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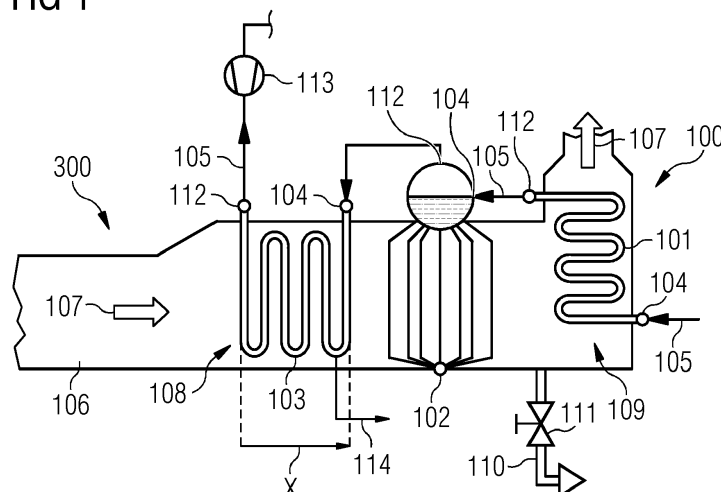
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(54) HEAT RECOVERY STEAM GENERATOR WITH MASS FLOW ADAPTION

(57) The present invention relates to a device (100) for heat recovery of a thermal system (300). The device (100) comprises a feeding line (106) through which a first fluid (107) of the thermal system (300) is streamable, wherein the first fluid (107) streams along a first streaming direction, a first thermal unit (101) for transforming a state of a second fluid (105) by thermal energy from the first fluid (107) and a second thermal unit (102) which is arranged adjacent to the first thermal unit (101) with respect to the first streaming direction of the first fluid. The second thermal unit (102) is configured for receiving the second fluid (105), wherein the second thermal unit (102)

is adapted for transforming a further state of the second fluid (105) by thermal energy from the first fluid (107) and wherein the first thermal unit (101) and/or the second thermal unit (102) are installed at least partially in a thermal transfer section (108) in the feeding line (106). In the thermal transfer section (108) thermal energy is transferable from the first fluid (107) to the second fluid (105). The device (100) further comprises a bleed section (110) coupled to the feeding line (106) at the thermal transfer section (108) for bleeding off a part of the first fluid (107) out of the feeding line (106).

FIG 1



DescriptionField of the invention

- 5 **[0001]** The present invention relates to a device and a method for heat recovery of a thermal system. Furthermore, the present invention relates to a thermal system, in particular a thermal storage, for providing thermal energy.

