIG. 1, where the fluid at the output of each heat exchanger is combined with the steam from the next steam chamber, the fluid at the output of each heat exchanger may be applied to the input of the next flash chamber, as shown in the process flow diagram of FIG. 4. In FIG. 4, the working fluid operates in the same closed loop 14 and passes through the same devices as representatively shown in FIG. 1, which devices have the same FIG.

numbers as the devices in FIG. 1. In the process flow diagram of FIG. 4, hot fluid, which is representatively shown as fluid from a geothermal well 50, is applied to a first flash chamber 51, operating at the desired temperature and pressure. The steam and any fixed gases in the hot fluid are transferred from flash chamber 51 to the first heat exchanger 12 for heating the working fluid that passes therethrough. The fixed gases are again removed at the output of the heat exchanger 12 in the same manner as in the process flow diagram of FIG. 1. Not all of the controls, such as liquid level controllers and control valves are shown in either FIGS. 1 or 4 because they do not form a part of this invention and the fact that the use of these devices as required is well understood by those skilled in the art.

The water at the output of heat exchanger 12 is combined with the brine or fluid which may contain salts or other dissolved minerals at the output of flash chamber 51 for insertion in the next lower temperature and flash chamber 52. Similarly, the fluid at the output of heat exchanger 17 is combined with the brine or fluid at the output of flash chamber 52 to be inserted together into flash chamber 53. In this way the heat remaining in the fluid after passing through a heat exchanger is recovered in one or more subsequent flash chambers for the efficient utilization of heat energy in the hot fluid. Also by combining the condensate with the brine, the deposition of salts and scale in the flash tanks and piping is reduced and the composition of the brine that is returned to the earth is substantially unaltered.

As another alternative to the process representatively shown by the process diagram of FIG. 1, one or more flash chambers may be operated below atmospheric pressure to increase the efficiency of the system by removing even more heat from the hot fluid. This process is representatively shown by the process flow diagram of FIG. 5. In FIG. 5 the working fluid operates in the same closed loop 14 and passes through the same devices as representatively shown in FIG. 1, which devices have the same FIG. numbers as the devices in FIG. 1. In the process flow diagram of FIG. 5, hot fluid, which is representatively shown as fluid from a geothermal well 60, is applied to a first flash chamber 61 operating at the desired temperature and pressure. Typically, the pressure of the first flash chamber will be above atmospheric pressure. The steam and any fixed gases in the hot fluid are transferred from flash chamber 61 to the first heat exchanger 12 for heating the working fluid that passes therethrough. The fixed gases are again removed at the output of the heat exchanger 12 in the same manner as in the process of FIG. 1. The fluid at the output of the heat exchanger 12 may be applied directly to the next heat exchanger or applied to the input of the next flash chamber as representatively shown in FIGS. 1 and 4, respectively. However, for purposes of illustration it is assumed, as shown in FIG. 5, that the fluid from each heat exchanger is applied directly to the next heat exchanger. The hot fluid from flash chamber 61 and any salts and/or minerals dissolved therein is passed to a second flash chamber 62 operating at a lower temperature and pressure than flash chamber 61. A separator 63 may be placed between flash chamber 61 and flash chamber 62 to remove the particulate matter from the hot fluid. Alternatively, the particulate matter may be permitted to remain in the hot fluid in passing through each of the flash chambers.

If each flash chamber is operated above atmospheric pressure, the lowest temperature the water may attain at the output of a flash chamber is 212°F. Thus, to recover more of the remaining heat, one or more flash chambers operating below atmospheric pressure may be employed. Such flash chambers, representatively shown by flash chamber 64, is connected to the output of flash chamber 62. Flash chamber 64 is operated below atmospheric pressure, and consequently, a pump 65 is coupled to the output of flash chamber 64 to remove the hot fluid or brine from this flash chamber. If no separators are employed between the flash chambers, then the particulate matter remaining in the fluid or brine may be removed by a separator 66 connected to the output of the pump 65. It is desirable to remove the particulate matter from the fluid or brine to avoid the plugging of the face of the sands when the fluid is reinjected into the earth, which plugging could stop or retard reinjection. Additionally, the particulate matter may have commercial value and may advantageously be recovered in a separator such as separator 66.

Since the lowest temperature and pressure flash chambers are operated below atmospheric pressure, a pump 67 is required to pump the low pressure condensate out of heat exchangers 19 and 20. The fluid at the output of these heat exchangers, when geothermal fluid is employed, is a relatively pure distilled water and may be recovered in a container 68 for further use at the output of pump 67.

