

[54] DUAL FLUID CYCLE

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[58] Field of Search ..... 60/38, 95

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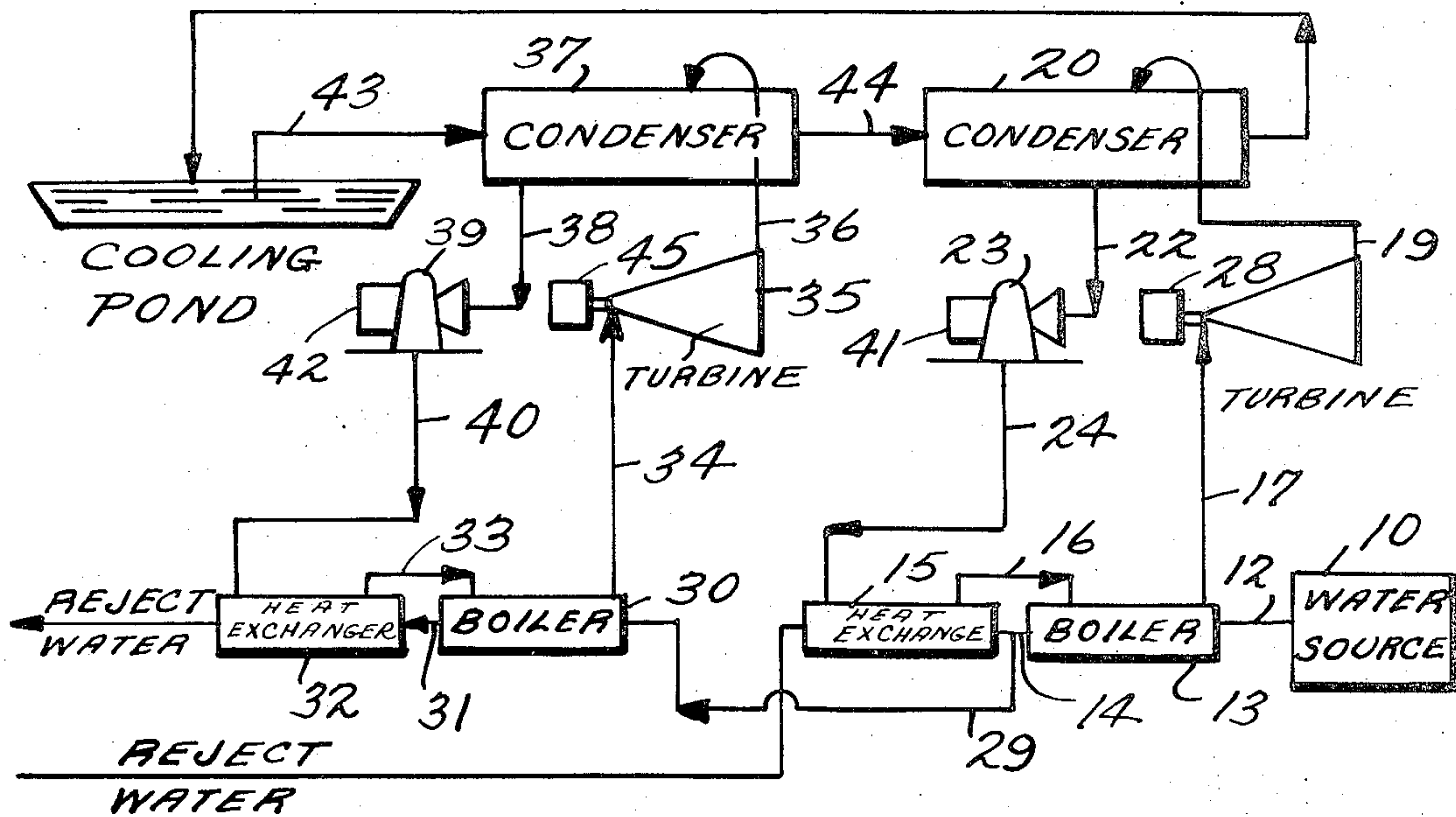