Art background

- 10 **[0002]** Heat Recovery Steam Generators (HRSGs) are common heat consumers for a thermal system providing heated gas. In a primary thermal cycle, heated first fluid may be provided which heats a further second fluid in a secondary cycle powered by the HRSG. Thermal systems may provide as a heat source for example thermal storage systems, heat pumps or gas turbines for providing heated first fluid. A HRSG partially comprising the secondary cycle heats the second fluid, such as water, and produces steam that can be used for further applications.
- 15 **[0003]** The air inflow of the primary thermal cycle into the HRSG contains thermal energy which was e.g. previously stored in the energy storage device. The air flow in the HRSG is thermally coupled to a water/steam part of the HRSG. Due to the heat exchange with the water/steam in the HRSG, the air outflow has a much lower temperature than the inflow.
- [0004]** For the water/steam side of the HRSG, the feedwater is first heated up in an economizer, then evaporated in an evaporator and finally optionally further heated up in a superheater, so that superheated steam leaves the HRSG.
- 20 **[0005]** Fig. 4 shows a temperature diagram of a conventional HRSG integrated into a heat storage system. The temperature of the conventional first fluid 407, such as air, is decreasing monotonously from an inflow of the HRSG to the outflow of the HRSG due to the heat transfer to the second fluid 405 inside the HRSG, such as water/steam. The feedwater is heated up to the saturation temperature, followed by an isothermal evaporation, thereafter the temperature of the saturated steam is further increased in a superheater. As can be seen from the diagram in Fig. 4, there is a point
- 25 where the temperature difference between the air and the water/steam reaches a minimum (ΔT_p). This point is called the "pinch point". As shown in Fig. 4, the temperature differences between air and water/steam will be a lot higher at the inlets and/or outlets of the HRSG.
- [0006]** Up to now, it is only possible to pivot the air temperature line around the fixed pinch point and it may not be possible to have both ends of the air temperature line at a low temperature difference to the water/steam. Exemplarily,
- 30 two possible curves are shown in Fig. 4. The first option is to choose a high air inflow temperature $T_{A,in}$, demonstrated by the curve A. Due to the fixed pinch point and the linearity of the temperature line, this will result in a low air outflow temperature $T_{A,out}$. Regarding e.g. an energy storage system to which the HRSG is coupled this means, that the system has to be operated at a very high temperature in order to provide air at the required inflow temperature $T_{A,in}$.
- [0007]** From an operational perspective however, it is very convenient to have a HRSG air inflow temperature that lies
- 35 well below the storage operating temperature. The surplus in storage air temperature can easily be reduced by the admixture of colder air and allows operation of the storage system in non-ideal conditions due to the high "safety margin", as fluctuations in the storage temperature can be compensated by a varying degree of admixture.
- [0008]** As the HRSG air inflow temperature in the case A is shifted towards the storage operating temperature however, this leads to a lower flexibility and a higher risk in the operation of the energy storage system.
- 40 **[0009]** The second option, demonstrated by the curve B in Fig. 4, is to have a low air inflow temperature $T_{B,in}$ which may bring the advantage of a higher "safety margin" as described above. Due to the previously mentioned restrictions, this will lead to a high air outflow temperature $T_{B,out}$ which in turn reduces the temperature difference between the hot and cold storage material states, as the HRSG air outflow temperature is directly related to the lower storage temperature. Since this temperature difference is directly related to the usable energy stored in the storage device, this leads to a
- 45 bigger storage and higher volume flow and lower efficiency compared to a storage system able to store the same amount of usable energy with a higher temperature difference.

Summary of the invention

- 50 **[0010]** It may be an object of the present invention to provide a more efficient heat recovery steam generator.
- [0011]** This object is solved by a device and a method for heat recovery of a thermal system, such as a thermal storage system, according to the subject matters of the independent claims.
- [0012]** According to a first aspect of the invention, a device for heat recovery of a thermal system is provided. The device comprises a feeding line through which a first fluid of the thermal system is streamable, wherein the first fluid
- 55 streams along a first streaming direction. The device further comprises a first thermal unit for transforming a state of a second fluid by thermal energy from the first fluid and a second thermal unit which is arranged adjacent to the first thermal unit with respect to the first streaming direction of the first fluid. The second thermal unit is configured for receiving the second fluid. The second thermal unit is adapted for transforming a further state of the second fluid by thermal energy

from the first fluid.

[0013] The first thermal unit and/or the second thermal unit are installed at least partially in a thermal transfer section in the feeding line, wherein in the thermal transfer section thermal energy is transferrable from the first fluid to the second fluid. In other words, the thermal transfer section defines the section, where a thermal transfer between the second fluid in a respective thermal unit (arranged at least partially within the feeding line) and the first fluid in the feeding line takes place.

[0014] The device further comprises a bleed section coupled to the feeding line at the thermal transfer section for bleeding off a part of the first fluid out of the feeding line.

[0015] According to a further aspect of the present invention, a thermal system for providing thermal energy, in particular a heat storage system, is provided. The thermal system comprises the above described device and the fluid line which is coupled to the feeding line such that heated first fluid is providable from the fluid line to the feeding line

[0016] According to a further aspect of the present invention a method for heat recovery of a thermal system by the above described device is provided.

