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(54) **LARGE CAPACITY HEAT SINK**

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(57) **ABSTRACT**

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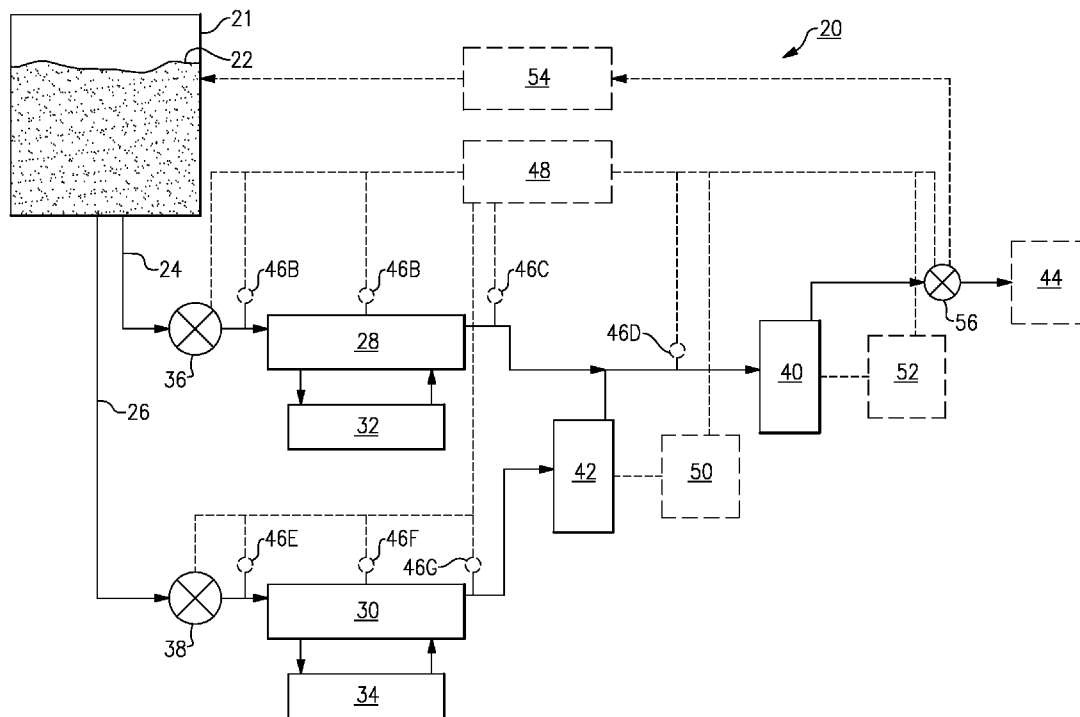
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A cooling system includes a first boiler defining a first flow path with a first thermal load. A second heat exchanger defines a second flow path with a second thermal load. A reservoir is configured to communicate a working fluid to at least one of the first boiler and second heat exchanger. A pump is configured to selectively exhaust the working fluid to an ambient environment. A method is also disclosed.