The majority of the fixed gases that appear in the hot fluid will be removed at the output of the first heat exchanger 12. Any fixed gases that remain in the hot fluid may be removed at the output of succeeding heat exchangers, such as representatively shown by the device 69 and ejector 70 connected to the output of heat exchanger 20.

Various changes may be made in the details of the process without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. A method of converting heat energy carried by brine to mechanical energy comprising the steps of:
 - passing the brine through successive flash chambers operating at progressively lower temperatures and pressures;
 - passing the steam from each flash chamber through an associated heat exchanger in heat exchange relationship with a working fluid to superheat the working fluid;
 - expanding the working fluid in a power extracting gas expansion device;
 - condensing the working fluid after expansion; and
 - circulating the working fluid in a closed loop including at least devices for heat exchange, gas expansion and fluid condensing.
2. The method in accordance with claim 1 wherein the working fluid is given sufficient superheat to avoid condensation in a prime mover having at least 75% conversion efficiency.
3. The method in accordance with claim 1 wherein the working fluid has a specific heat as a vapor that is at least 50% of the specific heat as a liquid over the same temperature range under the operating pressures of the system.
4. The method in accordance with claim 3 wherein the temperature range may be between 100°F. and 250°F. with the higher temperature of the range

being the maximum temperature of the working fluid at the output of the gas expansion device.

5. The method in accordance with claim 1 further comprising the additional step of:

passing the working fluid as a liquid in heat exchange relationship with the expanded working fluid.

6. The method in accordance with claim 1 further comprising the additional step of:

removing from one or more and at least the highest temperature heat exchanger up to 100% of the non-condensable gases carried in the steam in the heat exchanger.

7. The method in accordance with claim 1 further comprising the additional step of:

recovering the distilled water at the output of one or more of the heat exchangers.

8. The method in accordance with claim 1 comprising the further step of combining, at the input to lower temperature heat exchangers, the condensate from the preceding heat exchanger and the steam from the associated flash chamber.

9. The method in accordance with claim 1 comprising the further step of combining, at the input to lower temperature flash chambers, the condensate from the heat exchanger associated with the next higher temperature flash chamber and the unflashed fluid from the next higher temperature flash chamber.

10. Method of utilizing the heat in fluid from a geothermal well where the fluid may contain fixed gases and salts and other minerals dissolved therein to produce useful power comprising the steps of:

passing the fluid through successive flash chambers operating at progressively lower temperatures and pressures;

passing the steam from each flash chamber in heat exchange relationship with a working fluid to superheat the working fluid; and

expanding the working fluid in a power extracting gas expansion device.

11. The method in accordance with claim 10 comprising the further steps of:

condensing the working fluid after expansion; and circulating the working fluid in a closed loop including at least the devices for heat exchanging, gas expansion and fluid condensing.

12. The method in accordance with claim 10 comprising the further step of:

removing from one or more and at least the highest temperature heat exchanger up to 100% of the non-condensable gases carried in the steam in the heat exchanger.

13. The method in accordance with claim 10 comprising the further step of:

combining at the input to the next lower temperature heat exchanger the condensate at the output of the next higher temperature heat exchanger with the steam from the next lower temperature flash chamber.

14. The method in accordance with claim 10 comprising the further step of:

combining at the input to the next flash chamber the condensate at the output of each heat exchanger with the fluid at the output of the flash chamber from which the condensate originated.

15. A method of converting heat energy carried by hot fluid to mechanical energy comprising the steps of:

passing the hot fluid through successive flash chambers operating at progressively lower temperatures and pressures with at least one chamber operating above atmospheric pressure and at least one chamber operating below atmospheric pressure;
 passing the gas from each flash chamber through a heat exchanger in heat exchange relationship with a working fluid to superheat the working fluid; and
 expanding the working fluid in a power extracting gas expansion device.

16. A method of converting heat energy carried by a hot fluid having salts and/or other minerals dissolved therein or particulate matter to mechanical energy comprising the steps of:

passing the hot fluid through two or more flash chambers in succession, the successive flash chambers operating at progressively lower temperatures and pressures, with at least one flash chamber operating below atmospheric pressure;

passing the gas from each flash chamber through a heat exchanger in heat exchange relationship with a working fluid to superheat the working fluid; and
 expanding the working fluid in a power extracting gas expansion device.