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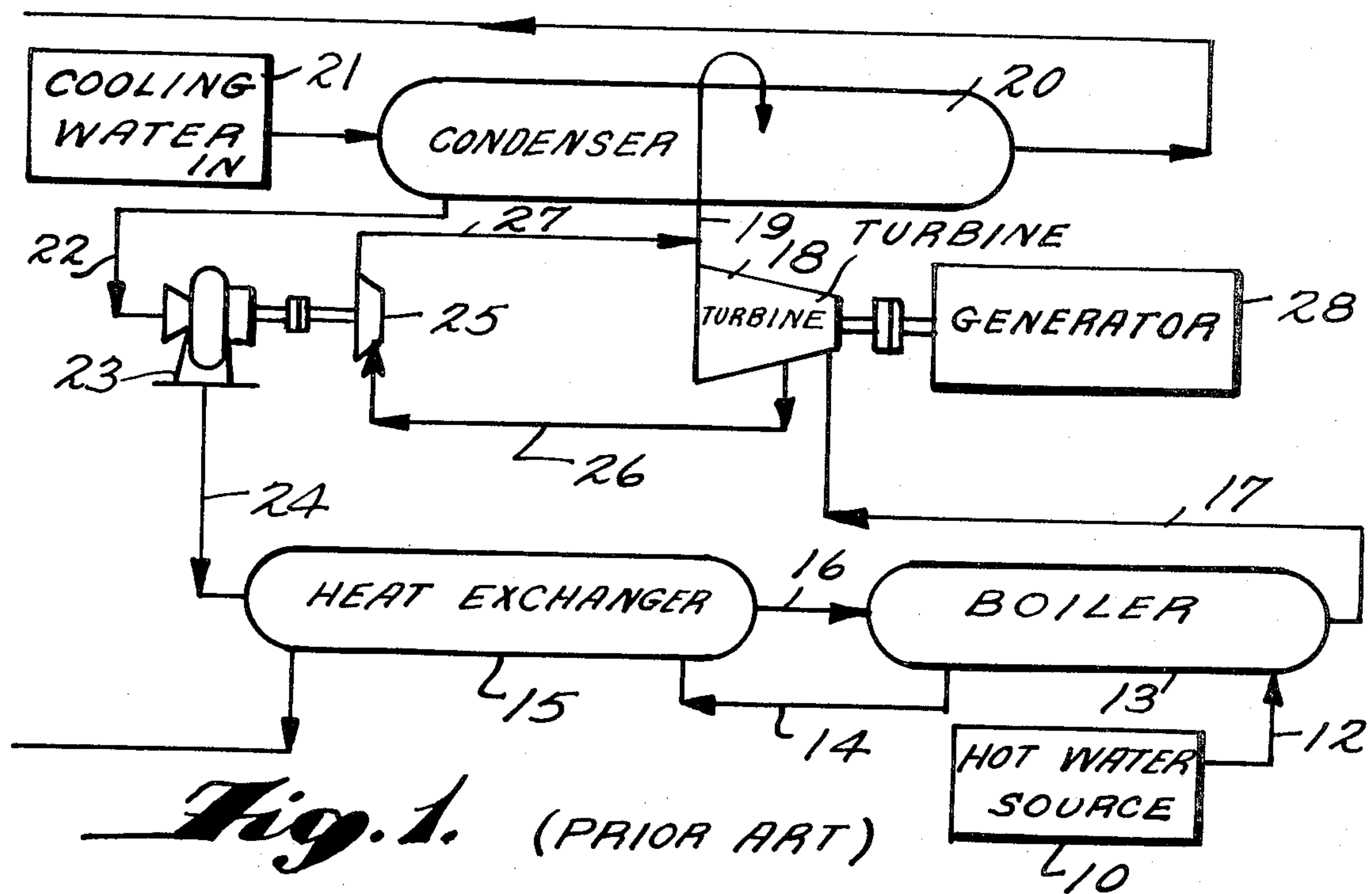
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[57] ABSTRACT