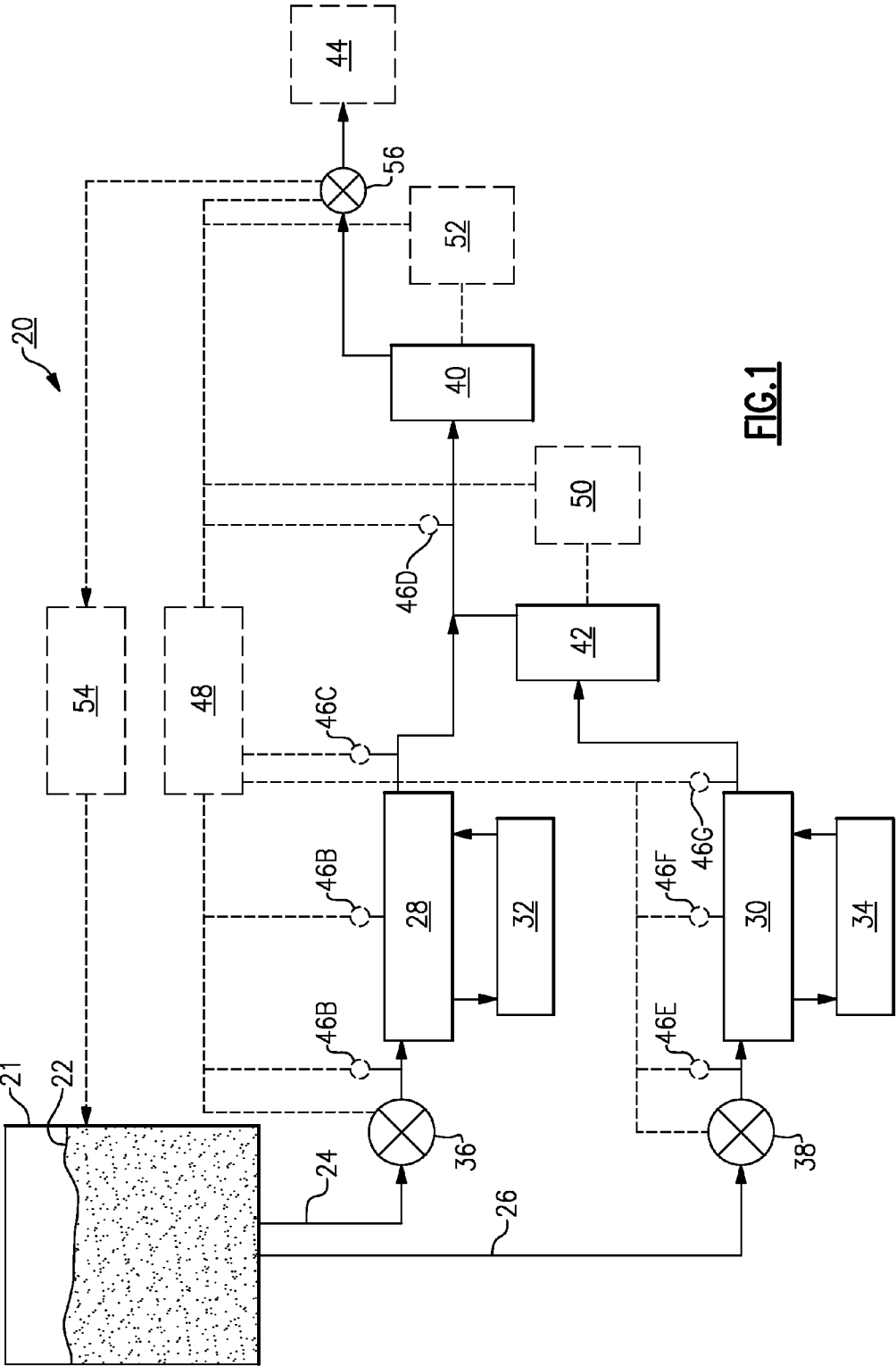


FIG. 1

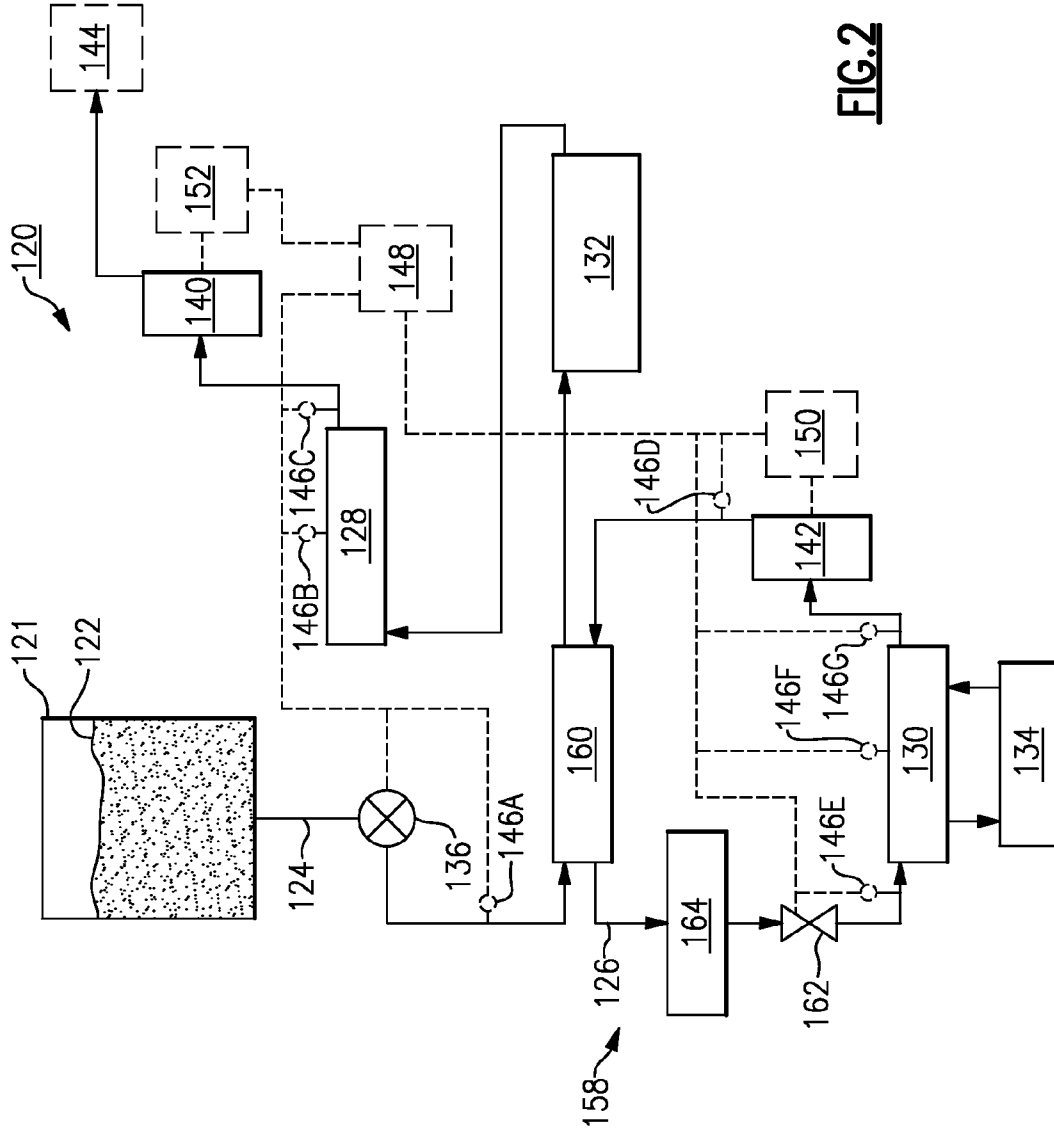


FIG. 2

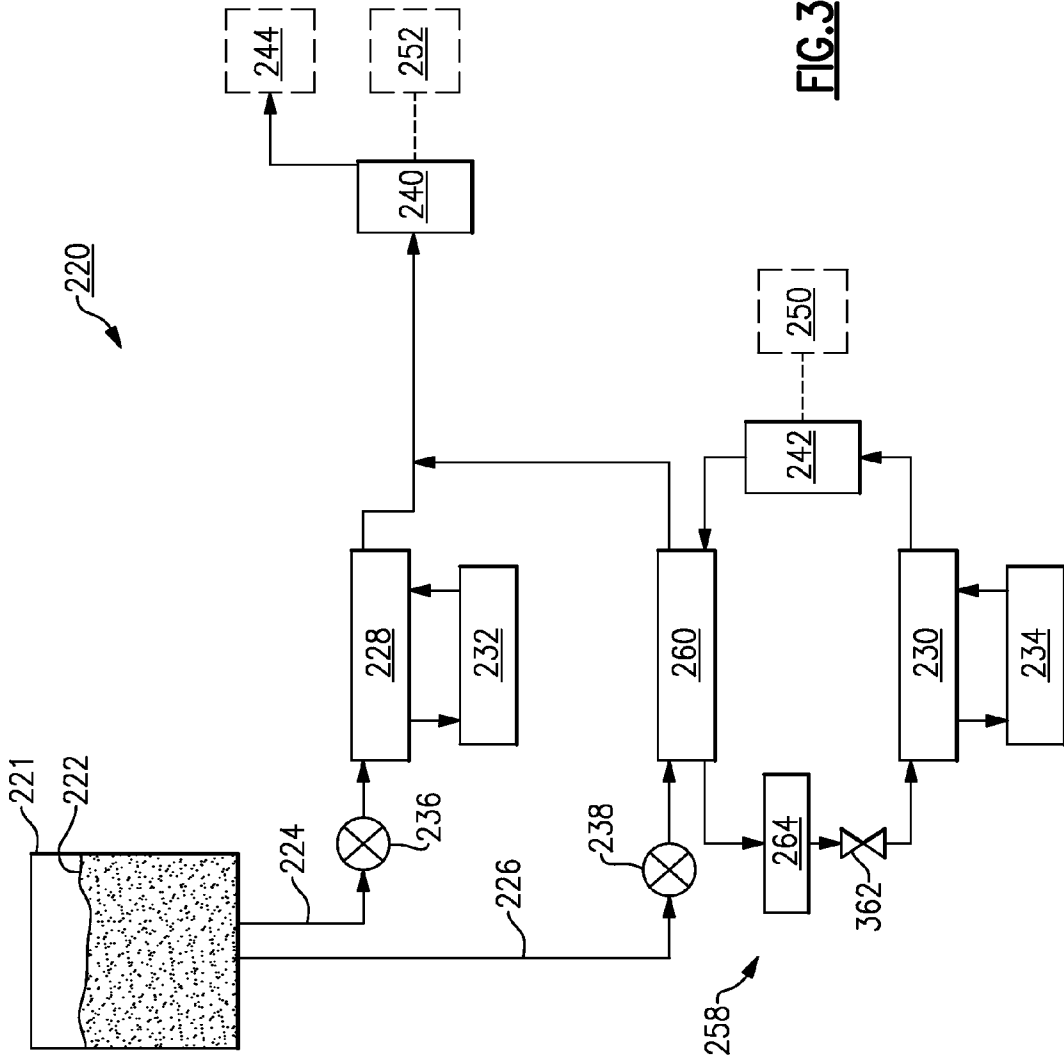


FIG. 3

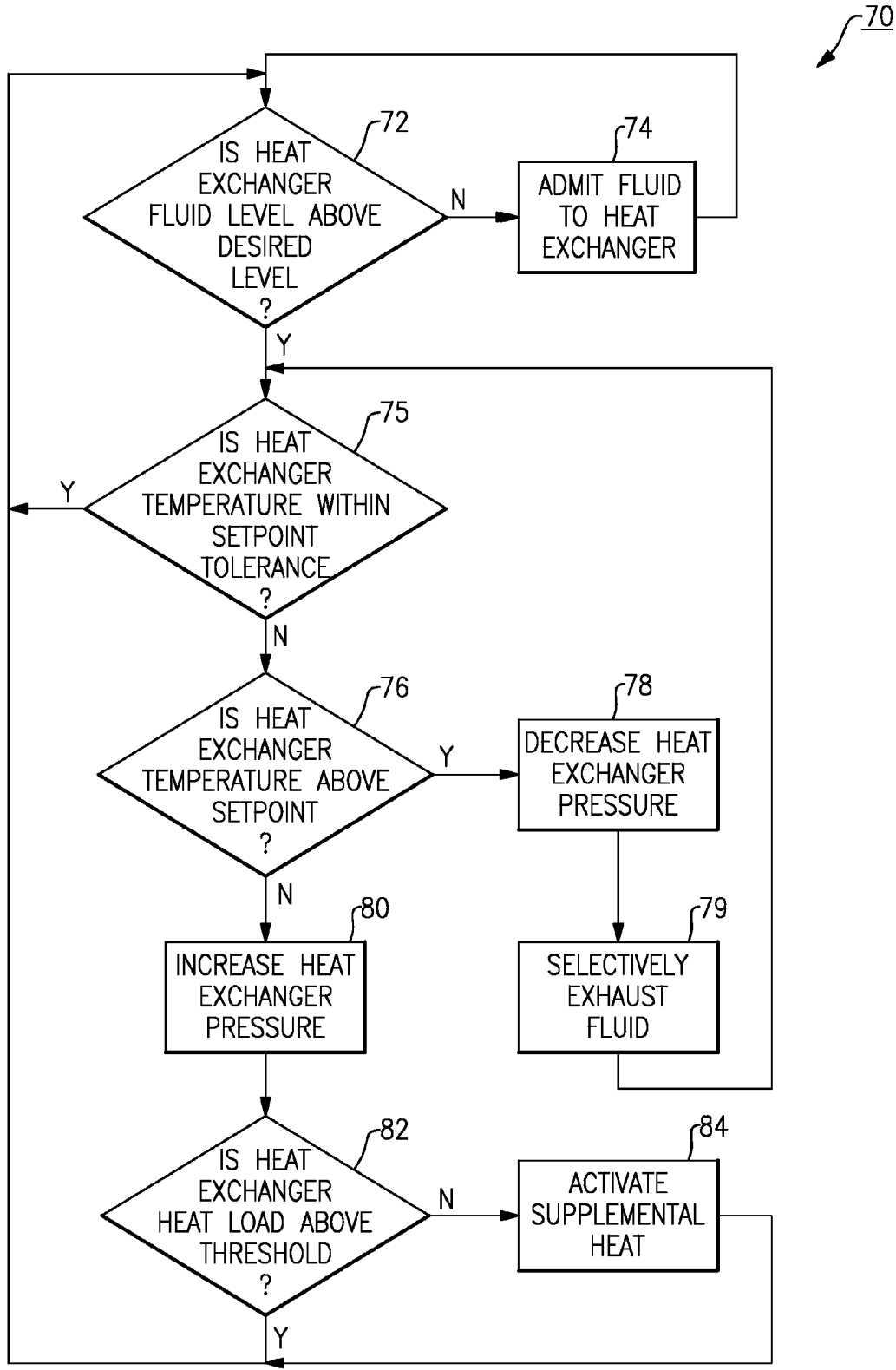


FIG.4

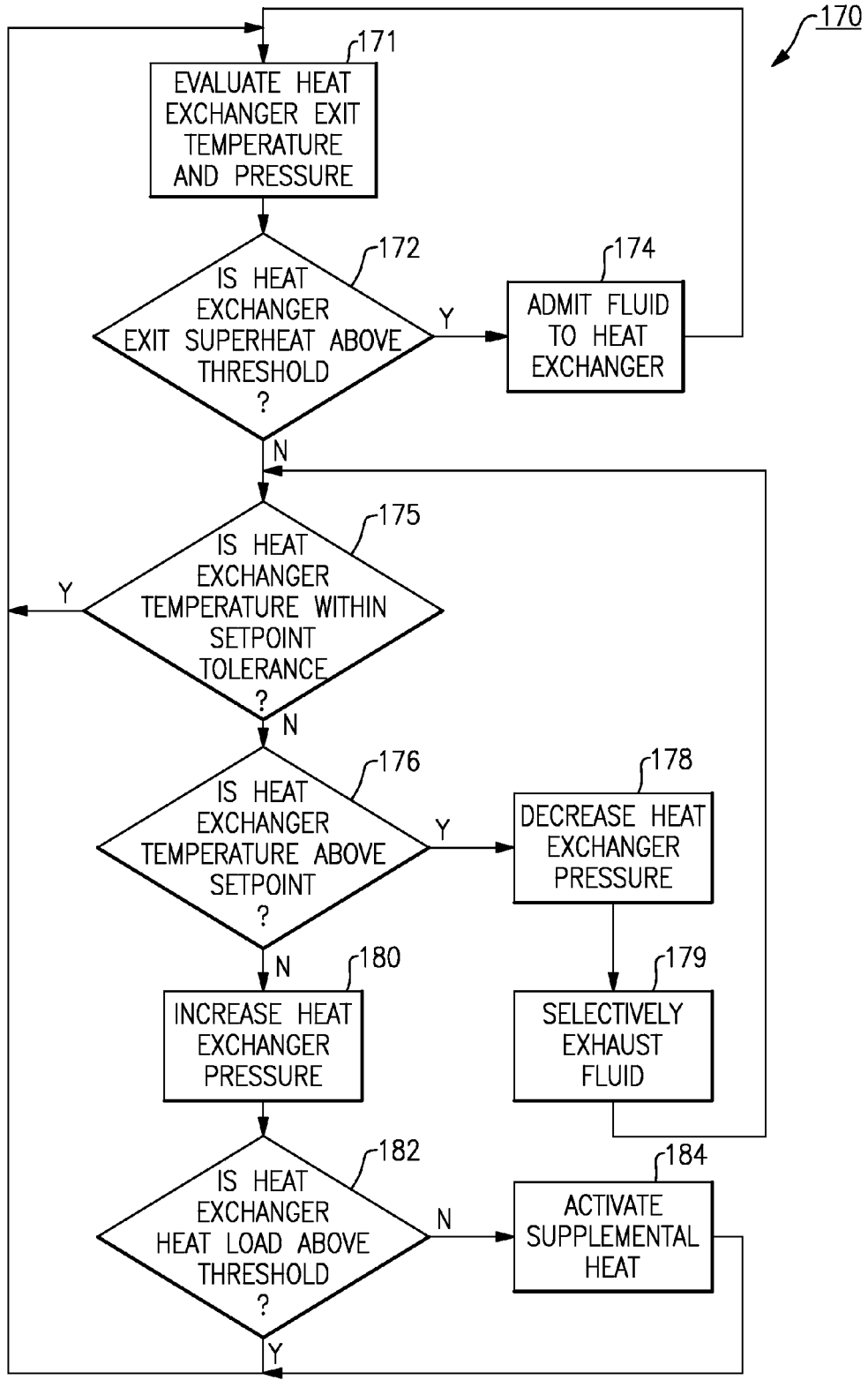


FIG.5

LARGE CAPACITY HEAT SINK

BACKGROUND

[0001] This application relates to a cooling system, and more particularly to a heat sink cooling arrangement utilizing an expendable fluid.

[0002] Modern vehicles are being provided with more sophisticated electric systems. The operating capability or performance of typical air and ground vehicles with high power systems generally depends on heat sink capacity and availability. Typical high power systems are designed to operate at a particular operating temperature, and thus are connected to a heat sink to reject excess heat.

[0003] Some known vehicle cooling systems utilize fuel as the primary heat sink, though its cooling capacity is below what may be desired. Other known cooling systems use ram air as a heat sink, though this method increases radar signature and adds to vehicle drag. Ground vehicles are often limited to ambient air as the heat sink, which may experience drawbacks of exhaust plume interference, acoustic noise hazard for nearby personnel, vehicle vibration and heat exchanger fouling.

