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Bronicki et al.

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[54] **HEAT TRANSFER APPARATUS**

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[30] **Foreign Application Priority Data**

Sept. 20, 1972 Israel 40390

[52] **U.S. Cl.** **60/656,** 60/646, 165/105

[51] **Int. Cl.** **F01b 7/00**

[58] **Field of Search** 60/646, 656, 649, 651; 165/105

[56] **References Cited**

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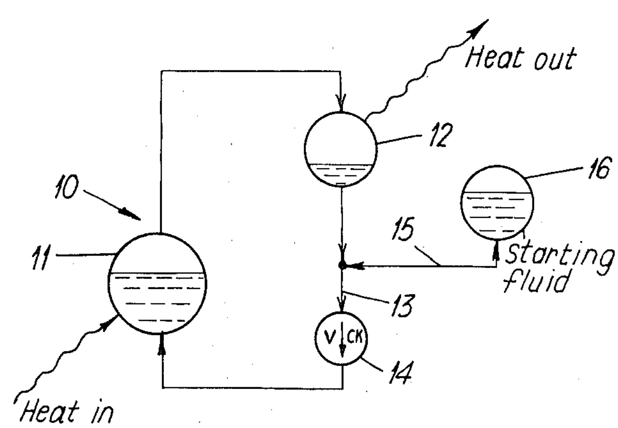
Attorney, Agent, or Firm—Ladas, Parry, Von Gehr, Goldsmith & Deschamps

[57] **ABSTRACT**

Heat transfer apparatus comprising a pair of heat exchangers connected in a closed system containing a heat transfer fluid made up of a mixture of at least two fluids having different boiling points, the starting fluid, i.e., the fluid with the lower boiling point having a freezing point lower than the freezing point of the operating fluid, i.e., the fluid with the higher boiling point; the application of heat to the first of the heat exchangers converting liquid fluid therein to vapor which flows into the second heat exchanger from which heat is extracted for converting the vapor therein to a liquid at a temperature and pressure lower than in the first heat exchanger; means to feed liquid from the second heat exchanger into the first heat exchanger; and means for trapping liquid starting fluid as it is produced by the second heat exchanger during the initial application of heat to the first heat exchanger and for preventing the return of the trapped liquid starting fluid to the first heat exchanger as long as sufficient heat is applied thereto whereby the operating fluid circulates around the system after the starting fluid is trapped.

15 Claims, 4 Drawing Figures



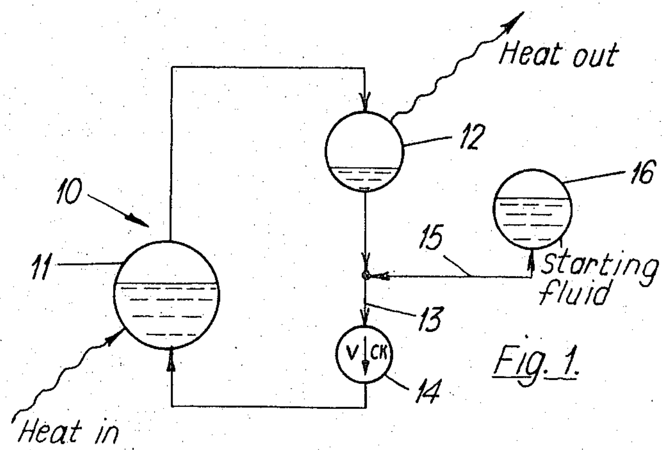

Heat out
12
16
10
15
11
Starting fluid
13
14
Heat in

Fig. 1.