[0017] The device may function as a heat recovery steam generator (HRSG), wherein heat from the first fluid exhausted by a thermal system can be used and recovered by heating up the second fluid of the device.

[0018] The thermal system provides a heated first fluid which is adapted to transfer heat to the respective second fluid of the device. The thermal system may be a thermal storage system which provides heated first fluid e.g. from a heat storage. Furthermore, the thermal system may comprise as a heat source a heat pump or a gas turbine in particular for generating electrical power.

[0019] The first fluid may be provided in a gaseous state. In the primary cycle of the thermal system, the first fluid does not necessarily conduct a phase transformation. The first fluid may be for example heated air or other heated gas. However, the first fluid may also be a heated liquid, such as water.

[0020] The device functioning as a heat recovery steam generator (HRSG) is installed for recovering heat from the first fluid, such as a hot gas stream. The device is using in a secondary cycle the second fluid which is for example water.

The device is coupled to a feeding line of the thermal system such that the first fluid flowing through the feeding line transfers thermal energy to the respective thermal units, such as an economizer unit and an evaporator unit. Specifically, the device transfers thermal energy from the first fluid to the second fluid such that a state of the second fluid is changed.

[0021] By transforming a state of the second fluid it is denoted that in a respective thermal unit one or a plurality of parameters of the second fluid, such as the pressure, the temperature, the specific enthalpy and/or the state of matter, is changed by the thermal energy of the first fluid. For example, in a thermal unit, the temperature and/or the pressure of the second fluid can be amended by the thermal energy of the first fluid. Additionally or alternatively, for example if the thermal unit is an evaporator, the first fluid transfers thermal energy to the second fluid and changes the state of matter of the second fluid for example from a liquid state to a saturated steam and vaporous state. The produced steam can be used in a subsequent process or used to drive e.g. a steam turbine.

[0022] Specifically, the first fluid streams along a streaming direction passing the heat exchangers of the device. The thermal units of the device are installed within the feeding line such that the first fluid passes the first thermal unit and the second thermal unit. In an exemplary embodiment, the second thermal unit is arranged adjacent to the first thermal unit upstream with respect to the first streaming direction of the first fluid. However, it is also possible that the first thermal unit is arranged upstream to the second thermal unit with respect to the first streaming direction of the first fluid.

[0023] Furthermore, in an exemplary embodiment, the second fluid may stream directly from the first thermal unit into the second thermal unit. However, in a further exemplary embodiment, the second fluid may stream from the first thermal unit to a further intermediate unit and subsequently into the second thermal unit. The intermediate unit may be arranged for example outside of the feeding line. For example, the intermediate unit may be for example a separator unit, a condenser unit or another heat exchanger arranged outside the feeding line.

[0024] As described above in connection with Fig. 4, it is an aim to provide an efficient thermal heat transfer between the first fluid and the second fluid. Thereby, it is important that at the pinch point, where the temperature difference between the first fluid and the second fluid reaches a local minimum, a sufficiently high temperature difference is provided, such that an efficient heat transfer between the second fluid and the first fluid at the pinch point is still possible. At the same time, the entrance temperature of the first fluid (i.e. before a pinch point, e.g. at the beginning of heating up the second fluid in a thermal unit) should be not too high and the exit temperature of the first fluid after heating up the second fluid in the economizer unit should be low in order to provide a more efficient heat recovery steam generator.

[0025] This object is achieved by the bleed section. According to the approach of the present invention, the bleed section is coupled to the feeding line for bleeding off the part of the first fluid in order to reduce the mass flow of the first fluid. Specifically, the mass flow of the first fluid streaming along the first thermal unit or the second thermal unit (e.g. an economizer unit or evaporator unit) for transferring thermal energy to the second fluid is reduced by bleeding off the first fluid out of the feeding line. Additionally, due to the reduced mass flow of the first fluid, the heat exchanger surfaces, i.e. the heat transfer surface, of the respective thermal units should be increased and hence adapted to the reduced mass flow. At the end, the thermal energy Q_{HRSG} induced by the first fluid into the second fluid may be kept constant

while the temperature of the first fluid after passing for example the economizer unit is lower than a temperature of the first fluid without bleeding off a part of the first fluid. As described further below, the bled off part of the first fluid may be used for further thermal processes or may be injected again into the feeding line upstream of the first or second thermal unit or upstream of the device.