[0004] Simple water boiler systems were used long ago in high speed aircraft. In such systems, an ejector was used below a set altitude to reduce the pressure in the boiler and thus the boiling temperature. However, these systems operate at a single cooling capacity. Operating temperatures of many heat generating components, such as laser diodes require tight temperature control for proper operation.

[0005] In some known cooling systems, vapor cycle systems are used as a heat pump due to their favorable size and weight and ability to use electricity for the energy input.

SUMMARY

[0006] A cooling system includes a first boiler defining a first flow path with a first thermal load. A second heat exchanger defines a second flow path with a second thermal load. A reservoir is configured to communicate a working fluid to at least one of the first boiler and second heat exchanger. A pump is configured to selectively exhaust the working fluid to an ambient environment. A method is also disclosed.

[0007] The various features and advantages of this invention will become apparent to those skilled in the art from the following detailed description of an embodiment. The drawings that accompany the detailed description can be briefly described as follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 shows a schematic view of a heat sink system according to a first embodiment.

[0009] FIG. 2 shows a schematic view of a heat sink system according to a second embodiment.

[0010] FIG. 3 shows a schematic view of a heat sink system according to a third embodiment.

[0011] FIG. 4 shows a cooling process utilizing a heat sink system, according to a first embodiment.

[0012] FIG. 5 shows a cooling process utilizing a heat sink system, according to a second embodiment.

DETAILED DESCRIPTION

[0013] Single water boiler systems were used long ago in high speed aircraft, but only provided cooling at a single

cooling capacity. A single boiler system will operate with the boiler temperature at the lowest required temperature of the heat loads, so higher temperature equipment is cooled at a temperature below what is necessary.

[0014] Referring to FIG. 1, a schematic view of a disclosed heat sink system 20 is shown. The system of this disclosure provides high temperature cooling for high temperature equipment, such as a generator or power conversion equipment, while providing additional cooling at low temperatures for low temperature equipment, such as a laser, for example.

[0015] The heat sink system 20 includes a reservoir 21 configured to store a quantity of coolant or working fluid 22 for cooling various thermal loads, such as high-power aircraft equipment. Other systems may also benefit from the teachings of this disclosure, such as ground or marine vehicles. In one embodiment, the working fluid 22 is an expendable fluid, such as water. Using water as the cooling fluid reduces ram drag and reduces the overall weight of the system or vehicle over a mission cycle. The expendable fluid can be supplied at the start of a mission or supplemented with condensed water vapor from the vehicle exhaust during transit or standby operation, for example. Other working fluids or coolants are also contemplated, however.

[0016] The system 20 has a first cooling path 24 defined by a first heat exchanger 28, and a second, different cooling path 26 defined by a second heat exchanger 30. The first heat exchanger 28 is in thermal communication with a first heat load 32, and the second heat exchanger 30 is in thermal communication with a second heat load 34. In an embodiment, the first and second heat exchangers 28, 30 are boilers configured to elevate the temperature of the working fluid 22 from heat rejected by the heat loads 32, 34.

[0017] In some embodiments, the first and second heat loads 32, 34 have different operating temperature ranges or tolerances. In one embodiment, first heat load 32 is a high temperature heat source, such as a generator and power conversion equipment, and second heat load 34 is a low temperature heat source, such as a laser, for example. In one embodiment, each of loads 32, 34 includes one or more electrical devices or components, such as various communications and/or computing devices of a vehicle, for example.