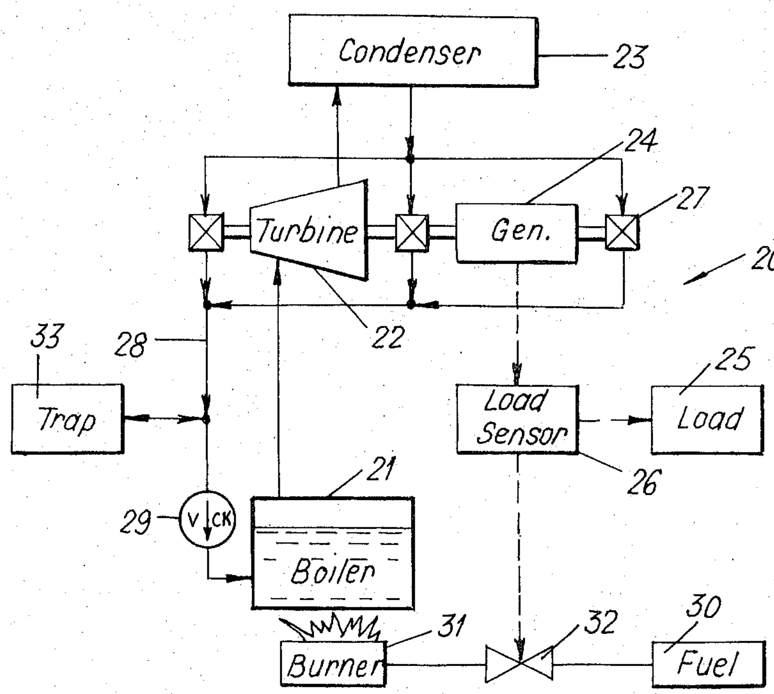

Condenser
23
24
27
Turbine
Gen.
20
22
33
28
25
Trap
Load Sensor
Load
26
21
29
Boiler
31
32
30
Burner
Fuel

Fig. 2.

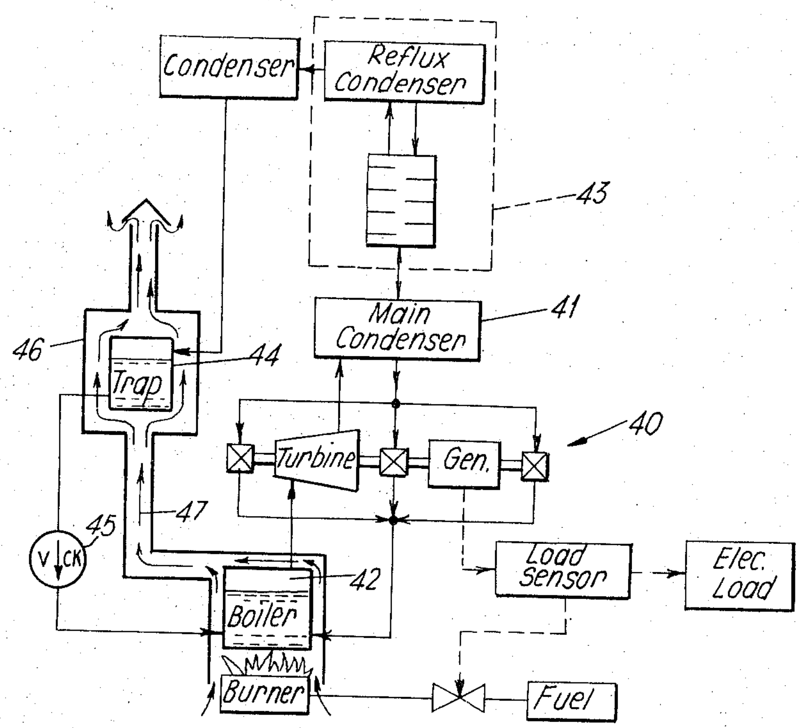

Condenser
Reflux Condenser
43
Main Condenser
41
46
Trap
44
40
Turbine
Gen.
47
45
V CK
42
Boiler
Load Sensor
Elec. Load
Burner
Fuel

Fig.3.

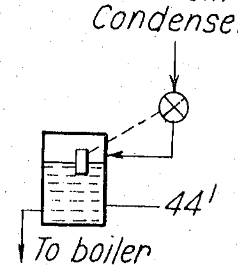

From Condenser
44'
To boiler

Fig.4.

HEAT TRANSFER APPARATUS

This invention relates to heat transfer apparatus of the type having a pair of heat exchangers interconnected in a closed system, and more particularly to a closed Rankine cycle power plant.

Heat transfer apparatus of the type having a pair of heat exchangers interconnected in a closed system finds wide use in many industrial processes. An extremely simple example is that of a water boiler furnishing steam to a heat exchanger in which heat is extracted from the steam in carrying out an industrial process thereby condensing the steam producing water which can be fed back into the boiler to complete a cycle. A more complex example is a closed Rankine cycle power plant that operates with an organic working fluid. Such a power plant corresponds to the above described heat transfer apparatus because the boiler that vaporizes the working fluid constitutes one of the heat exchangers of the apparatus, and while the other heat exchanger is constituted by the turbine and condenser. The turbine expands the vapour furnished by the boiler and drives a load such as an electrical generator while the condenser converts the turbine exhaust vapor into a liquid at a temperature and pressure lower than in the boiler. Suitable means are provided in the power plant for feeding the condensed liquid back into the boiler.

