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Bronicki et al.

[11] **3,842,593**

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[54] **CLOSED RANKINE CYCLE POWER PLANT**

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[51] **Int. Cl.** **F01k 25/00**

[58] **Field of Search** 60/36; 252/67, 68

[56] **References Cited**

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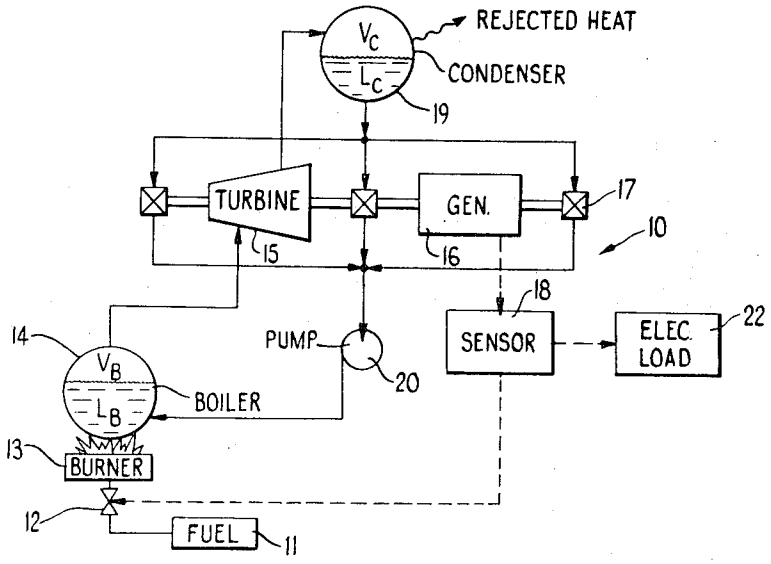
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[57] **ABSTRACT**

A closed Rankine cycle power plant wherein the working fluid is a mixture of ortho-dichlorobenzene (ODB) and meta-dichlorobenzene (MODB) in such relative proportions that in the condenser the proportion of ODB to MDB is in the range of from 2:3 to 3:2.

3 Claims, 2 Drawing Figures



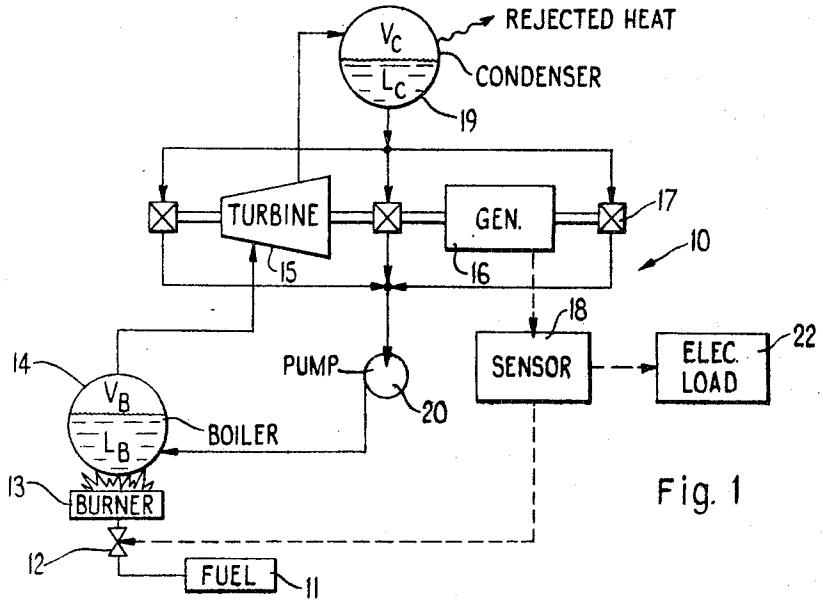

REJECTED HEAT
V_C
L_C
CONDENSER
19
TURBINE
GEN.
17
10
15
16
18
SENSOR
ELEC. LOAD
22
14
V_B
L_B
BOILER
PUMP
20
13
BURNER
12
FUEL
11