[0018] In an embodiment, the first and second heat exchangers 28, 30 are configured with different relative cooling capacities corresponding to the operating ranges of the first and second loads 32, 34. In an embodiment, the temperature requirements of the first heat load 32 will set the temperature for first heat exchanger 28, and the temperature requirements of the second heat load 34 will set the temperature for the second heat exchanger 30. This arrangement reduces the overall weight of the system 20 and consumption of the working fluid 22.

[0019] The first and second heat exchangers 28, 30 may be configured to have independent temperature and cooling capacity control. In one embodiment, a first flow control valve 36 meters working fluid 22 communicated to the first cooling path 24 from the reservoir 21, and a second flow control valve 38 meters working fluid 22 to the second cooling path 26 from the reservoir 21. Flow control valves 36, 38 are positioned upstream of heat exchangers 28, 30 and control flow to the heat exchangers 28, 30. In another embodiment, flow control valves 36, 38 are located downstream of heat exchangers 28, 30. This arrangement permits the relative cooling capacities of the heat exchangers 28, 30 to be selectively controlled or otherwise affected.

[0020] Flow control valves **36, 38** may be passive devices or active devices configured to control flow of the working fluid **22** to the heat exchangers **28, 30** such that a desired vapor quality is maintained as the working fluid **22** exits heat exchangers **28, 30**. In an embodiment, flow control valves **36, 38** are disc orifice valves, which communicate a predetermined quantity of fluid to each of the heat exchangers **28, 30**. In another embodiment, flow control valves **36, 38** are variable or thermostatic expansion valves actuated or moveable in response to variation of conditions of the cooling paths **24, 26** and/or thermal loads **32, 34**. In some embodiments, various conditions of the cooling paths **24, 26** and/or loads **32, 34** are measured by one or more of pressure and/or temperature sensors **46**, positioned at any of the locations **46A-G**, for example. In an embodiment, the variable flow control valves **36, 38** are movable in response to a signal provided by controller **48** in communication with at least one of the pressure and/or temperature sensors **46**.

[0021] A pump **40** is arranged downstream of the first heat exchanger **28** and is configured to selectively exhaust the working fluid **22** to an ambient environment **44**, such as overboard an aircraft, for example. In some embodiments, the system **20** includes at least one additional pump. In one embodiment, a second pump **42** is positioned downstream of the second heat exchanger **30**, and communicates the working fluid **22** from the second cooling path **26** to the first cooling path **24** upstream of the first pump **40**. In another embodiment, pumps **40, 42** are arranged in parallel, such that the pumps **40, 42** are operated independently. Alternatively, additional pumps are connected to at least one of heat exchangers **28, 30** arranged in series or parallel to accommodate varying quantities of exiting vapor in response to different thermal load requirements. The first pump **40** may have a pressure ratio required for the first heat exchanger **28**, and the second pump **42** may have a pressure ratio required for the second heat exchanger **30**.

[0022] The pumps **40, 42** are configured to lower the pressure in heat exchangers **28, 30**, thus lowering the boiling temperature of the working fluid **22** such that the fluid **22** can be exhausted as a superheated vapor. Exhausting the fluid as a superheated vapor reduces the likelihood of liquid coolant entering the pumps **40, 42**. In some embodiments, the pumps **40, 42** are ejectors. In an embodiment, each ejector is powered by bleed air provided by another system of the vehicle, such as a compressor section of an aircraft engine. In another embodiment, the pumps **40, 42** are vacuum pumps, which may be powered by electric motors **50** and **52**, for example. The operating capacity of motors **50, 52** may be controlled by a controller **48**, such that the relative cooling capacities of the heat exchangers **28, 30** are controlled or otherwise affected during system operation. In an embodiment, a temperature of cooling paths **24, 26** is controlled by varying the speed and pressure ratio of the pumps **40, 42** to control the boiling temperature and pressure of heat exchangers **28, 30**. In an embodiment, pumps **40, 42** are operated to change the pressure in heat exchangers **28, 30**, and thus the operating temperature of heat loads **32, 34** in response to different desired temperature setpoints. In yet another embodiment, one of pumps **40, 42** is an ejector and the other one of the pumps **40, 42** is a vacuum pump.

[0023] The working fluid **22** is selectively exhausted to the ambient environment **44** after exiting pump **40**. In some examples, a valve **56** is positioned between pump **40** and a condenser **54** to meter the flow of the working fluid **22**. In this

arrangement, the working fluid **22** is selectively communicated downstream to the condenser **54** and collected in reservoir **21** to be reused in the system **20**.

[0024] In one embodiment, the system **20** is configured such that working fluid **22** may be exhausted or recycled depending on a condition of heat loads **32, 34**. For example, when the heat load **34** is operating at a low power mode, such as during an aircraft cruise segment, at least some of the working fluid **22** is recycled back to the reservoir **21**, and when the heat load **34** is operating at a high power mode, at least some of the working fluid **22** is exhausted to the ambient environment **44**. In some examples, the valve **56** is moveable in response to a signal communicated from the controller **48**. In other examples, the valve **56** is a static device configured to exhaust a predetermined amount of working fluid **22** to the ambient environment **44** and return another predetermined amount of working fluid **22** to the reservoir **21**.