Power plants of this type are described in detail in U.S. Pat. Nos. 3,393,515 and 3,409,782. They can be designed to be highly reliable and relatively efficient; and are currently used, therefore, in powering communication equipment on either a continuous or standby basis in remote unmanned relay stations which, by reason of their inaccessibility, can be refuelled and serviced only infrequently.

A suitable working fluid for this type of power plant is ortho-dichlorobenzene (ODB) which has good thermodynamic properties, is satisfactory for lubricating the bearings of the rotating components of the power plant, and does not corrosively attack the material of the power plant at the usual boiler operating temperatures which may be as high as about 200°C.

Power plants using ODB are satisfactory in any environment where the ambient temperature exceeds the freezing point of ODB, which is about − 17°C. In general, the coldest part of the system in contact with the working fluid is the condenser which is usually designed to operate under steady state conditions at a particular incremental temperature difference above the ambient temperature to provide the desired rate of heat rejection. Thus, under steady state operating conditions, the liquid in the condenser can be maintained at a temperature above its freezing point, and the temperature of all the components in contact with the vapour can be maintained at a level that exceeds the dewpoint of the vapour. The problem, however, is in starting up the apparatus under ambient conditions below the freezing point of the working fluid when all of the components of the system are at ambient temperature.

In order to start up successfully, it is necessary to slowly and carefully warm the various components while at all times ensuring that liquid working fluid condensing on cold components will not freeze and block the system; and considerable time and manual effort is usually involved. This is not acceptable in any installation where, for example, the apparatus is on a standby

basis and must be capable of automatically starting up and rapidly reaching a steady state operating condition after being put into service.

It is therefore an object of the present invention to provide a new and improved heat transfer apparatus of the type having a pair of heat exchangers interconnected in a closed system, and more particularly a closed Rankine cycle power plant, in which the above referred to disadvantages and difficulties in starting up are substantially reduced or overcome.

According to the present invention, there is provided heat transfer apparatus comprising a pair of heat exchangers connected in a closed system containing a heat transfer fluid made up of a mixture of at least two fluids having different boiling points, the starting fluid, i.e., the fluid with the lower boiling point having a freezing point lower than the freezing point of the operating fluid, i.e., the fluid with the higher boiling point; the application of heat to the first of the heat exchangers converting liquid fluid therein to vapor which flows into the second heat exchanger from which heat is extracted for converting the vapor therein to a liquid at a temperature and pressure lower than in the first heat exchanger; means to feed liquid from the second heat exchanger into the first heat exchanger; and means for trapping liquid starting fluid as it is produced by the second heat exchanger during the initial application of heat to the first heat exchanger and for preventing the return of the trapped liquid starting fluid to the first heat exchanger as long as sufficient heat is applied thereto whereby the operating fluid circulates around the system after the starting fluid is trapped.

During the initial application of heat to the first heat exchanger in starting up the heat transfer apparatus, the starting fluid boils off before the operating fluid begins to vaporize. The vaporized starting fluid will give up heat to all of the components of the heat transfer apparatus in contact therewith and will eventually condense in the second heat exchanger and be trapped. Having a relatively low freezing point, the condensed starting fluid will not freeze when the ambient temperature is below the freezing point of the operating fluid. By the time most of the starting fluid in the system has been condensed by the second heat exchanger, the components of the heat transfer apparatus including the second heat exchanger, will be at a temperature above the freezing point of the operating fluid in the liquid state. At this point, the operating fluid will begin to be vaporized by the first heat exchanger and will begin to circulate around the system, the trapped starting fluid remaining trapped as long as sufficient heat is applied to the first heat exchanger.

In the preferred form of the invention, the liquid starting fluid is trapped in a tank connected to the second heat exchanger, the trapping being carried out automatically and independently of any sensor and control by means of a check-valve in the liquid line connecting the tank to the first heat exchanger. The check valve prevents pressurized liquid in the first heat exchanger from flowing into the tank but effects the gravity flow of liquid in the tank into the first heat exchanger in response to the termination of the application of heat thereto. In alternative arrangements, the check valve may be replaced by a solenoid or pneumatically operated valve which is closed when a sensor determines that all of the starting fluid has been trapped in the tank, or even by a manually operated valve if the circumstances of use permit.