[0026] Hence, by the present invention, it is sufficient to inject into the device a first fluid with a lower temperature and to provide a lower exit temperature of the first fluid at the point of leaving the device, while the thermal energy Q_{HRSG} induced by the first fluid into the second fluid may be kept constant. Hence, an efficient heat recovery process can be provided.

[0027] According to a further exemplary embodiment, the bleed section is arranged in the thermal transfer section (in particular near or at the location) where a temperature difference between the first fluid and the second fluid is minimized. In other words, within a thermal transfer section, a local minimum of the temperature difference between the first fluid and the second fluid may occur. However, throughout the feeding line, a plurality of local minima and hence a plurality of thermal transfer sections and bleed sections, respectively, can be arranged in order to control the mass flow of the first fluid within the feeding line. In the design phase of the respective device the locations of the local minima of the difference between the temperature of the first fluid and the second fluid can be predetermined such that the respective locations of the bleed sections can be designed.

[0028] According to a further exemplary embodiment, the bleed section is arranged in the thermal transfer section (in particular near or at the location) where the minimum temperature difference between the first fluid and the second fluid is below 50K (Kelvin), in particular below 20K, further in particular below 10K.

[0029] According to a further exemplary embodiment, the device further comprises a controllable bleed valve arranged at the bleed section for controlling the mass flow of the part of the first fluid to be bled off the feeding line. Hence, the mass flow of the bled off first fluid is adjustable for example in accordance with the respective temperatures of the first fluid and/or the second fluid. For example, if the temperature of the first fluid after passing the first thermal unit is too low, less mass flow of the first fluid is bled off and vice versa.

[0030] According to a further exemplary embodiment, the device further comprises a mass flow sensor arranged at the bleed section for measuring the mass flow in the bleed section, wherein the mass flow sensor is coupled to the bleed valve for controlling the mass flow of the part of the first fluid to be bled off the feeding line.

[0031] According to a further exemplary embodiment, the device further comprises a first sensor arranged in the thermal transfer section for determining the temperature of the second fluid and a second sensor arranged in the thermal transfer section for determining the temperature of the first fluid, such that a temperature difference between the second fluid and the first fluid at the thermal transfer section is determinable.

[0032] Specifically, respective (temperature) sensors may be installed at the first fluid entrance and first fluid exit of the first or second thermal unit and respective (temperature) sensors may be installed at the second fluid entrance and second fluid exit of the first or second thermal unit. Hence, based on the received signals of the respective sensors, the mass of the bled off part of the first fluid at the bleed section may be exactly adjusted by the bleeding valve such that an efficient operation of the device may be provided.

[0033] According to a further exemplary embodiment, the first fluid is flowable along the flow path passing the first thermal unit between a first fluid connection and a second fluid connection of the first thermal unit. The first fluid connection and the second fluid connection of a thermal unit define a respective inlet and outlet of the second fluid flowing through the respective thermal unit.

[0034] The flow path between the first fluid connection (where the second fluid e.g. enters a respective thermal unit) and the second fluid connection (where the second fluid e.g. exits the respective thermal unit) of the first thermal unit has a total length. The second fluid flows between the first fluid connection and the second fluid connection, wherein the bleed section is arranged 30 % or less of the total length of the flow path upstream or downstream (with respect to the first flow direction of the first fluid) of the first fluid connection, or wherein the bleed section is arranged 30 % or less of the total length of the flow path upstream or downstream (with respect to the first flow direction of the first fluid) of the second fluid connection.