Power is extracted from a stream of hot fluid, such as geothermal water, by passing the stream in heat exchange relationship with a working fluid to vaporize the latter, expanding the vapor through a turbine, and condensing the vapor in a conventional Rankine cycle. Additional power is obtained in a second Rankine cycle by employing a portion of the hot fluid after heat exchange with the working fluid to vaporize a second working fluid having a lower boiling point and higher vapor density than the first fluid. Isobutane and R-22 (CH C1 F<sub>2</sub>) may be employed as the first and second working fluids, respectively.

7 Claims, 2 Drawing Figures







## DUAL FLUID CYCLE

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention

This invention relates to systems for extracting power from the heat contained in hot fluids by passing such fluids in heat exchanging relation to other fluids to vaporize the other fluids and then expanding the other fluids through turbines in Rankine cycles to produce power.

## 2. Description of the Prior Art

It is well known to produce power from a source of hot fluid by passing that fluid in heat exchanging with a second fluid so that the second fluid is vaporized and then expanding the second fluid through a turbine to produce power.

One of the largest factors in the initial cost of such power plants is the cost of the heat exchangers in which the hot fluid is passed in heat exchanging relation to the second fluid. The size of the heat exchangers is controlled by the equation  $Q = U\Delta T A$  in which  $Q$  is the heat per unit time passed by the heat exchanger,  $A$  is the heat exchange area of the exchanger which, of course is determined by the size of the exchanger, and the numbers of tubes used therein,  $\Delta T$  is the log mean temperature difference between the fluid being heated and the fluid being cooled and  $U$  is a constant. The quantity  $Q$  is generally fixed by the requirements of the power system so the only way of reducing  $A$ , and thus the size of the heat exchanger is by increasing  $\Delta T$ .

One way to increase  $\Delta T$  is to increase the relative flow rate of the hot fluid to the cold fluid. In this way less heat is taken from each pound of hot fluid and thus the exit temperature of the hot fluid is higher and the log mean temperature difference  $\Delta T$  is greater. However, the increase in flow rate for the hot fluid would require an increase in operational costs in the power plant unless the hot fluid exiting from the heat exchanger can be further utilized, i.e., unless a means is used for producing additional power from the hot fluid.

## SUMMARY OF THE INVENTION

It is the object of this invention to provide a power plant for utilizing the heat from a hot fluid in which the constructional costs are low compared to the power output because the total area of the heat exchangers is small and yet the operational costs are low because a great amount of the heat in the hot fluid is used to produce power.

Basically, the invention comprises the addition to the power plant of a second power cycle using a second power fluid which has a lower boiling temperature as well as a higher vapor density than the first power fluid. A portion of the hot fluid is diverted from the first power cycle to heat and vaporize the second power fluid which is then expanded through a second turbine to produce power. Since the second power fluid has a higher vapor density than the first power fluid it requires a smaller turbine than would the first power fluid for an equivalent power output.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a prior art system for producing power from a hot fluid, and

FIG. 2 shows a system in accord with the invention for producing power from a hot fluid.

The same elements are referred to by the same reference numerals in both Figures.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 shows a conventional Rankine cycle system for producing power from a source of hot fluid which may be, for instance, a geothermal water source 10. Water from source 10 passes through a conduit 12 to a boiler 13 in which the first power fluid, which may be isobutane, is vaporized. The water exits from the boiler at a lower temperature since a portion of its heat has been used to vaporize the isobutane and the water then passes by conduit 14 to the isobutane heater 15 where it also runs in counter-heat exchanging relation to the isobutane to heat the isobutane prior to the power fluid flow through conduit 16 to the boiler 13. From the heater 15 the water is exhausted to a waste water reservoir (not shown).