[0025] FIG. 2 shows a schematic view of a second embodiment of a heat sink system **120**. In this disclosure, like reference numerals designate like elements where appropriate and reference numerals with the addition of one-hundred or multiples thereof designate modified elements that are understood to incorporate the same features and benefits of the corresponding original elements. In this embodiment, a closed-loop vapor cycle system **158** is arranged in series with a first heat exchanger **128**. The vapor cycle system **158** is configured to cool a second thermal load **134** with a refrigerant, different than an expendable working fluid **122** communicated from reservoir **121** to a first cooling path **124**.

[0026] The vapor cycle system **158** includes a heat exchanger **160**, such as a condenser or gas cooler, an expansion valve **162**, a heat exchanger **130**, such as an evaporator, and a pump **142** arranged in series to define a second cooling path or loop **126**. The heat exchanger **160** uses working fluid **122** to cool the refrigerant circulating in the second cooling loop **126**. In an embodiment, heat exchanger **160** acts as a condenser for the refrigerant in the system **158**, and a boiler for working fluid **122** in the first cooling path **124**. The second heat exchanger **130** is thermally coupled to the second heat load **134**, such that heat is rejected to the first cooling path **124** as a heat sink. This arrangement improves the coefficient of performance of the heat exchanger **130** coupled to the second thermal load **134**, resulting in lower overall power, size and weight of the system **120**.

[0027] In some embodiments, heat exchanger **160** can be relatively small because the heat transfer to working fluid **122** is much better than traditional air forced convection. In one example, quantitative power benefits of adding a vapor cycle system for a 40° F. evaporating temperature and 100 kW cooling capacity system are 85 kW for a fan forced air condenser and 60 kW for an evaporating water cooled condenser. Most of the power benefit is a result of lower water vapor volume flow required, resulting in lower pumping power requirements, than for the required air flow volume. An additional benefit is a result of an improved coefficient of performance of the vapor cycle system due to an assumed 120° F. condensing temperature for a water system compared to an assumed 160° F. condensing temperature for an air system. In one embodiment, 0.12 lbm/sec water mass flow for a total water requirement of 24 lbm or about 3 gallons will cool 200 seconds total of ON-time per mission.

[0028] The expansion valve **162** may be actuated by controller **148** utilizing data from at least one of sensors **146E-G**. In one embodiment, expansion valve **162** allows flow of

refrigerant proportional to the sensed vapor superheat at an exit of second heat exchanger 130, while a ratio of the speed and/or pressure of pump 142 is varied by the controller 148 to control the temperatures at the second heat exchanger 130 and the second heat load 134. As shown, the heat exchanger 160 is located in series with the first heat load 132. The heat exchanger 160 may be upstream or downstream of the first heat load 132, depending on the needs of a particular situation.

[0029] In one embodiment, a refrigerant accumulator 164 is positioned between the heat exchanger 160 and the expansion valve 162. The refrigerant accumulator 164 is configured to store liquid refrigerant during periods of low demand, and is configured to supply liquid refrigerant above a steady state capability during periods of high demand, allowing the system 120 to effectively control the temperature of the second heat load 134 utilizing a pulse heat load technique. For example, during a pulse load ON condition, the vapor superheat exiting heat exchanger 130 will initially increase, causing the expansion valve 162 to increase its opening. The temperature at heat load 134 will tend to increase and the speed of the pump 142 will also increase. As the pulse load continues and the refrigerant accumulator 164 empties, a pressure and temperature of heat exchanger 160 will increase due to an increased thermal load above a design capacity of the heat exchanger 160. A speed and pressure ratio of pump 142 will increase to maintain a constant pressure and temperature at heat exchanger 130.

[0030] During a pulse load OFF condition, the opening of expansion valve 162 will reduce due to the reduced thermal load on heat exchanger 130, and the flow of refrigerant into the pump 142 will decrease. In this condition, the vapor cycle system 158 will operate below the design capacity of the heat exchanger 160. Vapor in the heat exchanger 160 will condense at a greater rate than the flow at pump 142, causing pressure and temperature at the heat exchanger 160 to decrease. The increased liquid refrigerant flow from the heat exchanger 160 will collect in the refrigerant accumulator 164 until the next pulse load ON period occurs.

[0031] The refrigerant accumulator 164 provides further benefits in size and weight of the overall system due to the ability to reduce the size of the heat exchanger 160 and limit the size of the heat exchanger 130 to be close to the average thermal power requirement of load 134. The magnitude of this benefit will depend on the specific application of the pulse load cycle.

[0032] FIG. 3 shows a schematic view of a third embodiment of a heat sink system 220. In this embodiment, a heat exchanger 260 is arranged in parallel with a first heat exchanger 228 and a first heat load 232. It should be apparent that the heat exchanger 260 and the first heat load 232 may be arranged in series or parallel depending on the needs of a particular situation. In a further embodiment, additional heat loads are connected to the system 220 in series or parallel.

[0033] FIG. 4 shows a cooling process or algorithm 70 using an expendable heat sink and may be utilized with any of the systems 20, 120, 220 described in this disclosure. The cooling process 70 maintains a relatively constant expendable working fluid level in a heat exchanger. At block 72, a measured fluid level in a heat exchanger is compared to a desired fluid level. If the measured fluid level is not above the desired fluid level, fluid is admitted to the heat exchanger at block 74. If the measured fluid level is above the desired fluid level, the temperature at the heat exchanger is compared to a predeter-

mined temperature setpoint at block 75. If the temperature at the heat exchanger is within a tolerance of the setpoint, control then returns to block 72.