[0035] Hence, the bleed section is arranged in the vicinity of the fluid connection of the second fluid with a respective thermal unit. As described by the exemplary embodiment, the bleed section is arranged for example at the location of the feeding line, which location is with respect to the first flow path of the first fluid before or after the respective thermal unit. Additionally, the bleed section may be arranged for example at the location of the feeding line, which location is with respect to the first flow path of the first fluid within the region of the respective thermal unit close to the first or second fluid connections (inlets or outlets of the second fluid). Hence, an efficient control of the mass flow of the first fluid and the respective adjustment of the temperature difference and the pinch point, respectively, can be provided.

[0036] According to a further exemplary embodiment, the first thermal unit, the second thermal unit and/or a further third thermal unit is/are selected from one of the group consisting of an economizer unit, an evaporator unit, a superheater unit and a reheater unit.

[0037] Hence, in an exemplary embodiment, the first thermal unit is an economizer unit and the second thermal unit

is an evaporator unit. For example, first the evaporator unit is passed by the first fluid and, downstream with respect to the streaming direction of the first fluid, the economizer unit is installed. Hence, the first fluid passes the evaporator unit with a higher temperature level and subsequently passes the economizer unit with a lower temperature level.

[0038] Hence, the first fluid with a lower temperature level transfers thermal energy to the second fluid in the economizer until the second fluid comprises an amended state, i.e. a heated up liquid state. Before the first fluid passes the economizer unit, the first fluid with a higher temperature level transfers further thermal energy to the heated up second fluid in the evaporator unit such that after e.g. an isothermal evaporation the second fluid leaves the evaporator unit in a saturated steam state. Furthermore, a superheater unit may be provided in which further thermal energy is transferred from the first fluid to the second fluid such that the second fluid further heats up until a superheated steam state of the second fluid is provided. After leaving the device, the evaporated second fluid can be used for further processes, such as for electricity generation in a steam turbine with a connected generator or for other thermal processes.

[0039] According to a further exemplary embodiment of the invention, the bleed section is arranged at the feeding line in the vicinity of the second fluid outlet of the economizer unit. Between the outlet of the economizer unit and the inlet of the evaporator unit, it is very likely that the pinch point, where the lowest temperature difference between first fluid and second fluid occurs, is located. In order to provide an effective control of the mass flow of the first fluid with respect to the heat transfer efficiency, the location of the bleed section is advantageously at or in the vicinity of the location of the occurrence of the pinch point.

[0040] According to a further exemplary embodiment it is outlined, that the device further comprises a further bleed section coupled to the feeding line at the thermal transfer section for bleeding off a further part of the first fluid out of the feeding line.

[0041] Hence, a plurality of bleed sections may be provided, wherein each bleed section is arranged at a pinch point which may occur in an exemplary embodiment between the exit of the second fluid at the first thermal unit (e.g. an economizer unit) and the entry of the second thermal unit (e.g. an evaporator unit). A "pinch point" according to the present invention may be defined by a point, where the temperature difference between the first fluid and the second fluid reaches a local minimum. A pinch point may be defined at a section, where the temperature difference between the temperature of the first fluid and the temperature of the second fluid is below 50K (Kelvin), in particular below 20K, further in particular below 10 K.

[0042] According to a further exemplary embodiment, the device may further comprise a third thermal unit which is arranged adjacent to the second thermal unit with respect to the first streaming direction of the first fluid, wherein the third thermal unit is configured for receiving the second fluid, wherein the third thermal unit is adapted for transforming a further state of the second fluid by thermal energy from the first fluid. The second thermal unit and/or the third thermal unit are installed at least partially in a further thermal transfer section in the feeding line. Furthermore, the device comprises a further bleed section coupled to the feeding line at the further thermal transfer section for bleeding off a further part of the first fluid out of the feeding line.