The isobutane vapor issuing from the boiler 13 passes through conduit 17 to a conventional turbine 18 and is exhausted therethrough to low pressure vapor output 19 which is connected to a condenser 20 wherein the low pressure power fluid vapor is condensed by passing it in heat exchange relation to the cooling water from source 21. The power produced by turbine 18 may, for instance, be transformed to electrical power by use of a generator 28.

From the condenser 20, the isobutane, which is now in the liquid state, passes through a conduit 22, is pressurized by feed pump 23 and passes through conduit 24 back to the isobutane inlet of the heater 15.

The feed pump 23 is operated by a small turbine 25 which is powered by a portion of the isobutane vapor which is removed from turbine 18 at a position intermediate the high pressure and low pressure ends thereof. The vapor passes by conduit 26 to the turbine 25, is expanded through this turbine and is exhausted from the low pressure end thereof by a conduit 27 which communicates with conduit 19 and thus the condenser 20.

In order to decrease the size of boiler 13 and heater 15 it is desirable to increase the flow rate of the hot water passing therethrough. However, in this case, it is also desirable to utilize the heat remaining in the hot water exiting from exchanger 15 or boiler 13 in a subsequent system for producing power. Thus, in FIG. 2 a portion of the hot water flowing through conduit 14 is removed via conduit 29 and passes through a boiler 30 in which a second power fluid for instance, the refrigerant, R-22,  $\text{CHClF}_2$ , chlorodifluoromethane, having a lower boiling temperature than isobutane, is vaporized by the hot water. The water then passes via conduit 31 to a heat exchanger 32 in which the R-22 is heated prior to its vaporization.

Finally, the water, having been relieved of much of its heat content, is rejected from heater 32 to a waste water reservoir. Meanwhile, in the second power cycle, the R-22 which is heated in heater 32 passes by a conduit 33 to the boiler 30 and it is vaporized therein. The R-22 which is now in the vapor state then passes through a conduit 34, to turbine 35 and is expanded therethrough. The R-22 vapor then exits from the low pressure end thereof through a low pressure exhaust conduit 36 to the R-22 condenser 37 where the R-22 changes back to the liquid state.



In the liquid state, the second power fluid passes through conduit 38, a pressurizing pump 39 and conduit 40 to the second power fluid input to heater 32. It is noted that both the pumps 23 and 39 shown in FIG. 2 may be powered, as is the pump in FIG. 1, by a turbine run by the power fluids or they may be powered, as is shown, by motors 41 and 42, respectively.

It is further noted that the cooling water which passes from the cooling pond, through conduit 43 and into the condenser 37 for condensing the R-22 then passes through conduit 44 to the condenser 20 for condensing the isobutane. Since the condensing temperature as well as the boiling temperature of R-22 is lower than that of isobutane, the cooling water is still cool enough after passing through the R-22 condenser fluid 37 to condense the isobutane in condenser 20 and since the isobutane is condensed at a higher temperature, the specific volume at the exhaust of turbine 18 is reduced and thus the size of the turbine 18 is reduced. Furthermore, since R-22 not only has a lower boiling temperature at a given pressure than isobutane, but also has a higher vapor density, the R-22 turbine can be smaller for the same power output than the isobutane turbine. Thus, in FIG. 2 a system is shown which produces a greater power output for a given turbine size, i.e., size of turbine 18 plus turbine 35 and a smaller heat exchanger area, i.e., the total area of the exchangers 13, 15, 30 and 32 than would be required by a single Rankine cycle using the same amount of hot water and a single power fluid, or by two Rankine cycles using a single power fluid.

An example of the efficiencies possible utilizing the system shown in FIG. 2 is described in the following example in which the first power fluid is isobutane, the second power fluid is R-22, and the hot fluid is water. In this example it is assumed that the water issuing from source 10 through conduit 12 has a temperature of approximately 325°F. and the isobutane is heated to a superheat temperature of 300°F. at a pressure of 500 psi in heat exchanger 15 and boiler 13 and that the temperature of the water exiting from boiler 13 into conduit 14 is 277°F. Given these factors, it can be shown through standard calculations that 1.385 pounds of water per pound of isobutane must flow through the boiler 13. If it is further assumed that the isobutane is condensed at a temperature of approximately 72°F. and is vaporized at a temperature of approximately 269°F. then 0.830 pounds of water per pound of isobutane will be needed to raise the isobutane from its condensate temperature of approximately 72°F. to its boiling temperature of approximately 269°F. In other words, 1.385 minus 0.830 or 0.555 pounds of water per pound of isobutane which is needed in the boiler 13 is not needed in the heat exchanger 15 and thus may be split off at conduit 14 for the purpose of heating and boiling R-22.