In one embodiment of the invention, the check valve is positioned below the tank and remains closed until a predetermined quantity of the liquid starting fluid is in the tank. The location of the tank relative to the first heat exchanger is such that after such predetermined quantity of starting fluid is in the tank, the hydrostatic head on the check valve causes the valve to open and effects the passage of liquid from the second heat exchanger into the first heat exchanger. Most or all of this liquid will be in the operating fluid. In this form of the invention, the starting fluid may have a boiling point much lower than that of the operating liquid. In the preferred embodiment of this form of the invention, the heat transfer apparatus is in the form of a closed Rankine cycle power plant, the boiler of which constitutes the first exchanger and the turbine and condenser of which constitute the second heat exchanger. In this embodiment of the invention, the starting fluid is preferably a lower aliphatic monohydric alcohol of up to three carbon atoms, and is preferably methyl alcohol while the operating fluid is preferably ODB. Alternatively, the heat transfer fluid could be a mixture of inorganic fluids such as $SnCl_4$ and $SnBr_4$.

In another form of the invention, a connection may exist between the vapor side of the tank and the vapor side of the second heat exchanger for feeding vaporized starting fluid back into the second heat exchanger when the vapor pressure in the tank exceeds the vapor pressure in the second heat exchanger. With this arrangement the starting fluid should have a vapor pressure at ambient temperature which is no greater than the vapor pressure in the second heat exchanger under steady state operating conditions. This arrangement will preclude feedback of the vaporized starting fluid under steady state operating conditions but will permit feedback to occur when the temperature in the second heat exchanger begins to drop to a level which may result in the freezing of the liquid operating fluid in the second heat exchanger. The feedback of vapor of the starting fluid into the second heat exchanger under these conditions will result in the condensation of some of the starting fluid, and the resultant liquid will mix with the operating fluid in the liquid in the second heat exchanger thereby depressing its freezing point and preventing solidifcation.

In order to remove the starting fluid from the cycle after the heat transfer apparatus is brought back to its desired operating conditions, the connection between the vapor side of the tank and the vapor side of the second heat exchanger preferably includes a distillation column separate from or functionally a part of the second heat exchanger for condensing starting fluid from the vapor in the second heat exchanger. Optionally, a shut-off valve may be interposed between the tank and the vapor side of the second heat exchanger, which valve is controlled, for example, by a sensor, by a float in the tank, or by manual operation.

In the preferred embodiment of this form of the invention, the heat transfer apparatus is a closed Rankine cycle power plant wherein the operating fluid is ODB. The preferred starting fluid is methylcyclohexane. To provide additional control over the feedback of the vaporized starting liquid from the tank, it is optional to maintain the tank at a substantially constant temperature independent of ambient conditions. One way in which to achieve this when the boiler is heated by burning fuel is to locate the tank in the flue through which are vented the gases produced by the burning fuel.

The heat transfer fluid according to the present invention is preferably a mixture of the starting and operating fluids. Optionally, however, the heat transfer fluid can be any mixture of other fluids with the starting and operating fluids such that the starting fluid is separatable by distillation. In general, the heat transfer fluid according to the present invention could also be a mixture of organic and inorganic fluids, or all inorganic fluids. For example, the starting fluid could be $SnCl_4$ and $SnBr_4$ which are suitable for turbine operation.

Embodiments of the invention are illustrated by way of example in the accompanying drawings, wherein:

FIG. **1** is a block diagram of one form of a transfer apparatus according to the present invention;

FIG. **2** is the preferred form of the embodiment shown in FIG. **1**;

FIG. **3** is another embodiment of the present invention; and

FIG. **4** is a control system particularly applicable to the embodiment of the invention shown in FIG. **3**.

Referring now to FIG. **1** of the drawings, reference numeral **10** designates heat transfer apparatus of the type having a pair of heat exchangers **11** and **12** interconnected in a closed system. Contained within the system is a heat transfer fluid made up of a mixture of two fluids having different boiling points. The fluid with the lower boiling point is termed the starting fluid and has a freezing point lower than the other fluid which is termed the operating fluid. For example, the operating fluid may be water and the starting fluid may be methyl alcohol.