[0034] If the temperature at the heat exchanger is not within the setpoint tolerance, the algorithm 70 determines whether the temperature is above the setpoint at block 76. If the temperature at the heat exchanger is above the temperature setpoint, the pressure in the heat exchanger over the expendable fluid is reduced at block 78. In an embodiment, the pressure is reduced by increasing a flow rate of a vacuum pump, ejector or similar device. The reduction in pressure will increase the fluid vaporization rate at the heat exchanger until the fluid is at the temperature corresponding to the boiling temperature at the new lower pressure. A quantity of fluid is then selectively exhausted to an ambient environment, such as overboard an aircraft at block 79. If the temperature at the heat exchanger is below the temperature setpoint, the pressure in the heat exchanger is increased by decreasing the flow rate of the vacuum pump, ejector or similar device at block 80.

[0035] At block 82 a measured temperature at a heat load thermally coupled to the heat exchanger is compared to a heat load threshold temperature. If the temperature at the heat load is below the threshold temperature, then supplemental heat is added at block 84 to increase the temperature of the heat exchanger. This may occur during initial operation of the system when heat is not yet generated by the heat load and the heat load is below a desired operating temperature. Control then returns to block 72.

[0036] FIG. 5 shows a cooling process or algorithm 170 according to a second embodiment using an expendable heat sink and may be utilized with any of the systems 20, 120, 220 as described in this disclosure. This process controls fluid level to maintain a fluid vapor exiting the heat exchanger at a relatively constant superheat, whereas process 70 controls the heat exchanger temperature by varying the heat exchanger pressure. Algorithm 170 measures the temperature and pressure of fluid vapor exiting the heat exchanger at block 171. The vapor temperature and pressure are used to determine the superheat of the vapor by a saturation curve fit calculation, table look up, or similar process. The determined superheat is compared to a predetermined superheat threshold at block 172. If the determined superheat is greater than the superheat threshold, additional expendable fluid is added to the heat exchanger at block 174 until the superheat is at or below the superheat threshold. Blocks 175-184 operate in a similar manner as blocks 75-84 of process 70. The algorithms 70, 170 may be performed with the controller 148.

[0037] Although two cooling paths or loops are primarily discussed in this disclosure, it should be appreciated that any number of cooling paths are contemplated. Any number of cooling paths or loops can be arranged in series and/or parallel to provide the desired solution. Additionally, any number of thermal loads may be arranged within the system to provide the desired solution. The cooling processes described discuss a single heat exchanger and a single load, but may be duplicated for multiple heat exchangers and/or loads and further adapted to the particular application and operating requirements.

[0038] Although the different examples have a specific component shown in the illustrations, embodiments of this disclosure are not limited to those particular combinations. It is possible to use some of the components or features from one of the examples in combination with features or components from another one of the examples. Also, although par-

ticular step sequences are shown, described, and claimed, it should be understood that steps may be performed in any order, separated or combined unless otherwise indicated and will still benefit from the present disclosure.

[0039] Furthermore, the foregoing description shall be interpreted as illustrative and not in any limiting sense. A worker of ordinary skill in the art would understand that certain modifications could come within the scope of this disclosure. For these reasons, the following claims should be studied to determine the true scope and content of this disclosure.

What is claimed is:

1. A system for cooling a thermal load, comprising:
a reservoir configured to communicate a working fluid to a first boiler defining a first flow path, wherein the first boiler is configured to cool a first load;
a second heat exchanger defining a second flow path and configured to cool a second, different load; and
a first pump configured to selectively exhaust the working fluid from the first boiler to an ambient environment.
2. The system of claim 1, wherein the working fluid is communicated from the reservoir to the second heat exchanger.
3. The system of claim 2, wherein the second heat exchanger is a second boiler.
4. The system of claim 2, wherein the second flow path comprises a second pump positioned downstream of the second heat exchanger, configured to communicate the working fluid from the second flow path to the first flow path upstream of the first pump.
5. The system of claim 1, wherein the second cooling path is a closed loop vapor cycle system including a condenser configured to reject heat from the second cooling path to the first cooling path.

6. The system of claim 5, wherein the condenser is arranged in series with the first boiler.

7. The system of claim 5, wherein the condenser is arranged in parallel with the first boiler.

8. The system of claim 5, wherein the vapor cycle system includes a refrigerant accumulator arranged between the condenser and an expansion valve.

9. The system of claim 1, wherein the working fluid includes water.

10. The system of claim 1, comprising at least one flow control valve configured to meter flow between the reservoir and at least one of the first flow path and the second flow path.

11. The system of claim 1, wherein a first cooling capacity of the first boiler is different than a second cooling capacity of the second heat exchanger.

12. The system of claim 1, wherein the first heat load is a high temperature heat source and the second heat load is a lower temperature heat source.

13. A method of cooling a thermal load, comprising:
providing a reservoir configured to communicate a working fluid to a boiler defining a first flow path and with a first cooling capacity, wherein the boiler is thermally coupled to a first load;
providing a heat exchanger defining a second flow path and with a second cooling capacity, wherein the heat exchanger is thermally coupled to a second load; and
selectively exhausting the working fluid to an ambient environment downstream from the boiler.

14. The method as recited in claim 13, the working fluid is communicated from the reservoir to the heat exchanger.

15. The method as recited in claim 13, wherein the second flow path is a closed loop vapor cycle system including a condenser configured to reject heat from the second cooling path to the first cooling path.

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