[0043] Hence, a device according to the present invention may comprise a further plurality of thermal units being arranged within the feeding line, wherein through each of the thermal units the respective second fluid flows. Furthermore, the plurality of thermal units is thermally coupled with the first fluid. Hence, a plurality of minima of the temperature differences and a plurality of pinch points, respectively, may exist. Hence, respective bleed sections may be arranged at the respective pinch points. For example, the thermal unit is a saturated steam unit, wherein in the saturated steam unit a plurality, e.g. three minima (i.e. pinch points) of the temperature difference between the first fluid and the second fluid exist. At each of the pinch points, a bleed section may be provided for bleeding off a part of the first fluid.

[0044] According to a further exemplary embodiment, the device comprises an injection section coupled to the feeding line for injecting a part of the first fluid into the feeding line. Hence, throughout the feeding line, one or a plurality of injection sections may be provided in order to add further first fluid into the feeding line. Hence, throughout the first flow path, the mass flow of the first fluid may be increased at desired locations. Hence, if at some locations a pinch point occurs and a part of the first fluid is bled off, downstream of the locations additionally a further mass of the first fluid may be injected in order to increase again the mass of the first fluid within the feeding line.

[0045] According to a further exemplary embodiment, the device further comprises a coupling section for feeding the second fluid to a steam turbine for driving the steam turbine. The steam turbine may be coupled to the second thermal unit, such as a superheater unit being e.g. a third thermal unit, for receiving the heated second fluid for driving the turbine.

[0046] According to a further exemplary embodiment, the thermal system comprises a bleed line coupled to the bleed section and the fluid line for injecting the bled off first fluid into the fluid line. Additionally or alternatively, the thermal system further comprises a compressor which is arranged in the bleed line for pumping the first fluid into the fluid line. Additionally or alternatively, the thermal system further comprises a heater coupled to the fluid line for heating the first fluid.

[0047] According to a further exemplary embodiment of the thermal system, the bleed line is coupled to the fluid line between the heater and the feeding line of the device for injecting the bled off first fluid downstream of the heater.

[0048] Hence, the extracted and bled off first fluid is injected again upstream of the device (i.e. the HRSG device). Hence, the temperature at the entrance of the device is reduced as well as the mass flow of the first fluid at the entrance

of the device is increased.

[0049] According to a further exemplary embodiment, the thermal system is a heat energy storage unit for storing heat energy, wherein the fluid line is coupled to the heat storage unit such that heated first fluid is injectable into the fluid line. In heat energy storages, the stored thermal energy is extracted by flushing the heat storage with a carrier fluid, such as the first fluid. The heated first fluid is then used for further thermal processes, such as driving a steam turbine or transferring heat to a second fluid.

[0050] The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited.

Brief Description of the Drawings

[0051]

Fig. 1 shows a schematic view of a device for heat recovery coupled to a thermal system according to an exemplary embodiment of the present invention.

Fig. 2 shows a temperature diagram of the device according to Fig. 1 installed in a thermal system according to an exemplary embodiment of the present invention.

Fig. 3 shows a schematic view of a device for heat recovery installed in a heat storage system according to an exemplary embodiment of the present invention.

Fig. 4 shows a conventional temperature diagram of a conventional HRSG installed in a thermal system

Detailed Description

[0052] The illustrations in the drawings are schematically. It is noted that in different figures, similar or identical elements are provided with the same reference signs.

[0053] **Fig. 1** shows a device 100 for heat recovery coupled to a thermal system 300 (shown in Fig. 3) according to an exemplary embodiment of the present invention. In **Fig. 2** the temperatures of a respective first fluid 107 of the thermal system 300 and a second fluid of the device 100 according to Fig. 1 is shown.