Fig. 1

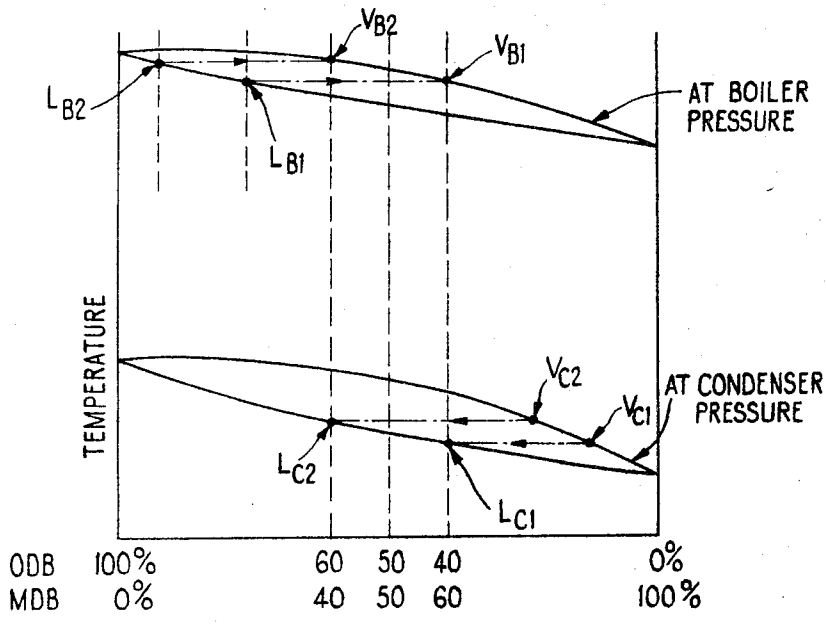

V_{B2}
V_{B1}
L_{B2}
L_{B1}
AT BOILER PRESSURE
TEMPERATURE
V_{C2}
V_{C1}
AT CONDENSER PRESSURE
L_{C2}
L_{C1}
ODB 100% 60 50 40 0%
MDB 0% 40 50 60 100%

Fig. 2

CLOSED RANKINE CYCLE POWER PLANT

This invention relates to a closed Rankine cycle power plant operating with an organic working fluid.

This type of power plant comprises a boiler for vaporizing the working fluid, a turbine for expanding the vapors and driving a load such as an electrical generator, a condenser for converting the turbine exhaust vapor to a liquid at a lower temperature and pressure than the boiler, and means for feeding the condensed liquid back into the boiler which operates at a higher pressure. Such power plants are described in detail in U.S. Pat. Nos. 3,393,515 and 3,409,782; and can be designed to be highly reliable and relatively efficient. They are currently used, therefore, in powering communication equipment on either a continuous or standby basis, in remote unmanned relayed 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 exceed 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.

If it is desired to utilize such a conventional power plant in an environment where the ambient temperature will drop below the freezing point of the working fluid, for example, in parts of Alaska and Canada, then it is not practical to employ ODB as a working fluid because of the danger that the liquid formed in the condenser will freeze and block the flow of working fluid in the system causing damage or automatic shut-down. In a way analogous to adding anti-freeze to the water cooled radiator of a motor vehicle when the latter is to be used under ambient conditions below the freezing point of water, it has been suggested that an additive could be used with ODB for the purpose of depressing its freezing point. This approach would permit existing power plants to be adapted for use in very cold environments without further modification.

There are a number of problems with this approach. As is well known, an admixture of two organic liquids will generally have a freezing point lower than the freezing point of either of the two liquids individually. The particular mixture having the lowest freezing point is termed the eutectic mixture, and its freezing point is termed the eutectic point. In most eutectic mixtures in which the eutectic point is 30°–40° below the freezing point of either of the liquids, the viscosity at the eutectic point will be in the range 20 to 40 times higher than the viscosity at room temperature. Such a high viscosity is totally unsatisfactory for power plant use because of the added work required to transfer the viscous condensed liquid back into the boiler. Secondly, because the power plant operates with the working fluid in two phases, namely the liquid and the vapor phase, the turbine and condenser will operate as a distillation column separating the more volatile liquid from the less volatile liquid when there is a significant difference in the boiling point of the two liquids. As a consequence, the more volatile liquid will remain in the vapor phase and not contribute to the lowering of the freezing point of the liquid in the condenser.

It is therefore an object of the present invention to provide a closed Rankine cycle power plant using a working fluid which will retain good flow characteristics at low temperatures.

According to the present invention, there is provided a closed Rankine cycle power plant of the type comprising a boiler for vaporizing a high molecular weight working fluid, a turbine for expanding the vapor and driving a load such as an electrical generator, and a condenser for converting the turbine exhaust vapors to a liquid at a lower temperature and pressure than that in the boiler and means for causing the liquid in the condenser to be fed into the boiler at a higher pressure wherein the working fluid is a mixture of ODB and MDB such that the composition of the liquid in the condenser is in the range 2:3 to 3:2 of ODB to MDB when the power plant is in steady state operation at which the composition of liquid in the condenser is the same as the composition of vapor in the boiler.

The eutectic mixture of ODB and MDB (meta-dichlorobenzene), which is about 1:1, is preferred. The eutectic point at about −60°C, significantly below the freezing point of pure ODB which is about −17°C, and of pure MDB which is about −25°C. The viscosity of the preferred mixture at −50°C is about 6cp. which is essentially of the same order of magnitude as the viscosity at room temperature (i.e., 2cp.). Consequently, the flow characteristics of the mixture of liquids in the condenser will not be significantly different from the flow characteristics of the mixture at room temperature. This is advantageous in affecting the transfer of liquid from the condenser into the boiler. In addition, the mixture of ODB and MDB in the vapor phase in the boiler and turbine is no more corrosive than ODB itself. Furthermore, the boiling points of ODB and MDB are quite close, and the thermodynamic properties of these two organic fluids are essentially the same. Therefore, their use in a power plant does not substantially alter the operating characteristics or the efficiency of the power plant permitting a system designed to use use ODB to be converted for use under colder ambient conditions by merely substituting for some of the ODB sufficient MDB to yield the proper mixture in the condenser liquid.