When apparatus **10** is in its quiescent state, all of the heat transfer fluid is contained within the heat exchanger **11** and all of the various components of the system are at ambient temperature which may be in the range between the freezing points of the two fluids that constitute the heat transfer fluid. As heat is applied to heat exchanger **11** to start up the system from its quiscent state, the starting fluid vaporizes before the operating fluid by reason of its lower boiling point, and vaporized starting fluid flows into heat exchanger **12** where heat in the vapor is extracted and the vaporized starting fluid is converted to a liquid which flows down into vertical pipe **13.** Check valve **14,** closed by the pressure in the heat exchanger **11** due to the application of heat thereto, is also closed to the flow of the starting liquid in pipe **13** above the checkvalve. At this point, a discontinuity exists in the closed cycle and the starting fluid vaporized in heat exchanger **11** is not returned to the heat exchanger. Instead, the liquid starting fluid travels through pipe **15** and collects in tank **16.**

The check valve **14** is spring loaded to prevent the fluid in vertical pipe **13** from returning to heat exchanger **11** until a predetermined pressure differential exists across the valve. Consequently, tank **16** fills with liquid starting fluid as this fluid is boiled off in the heat exchanger **11** and is condensed in heat exchanger **12.**

During the time that the starting fluid is filling tank **16,** the heat in the vaporized starting fluid is given up to the piping associated with the heat transfer apparatus as well as to the structure of the heat exchanger **12** thereby warming all of these components. Eventually, all of the starting fluid will be boiled off in heat exchanger **11** and condensed in heat exchanger **12**, the liquid starting fluid being trapped in tank **16**. At this point, the components of the system will be warmed to a temperature at least above the freezing point of the operating fluid, and most of the components in contact with the vaporized operating fluid will be at a temperature above the dew point of the operating fluid. The vapor pressure in the tank **16**, combined with the hydrostatic head of liquid in the vertical pipe **13**, acting in one direction on the check valve **14** will now exceed the combined spring load on the check valve and the pressure and hydrostatic head on the valve due to the liquid and the vapor in heat exchanger **11**. Consequently, the check valve will now open and the liquid in vertical pipe **13** will begin to flow through the valve and into heat exchanger **11**. Such liquid, at this point, will be the operating fluid which will continue to circulate around the system to the exclusion of the starting fluid which remains trapped in the tank **16** as long as heat is applied to heat exchanger **11**. Thus, by the time the operating fluid begins to circulate through the system, the latter will be warmed sufficiently to prevent any condensation of the operating fluid from freezing despite an ambient termperature that is below the freezing point of this fluid.

Alternative to the above described arrangement, which is a passive system that is automatically operable without sensor and controls, the check valve may be replaced with a pump which is turned on when the liquid in tank **16** reaches a predetermined level as sensed, for example, by a float valve, indicating that all of the starting fluid has been trapped in the tank. This arrangement eliminates the gravity feed aspect of the apparatus and is of general application when the density of fluids employed and the space considerations involved are not amenable to the arrangement for gravity feed shown in FIG. **1**.

In one embodiment of the present invention based on the general system shown in FIG. **1**, the heat transfer apparatus takes the form of a closed Rankine cycle power plant **20**, as shown in FIG. **2**, utilizing an organic or an inorganic operating fluid. Here, boiler **21** corresponds to heat exchanger **11** in FIG. **1**, and turbine **22** and condenser **23** correspond to heat exchanger **12**. In a power plant designed to furnish power in remote communication relay stations, the preferred operating fluid is ortho-dichlorobenzene (ODB), and in its ready state of operation saturated vaporized ODB from boiler **21** is delivered to turbine **22** which expands the vapors driving electric generator **24** which furnishes power to an electrical load **25** through a load sensor device **26**. Condenser **23** functions to convert the turbine exhaust vapor into a liquid at a pressure lower than in the boiler **21** and at a temperature that is a predetermined increment above ambient temperature which may lower than the freezing point of ODB, namely lower than about −17°C. In steady state operation, therefore, the liquid in the condenser will not freeze since the condenser is designed to hold the liquid at a temperature of above its freezing point.

As explained in the U.S. patents identified earlier, the condenser liquid may pass by gravity through the bearings **27** of the rotating components of the power plant, and by reason of the hydrostatic head in vertical pipe **28**, the liquid therein may pass through check valve **29** and into boiler **21** completing a cycle. Heat is applied to the boiler by burning fuel such as a bottled gas contained in a tank **30** and supplied to a burner **31** through control valve **32** whose setting is established by the load sensor **26**.