[0054] The device 100 comprises a feeding line 106 through which a first fluid 107 of the thermal system 300 is streamable, wherein the first fluid 107 streams along a first streaming direction, a first thermal unit 101 for transforming a state of a second fluid 105 by thermal energy from the first fluid 107 and a second thermal unit 102 which is arranged adjacent to the first thermal unit 101 with respect to the first streaming direction of the first fluid. The second thermal unit 102 is configured for receiving the second fluid 105, wherein the second thermal unit 102 is adapted for transforming a further state of the second fluid 105 by thermal energy from the first fluid 107 and wherein the first thermal unit 101 and/or the second thermal unit 102 are installed at least partially in a thermal transfer section 108, 109 in the feeding line 106. In the thermal transfer section 108, 109 thermal energy is transferrable from the first fluid 107 to the second fluid 105. The device 100 further comprises a bleed section 110 coupled to the feeding line 106 at the thermal transfer section 108, 109 for bleeding off a part of the first fluid 107 out of the feeding line 106.

[0055] By transforming a state of the second fluid 105 in a respective thermal unit 101, 102, 103 a parameter of the second fluid 105, such as the pressure, the temperature, the specific enthalpy and/or the state of matter, is changed by the thermal energy of the first fluid 107. For example, in a thermal unit, the temperature and/or the pressure of the second fluid 105 can be amended by the thermal energy of the first fluid 107. Additionally or alternatively, for example if the second thermal unit 102 is an evaporator, the first fluid 107 transfers thermal energy to the second fluid 105 and changes the state of matter of the second fluid 105 for example from a liquid state to a saturated steam and vaporous state. The produced steam can be used in a subsequent process or used to drive e.g. a steam turbine 113.

[0056] Specifically, the first fluid 107 streams along a first streaming direction and a first flow path, respectively, passing the heat exchangers of the thermal units 101, 102, 103. The thermal units 101, 102, 103 of the device 100 are installed within the feeding line 106 such that the first fluid 107 passes the first thermal unit 101, the second thermal unit 102 and the third thermal unit 103. In the exemplary embodiment, the second thermal unit 102 is arranged adjacent to the first thermal unit 101 upstream with respect to the first streaming direction of the first fluid 107.

[0057] The second fluid 105 streams directly from the first thermal unit 101 into the second thermal unit 102. The second fluid 105 may stream also from the first thermal unit 101 to a further intermediate unit (arranged outside of the feeding line 106) and subsequently into the second thermal unit 102 arranged inside the feeding line 106. For example,

the intermediate unit may be for example a condenser unit or another heat exchanger arranged outside the feeding line.

[0058] In the exemplary embodiment shown in Fig. 1 the first thermal unit 101 may be an economizer unit 101 for heating the second fluid 105 in a liquid state of the second fluid 105 and an evaporator unit 102 coupled to the economizer unit 101 for receiving the heated second fluid 105, wherein the evaporator unit 102 is adapted for heating the second fluid 105 up to a saturated steam state.

[0059] Specifically, in the evaporator unit 102, the second fluid 105 enters as feedwater in a liquid state. In the evaporator unit 102, the second fluid 105 is evaporated by thermal energy of the first fluid 107 such that steam is generated. Furthermore, the third thermal unit 103 may be a superheater unit configured for receiving the second fluid 105 from the evaporator unit 102.

[0060] The feeding line 106 is provided through which the first fluid 107, such as heated air in a gaseous state, of the thermal system 300 is streamable, wherein the feeding line 106 is thermally coupled by a first thermal transfer section 108 to the evaporator unit 102 and by a second thermal transfer section 109 to the economizer unit 101 in such a manner that along a streaming direction of the first fluid 107 firstly thermal energy is transferrable to the second fluid 105 in the evaporator unit 102 and secondly thermal energy is transferrable to the second fluid 105 in the economizer unit 101.

[0061] The bleed section 110 is coupled to the feeding line 106, wherein the bleed section 110 is arranged between the thermal transfer section 108 and the thermal transfer section 109 for bleeding off a part of the first fluid 107 out of the feeding line 106.