An embodiment of the invention is illustrated by way of example in the accompanying drawings, wherein:

FIG. **1** is a block diagram of a conventional closed Rankine cycle power plant employing a high molecular weight organic working fluid; and

FIG. **2** is a schematic vapor-liquid phase diagram for mixtures of ODB and MDB.

When a high molecular weight organic liquid is employed as the working fluid for the power plant shown in FIG. **1**, and a steady state of operation has been achieved, the composition of vapor in the boiler will be the same as the composition of the liquid in the condenser. In operation, a mixture of ODB and MDB of a composition L_{B1} in the boiler **14** will produce vapour of composition V_{B1} as shown in the phase diagram of FIG. **2.** After the vapors have been expanded in turbine **15** and delivered to the condenser **19,** the vapors within the condenser will have a composition V_{C1} which will be an equilibrium with the liquid of composition L_{C1} also shown in FIG. **2.** By reason of the requirements for steady state operation, namely that the composition of

vapor in the boiler must be the same as the composition of liquid in the condenser, the points V_{B1} and L_{C1} will lie on the same absissa on the phase diagram of FIG. 2.

In accordance with the present invention, the range of composition for the liquid in the condenser lies between the limit 60% ODB and 40% MDB and the limit 40% ODB and 60% MDB. Within this range, successful operation of the power plant shown in FIG. 1 can be accomplished under any ambient temperature condition approaching −50°C. In this region, the viscosity of the condensed liquid will be of the same order of magnitude as the viscosity of the mixture at room temperature which will facilitate the return of liquid from the condenser to the boiler.

It should be noted that the phase curves shown in FIG. 2 are applicable to particular boiler and condenser pressures, it being understood that a change in the boiler pressure due to a change in the electrical load will shift the boiler pressure curve, and a change in the ability of the condenser to reject heat occasioned by a change in ambient weather conditions will shift the condenser pressure curve. In either case, it is essential that the liquid contained within the condenser be a mixture whose composition is within the limits specified in FIG. 2. Because of the variables with respect to the boiler pressure and the condenser pressure, there are wide limits in the variation in composition of the liquid in the boiler during steady state operation. As a consequence, there is a correspondingly wide range of variation in the mixture with which the power plant can be charged in order to yield the proper results during steady state operation in the condenser.

In the preferred manner of operation of the invention, the boiler operates to provide saturated vapor to the turbine at a temperature between 110°C and 135°C, depending on the turbine load. Under steady-state conditions of operation, it is preferred to have the liquid in the condenser be the eutectic mixture of ODB and MDB, namely a mixture of equal parts of ODB and MDB, since this mixture has the lowest possible freezing point of all the possible mixtures. Recalling that steady state operation requires the mixture of the condenser liquid to be the same as the mixture in the boiler vapor, it follows that the liquid in the boiler must be such as to produce a eutectic vapor mixture when the liquid boils. This result is achieved with a mixture of liquid in the boiler of 5 parts of MDB and 6 parts of ODB.

With less than a 5 percent "hold-up" (i.e., the ratio of liquid trapped in the various components of the system on shut-down to the liquid contained in the boiler), it is possible to initially charge the system with a mixture of MDB to ODB in the ratio of 5:6 to obtain what will be essentially the eutectic mixture in the condenser liquid under steady-state operating conditions. With other systems, other operating conditions and with a larger "hold-up," a different mixture of MDB and ODB may be required to obtain the eutectic mixture in the condenser liquid under steady state operating conditions. In general, a trial and error procedure can be used to determine the amount of each of MDB and ODB to have in the system, since sampling of the condenser liquid under steady state conditions of operation will provide information on possible changes required in the system. Once the required amount of each liquid has been added to the system, further operation will always be such that the liquid in the condenser will be the eutectic mixture of MDB and ODB, or within the desired range of from 3:2 to 2:3.

We claim:

1. A closed Rankine cycle power plant of the type comprising a boiler for vaporizing a high molecular weight working fluid, a turbine for expanding the vapor and driving a load such as an electrical generator, a condenser for converting the turbine exhaust vapors to a liquid at a lower temperature and pressure than that in the boiler, and means for feeding condensed liquid in the condenser into the boiler at a high pressure wherein the working fluid is a mixture of ortho-dichlorobenzene and meta-dichlorobenzene such that the composition of the liquid in the condenser is in the range 2:3 to 3:2 of ortho-dichlorobenzene and meta-dichlorobenzene when the power plant is in steady state operation at which the composition of liquid in the condenser is the same as the composition of vapor in the boiler.

2. A closed Rankine cycle power plant according to claim **1** wherein the mixture of ortho-dichlorobenzene and meta-dichlorobenzene is such that the composition of liquid in the condenser is 1:1 of ortho-dichlorobenzene and meta-dichlorobenzene during steady state operation.

3. A closed Rankine cycle power plant according to claim **2** wherein the liquid in the boiler is composed of ortho-dichlorobenzene and meta-dichlorobenzene in the ratio of 5:6.

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