17. The method in accordance with claim 16 comprising the further step of:

recovering the particulate matter at the output of each flash chamber.

18. The method in accordance with claim 16 comprising the further step of:

recovering the particulate matter from the flash chamber operating at the lowest temperature and pressure.

19. The method in accordance with claim 16 comprising the further step of:

removing any fixed gases in the hot fluid at the output of at least the heat exchanger operating at the highest temperature.

20. The method in accordance with claim 19 comprising the further step of passing the recovered fixed gases through a power extracting gas expansion device.

21. A method of converting heat energy carried by hot fluid to mechanical energy comprising the steps of:

passing the hot fluid through successive flash chambers operating at progressively lower temperatures and pressures;

passing the gas from each flash chamber through a heat exchanger in heat exchange relationship with a working fluid to superheat the working fluid; expanding the working fluid in a power extracting gas expansion device;

condensing the working fluid after expansion; and
 circulating the working fluid in a closed loop including at least devices for heat exchange, gas expansion and fluid condensing.

22. A method of converting heat energy carried by a hot fluid to mechanical energy comprising the steps of:

passing the hot fluid through two or more flash chambers in succession, the successive flash chambers operating at progressively lower temperatures and pressures, with at least one flash chamber operating above atmospheric pressure;

passing the gas from each flash chamber through a heat exchanger in heat exchange relationship with a working fluid to superheat the working fluid; expanding the working fluid in a power extracting gas expansion device;

condensing the working fluid after expansion; and
 circulating the working fluid in a closed loop including at least devices for heat exchange, gas expansion and fluid condensing.

23. A method of converting heat energy carried by a hot fluid having salts and/or other minerals dissolved therein or particulate matter to mechanical energy comprising the steps of:

passing the hot fluid having salts and/or other minerals dissolved therein as particulate matter through two or more flash chambers in succession, the successive flash chambers operating at progressively lower temperatures and pressures, with at least one flash chamber operating above atmospheric pressure;

passing the gas from each flash chamber through a heat exchanger in heat exchange relationship with a working fluid to superheat the working fluid; expanding the working fluid in a power extracting gas expansion device;

condensing the working fluid after expansion; circulating the working fluid in a closed loop including at least devices for heat exchange, gas expansion and fluid condensing; and

recovering the particulate matter at the output of each flash chamber.

24. A method of converting heat energy carried by a hot fluid having salts and/or other minerals dissolved therein as particulate matter to mechanical energy comprising the steps of:

passing the hot fluid having salts and/or other minerals dissolved therein as particulate matter through two or more flash chambers in succession, the successive flash chambers operating at progressively lower temperatures and pressures, with at least one flash chamber operating above atmospheric pressure;

passing the gas from each flash chamber through a heat exchanger in heat exchange relationship with a working fluid to superheat the working fluid; expanding the working fluid after expansion;

circulating the working fluid in a closed loop including at least devices for heat exchange, gas expansion and fluid condensing; and

recovering the particulate matter from the flash chamber operating at the lowest temperature and pressure.

25. A method of converting heat energy carried by a hot fluid having fixed gases therein to mechanical energy comprising the steps of:

passing the hot fluid having fixed gases therein through two or more flash chambers in succession, the successive flash chambers operating at progressively lower temperatures and pressures, with at least one flash chamber operating above atmospheric pressure;

passing the gas from each flash chamber through a heat exchanger in heat exchange relationship with a working fluid to superheat the working fluid; expanding the working fluid in a power extracting gas expansion device;

condensing the working fluid after expansion; circulating the working fluid in a closed loop including at least devices for heat exchange, gas expansion and fluid condensing; and

13

removing the fixed gases in the hot fluid at the output of at least the heat exchanger operating at the highest temperature.

26. The method in accordance with claim 25 comprising the further step of passing the recovered fixed gases through a power extracting gas expansion device.

27. A method in accordance with claim 1 wherein the working fluid is a mixture of substances.

28. A method in accordance with claim 1 comprising the further step of maintaining the pressure of the working fluid at the input to the power extracting gas

14

expansion device above the critical pressure of the working fluid.

29. A method in accordance with claim 10 wherein the working fluid is a mixture of substances.

30. A method in accordance with claim 10 comprising the further step of maintaining the pressure of the working fluid at the input to the power extracting gas expansion device above the critical pressure of the working fluid.

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