When the power plant is on a stand-by basis in an environment, such as Canada or Alaska where the ambient temperature is often below the freezing point of ODB, all of the liquid in the system will be drained into boiler **21**. The contents of the boiler under such circumstances will be the operating fluid ODB and the starting fluid which may be lower aliphatic monohydric alcohol of up to three carbon atoms, and preferably is methyl alcohol. The volume of starting fluid will be such as to completely fill tank **33** at the instant check valve **29** is opened by the hydrostatic head thereon. With this arrangement, the initial application of heat to boiler **21** occasioned by the opening of control valve **32** and the ignition of burner **31** will cause the starting fluid to boil off and pass into the turbine and condenser. The starting fluid, having poor thermodynamic properties so far as having the turbine extract work therefrom, will have little effect on driving the turbine with the result that the bearings **27** will be lubricated well before rotation occurs. More importantly, however, all of the various structural members and the various components of the power plant will be heated to a level that will prevent freezing of condensed operating fluid when the latter begins to boil off in the boiler. Thereafter, the operating of the power plant **20** is the same as described above in connection with FIG. **1**.

Starting fluids other than those identified above can be utilized with the power plant shown in FIG. **2** subject to the constraint that the starting fluid should have a freezing point of the operating fluid ODB, and a boiling point considerably below the boiling point of ODB. Alternatively, inorganic fluids such as $SnCl_4$ and $SnBr_4$ can be used as the heat transfer fluid.

One of the problems with the power plant shown in FIG. **2** is the possibility that under certain ambient conditions and under very light loads on the power plant the temperature of the liquid in condenser **23** will approach the freezing point of the operating fluid. Under these circumstances it would be desirable to feed back into the condenser some of the starting fluid trapped in tank **33**, in order to have the vaporized starting fluid condense in condenser **23** and lower the freezing point of the liquid therein. In this manner, a portion of the starting fluid will reamin in the operating fluid maintaining the temperature of the liquid in the system at a level above its freezing point. The problem with this approach is the elimination of the starting fluid from the system once the power plant is brought back up to higher power levels or when the ambient temperature increases.

This problem is solved, by utilizing configuration **40** as shown in FIG. **3**. In this configuration, the boiler **42** is positioned below the main condenser **41** at a level that provides a sufficient hydrostatic head for the condensed liquid to enter the boiler. Associated with the vapor side of the condenser is a distillation column designated generally by reference numeral **43** and designed to condense starting fluid contained in the main condenser and cause the liquid starting fluid to be collected to tank **44** which is connected to boiler **42** by means of check valve **45** operating on the same principles as the check valve in the previous embodiment.

During steady state operating, the tank **44** is preferably held at a fixed temperature by jacket **46** through which pass the flue gases **47** generated by the combustion of fuel by the burner. Consequently, the vapor pressure in the tank will be maintained at a substantially constant level independent of ambient weather conditions. The starting fluid is selected so that its vapor pressure at the reference temperature established by the jacket **46** will be no greater than the vapor pressure of the operating fluid in the condenser at its design operating point. Consequently, when the weather turns colder than the design calls for or the load on the turbine is lighter than the design load, the temperature of the liquid operating fluid in the condenser will drop causing a drop in the vapor pressure in the main condenser. With a suitable starting fluid in the tank **44,** feedback of vaporized starting fluid will occur depressing the freezing point of the liquid circulating through the power plant thus preventing the freezing of the liquid in the main condenser. When the weather turns warmer or the load increases, the starting fluid will be distilled out of the vapor in the condenser and collected once more in tank **44.** At shutdown, the liquid in tank **44** will pass through check valve **45** due to the decrease in the boiler pressure and into the boiler as described previously.

At start-up, the starting fluid will boil off first and function to heat up the structure and the components of the power plant or as described previously. The preferred starting fluid for this embodiment is methylcyclohexane whose vapor pressure, boiling point and freezing point have the desired relationship with the vapor pressure boiling point and freezing of ODB in the temperature and pressure range of interest.

Holding the temperature of tank **44** at a constant reference temperature is the preferred arrangement since this will isolate the control of feedback from ambient temperature. This will also ensure that the starting fluid will not freeze under extremely cold conditions during steady state operation. However, it is also possbile under many circumstances to dispense with the jacket **46** and permit the tank **44** to be exposed to ambient conditions.