If it is also assumed that boiler 30 and heater 32 are so designed that the water temperature leaving the boiler 30 is 178°F. and the temperature of water leaving the heater 32 is 121.5°F., it can be determined through well-known calculations that the gross generator output from generator 45 which is attached to turbine 35 is 16.04 Btu per pound of water flowing through the R-22 cycle. It can also be determined from the same type of calculations that for the isobutane cycle described above the gross generator output and Btu per pound of water would be 21.4 Btu per pound

of water entering the isobutane cycle. Thus, for each point of water which enters the isobutane cycle 21.4 Btu of power would be produced from the system and since 0.555/1.385 of each initial pound of water is shunted through the R-22 system an additional 0.555/1.385 (16.04) of 6.4 Btu per pound of water entering the isobutane cycle would be produced by the R-22 system.

This represents a 30 percent increase in the gross generator output per pound of water entering the isobutane cycle over a system such as shown in FIG. 1 and this increase is not accompanied by a great increase in equipment cost. The heat exchangers 32 and 15 and the boilers 30 and 13 may be made much smaller due to the increased water flow therethrough and the additional turbine 35 is smaller than an addition to turbine 18 which would produce equivalent power due to the higher vapor density of R-22.

As a corollary, a system as shown in FIG. 2 may produce equal power to that produced by the system of FIG. 1 while using less total heat exchanger area and less total turbine investment.

While the above description and example fully describe the preferred embodiment of applicant's invention, it should be obvious to one skilled in the art that many modifications are possible within the scope of this invention. Thus, for example, other fluid combinations could be used besides isobutane and R-22. The important factor in selecting the appropriate fluids is that the higher boiling temperature fluid must be at the hotter end of the cycle. In addition, it is obvious that these principles could be extended to apply to a plurality of fluid cycles and need not be limited to two fluid cycles.

Also, both of the turbines in FIG. 2 could be connected to a single generator instead of being as shown connected to separate generators.

What is claimed is:

1. In the method of producing power by vaporizing a first power fluid with a stream of hot fluid passed in heat exchange relationship in a first region with said first power fluid, expanding the vaporized first power fluid to produce power, condensing the first power fluid vapor and passing the condensed power fluid in heat exchange relationship in a second region with said hot fluid, the improvement comprising: passing the hot fluid sequentially through said first and second regions while passing said first power fluid sequentially through said regions in the opposite direction to thereby heat said first power fluid in said second region and to vaporize said first power fluid in said first region, passing a portion of the hot fluid from between said first and second regions into heat exchange relationship with a second power fluid having a lower boiling temperature than said first power fluid to vaporize said second power fluid, expanding said second power fluid to produce power, condensing said second power fluid by passing it in heat exchange relationship with a cooling fluid, then passing the cooling fluid in heat exchange relationship with said vaporized first power fluid to condense the latter.

2. The method of claim 1 wherein said second power fluid has a higher vapor density than said first power fluid.

3. The method of claim 1 wherein said hot fluid is water.



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4. The method of claim 2 wherein said first power fluid is isobutane.

5. The method of claim 4 wherein said second power fluid is R-22.

6. The method of claim 1 wherein said hot fluid is passed in heat exchange relationship with at least a third power fluid after said hot fluid has been passed in

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heat exchange relationship with said second power fluid to produce power in a vaporization and expansion cycle.

7. The method of claim 1 wherein said cooling fluid is a stream of recycled cooling water.

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