In a further optional arrangement, it is also possible to control the feedback by means of a valve interposed between the distillation column and the tank in which the starting fluid is collected. Reference is made to FIG. **4** which shows one way in which the disconnection of the distillation column from the tank can be achieved. Specifically, a valve is provided in the line connecting the distillation column to the trap, and the operation of the valve is controlled by a float in the tank. In this manner, the level of liquid in the tank can be utilized to effect its disconnection from the distillation column. Alternatively, disconnection can be by way of a solenoid, pneumatic or manually operated valve.

We claim:

1. Heat transfer apparatus comprising:

a. a pair of heat exchangers connected in a closed system;

b. a heat transfer fluid contained within the system and made up of a mixture of at least two fluids termed the starting and the operating fluids, the starting fluid having a lower boiling point than the operating fluid, and a freezing point lower than the freezing point of the operating fluid whereby the application of heat to the first of the heat exchangers converts liquid fluid therein to vapor which flows into the second heat exchanger from which heat is extracted for converting the vapor therein to a liquid at a temperature and pressure lower than in the first heat exchanger;

c. means to feed liquid from the second heat exchanger into the first heat exchanger; and

d. means for trapping liquid starting fluid as it is produced by the second heat exchanger during the initial application of heat to the first heat exchanger and for preventing the return of the trapped liquid starting fluid to the first heat exchanger as long as sufficient heat is applied thereto whereby the operating fluid circulates around the system after the starting fluid is trapped.

2. Heat transfer apparatus according to claim **1,** wherein the means for trapping the liquid starting fluid includes a tank connected to the second heat exchanger, and a check valve in the liquid line connecting the tank to the first heat exchanger for preventing pressurized liquid therein from flowing into the tank and for effecting the gravity flow of liquid in the tank into the first heat exchanger in response to the termination of the application of heat thereto.

3. Heat transfer apparatus according to claim **2,** wherein the check valve is positioned below the tank and remains closed until the tank fills with liquid starting fluid after which the hydrostatic head on the check valve causes the valve to open and effect the passage of liquid from the second heat exchanger into the first heat exchanger.

4. Heat transfer apparatus according to claim **2** wherein a shut-off valve is interposed between the tank and the check valve for selectively disconnecting the tank from the first heat exchanger.

5. Heat transfer apparatus according to claim **1** wherein the heat transfer apparatus is a closed Rankine cycle power plant, the first heat exchanger is a boiler, and the second heat exchanger includes a turbine for expanding the boiler vapor and driving a load such as an electrical generator, and a condenser for converting the turbine exhaust vapor to a liquid at a temperature and pressure lower than in the boiler.

6. Heat transfer apparatus according to claim **5,** wherein the starting fluid is a lower aliphatic monohydric alcohol of up to three carbon atoms, and is preferably methyl alcohol, and the operating fluid is ODB.

7. Heat transfer apparatus according to claim **2,** wherein a connection exists between the vapour side of the tank and the vapour side of the second heat exchanger for feeding vapourized starting fluid back into the second heat exchanger when the vapour pressure in the tank exceeds the vapour pressire in the second heat exchanger.

8. Heat transfer apparatus according to claim **7,** wherein the starting fluid has a vapour pressure at ambient temperature that is no greater than the vapour pressure in the second heat exchanger under design operating conditions.

9. Heat transfer apparatus according to claim **7,** wherein the connection includes a distillation column separate from or a part of the second heat exchanger for condensing starting fluid from the vapour in the second heat exchanger.

10. Heat transfer apparatus according to claim 6, wherein a shut-off valve is interposed between tbe tank and the vapour side of the second heat exchanger.

11. Heat transfer apparatus according to claim 10, wherein the shut-off valve is operated by a float in the tank.

12. Heat transfer apparatus according to claim 7, wherein the heat transfer apparatus is a closed Rankine cycle power plant, the first heat exchanger is a boiler, and the second heat exchanger includes a turbine for expanding the boiler vapour and driving a load such as an electrical generator, and a condenser for converting the turbine exhaust vapour to a liquid at a temperature and pressure lower than in the boiler.

13. Heat transfer apparatus according to claim 10, wherein the operating fluid is ODB and the starting fluid is methylcyclohexane.

14. Heat transfer apparatus according to claim 12 wherein the tank is maintained at a substantially constant temperature independent of ambient conditions.

15. Heat transfer apparatus according to claim 14, wherein heat is applied to the boiler by burning fuel and the tank is heated by the flue gases.

* * * * *