[0062] The device 100 functions as a heat recovery steam generator (HRSG), wherein heat from the first fluid 107 exhausted by a thermal system 300 can be used and recovered by heating up the second fluid 105 of the device 100. For example, a steam turbine 113 is coupled to the third thermal unit 103 for receiving the heated second fluid 105 such that mechanical energy for driving e.g. an electrical generator is generated.

[0063] The first fluid, such as air, is provided in a gaseous state. The second fluid 105 is for example water.

[0064] The thermal units 101, 102, 103 are coupled to the feeding line 106 of the thermal system 300 such that the first fluid 107 flowing through the feeding line 106 heats up the respective units 101, 102, 103, such as the economizer unit 101 and the evaporator unit 102 of the device 100. Specifically, the device 100 heats the second fluid 105 such that at the end steam is produced that can be used e.g. to drive the steam turbine 113.

[0065] Specifically, the first fluid 107 streams along a streaming direction through the feeding line 106. The thermal units 101, 102, 103 are installed within the feeding line 106 such that, along the streaming direction of the first fluid 107, first the superheater unit 103 and then the evaporator unit 102 is passed by the first fluid 107 and, downstream with respect to the streaming direction of the first fluid 107, the economizer unit 101 is passed. Hence, as can be taken from the associated temperature diagram in Fig. 2, the first fluid 107 passes e.g. the evaporator unit 102 (second thermal unit 102) with a higher temperature level and subsequently passes the economizer unit 101 (first thermal unit 101) with a lower temperature level.

[0066] Hence, the first fluid 107 with the highest temperature level (upon entering the feeding line 106) heats up the second fluid 105 in the superheater unit (third thermal unit) 103 until the second fluid 105 leaves the device 100 in a superheated steam state (heating section III in Fig. 2)

[0067] Next, the first fluid 107 heats up the heated up second fluid 105 in the evaporator unit (second thermal unit) 102 by an isothermal evaporation till the second fluid 105 leaves the evaporator unit 102 in a saturated steam state (heating section II in Fig. 2).

[0068] Next, the first fluid 107 with a lower temperature level heats up the second fluid 105 in the economizer unit 101 until the second fluid 105 comprises a heated up liquid state (heating section I in Fig. 2).

[0069] Furthermore, a further bleed section 114 is shown at the third thermal unit 103. The first fluid 107 is flowable along the flow path passing the third thermal unit 103 between a first fluid connection 104 and a second fluid connection 112 of the third thermal unit 103. The first fluid connection 104 and the second fluid connection 112 of a thermal unit 101, 102, 103 define a respective inlet and outlet of the second fluid 105 flowing through the respective thermal unit 101, 102, 103.

[0070] The flow path between the first fluid connection 104 (where the second fluid 105 e.g. enters a respective thermal unit 101, 102, 103) and the second fluid connection 112 (where the second fluid 105 e.g. exits the respective thermal unit 101, 102, 103) of the third thermal unit 103 has a total length x. The second fluid 105 flows between the first fluid connection 104 and the second fluid connection 112, wherein the bleed section 114 is arranged 30 % or less of the total length of the flow path upstream with respect to the first flow direction of the first fluid connection 104.

[0071] Hence, the bleed section 114 is arranged in the vicinity of the fluid connection 104 of the second fluid 105 with the third thermal unit 103. The bleed section 110 in the shown example is arranged for example at the location of the feeding line 106, which location is with respect to the first flow path of the first fluid 107 within the transfer section 109 of the respective thermal unit 103.

[0072] As shown in Fig. 2, a pinch point PP is defined, where the temperature difference ΔT_p between the first fluid 107 and the second fluid 105 is the lowest, a sufficient high-temperature difference ΔT_p is provided, such that an efficient heat transfer between the second fluid 105 and the first fluid 107 at the pinch point PP is still possible. At the same time,

the entrance temperature $T_{A,in}$ of the first fluid 107 (i.e. at the beginning of heating up the evaporator unit 102) should be not too high and the exit temperature $T_{B,2}$ of the first fluid 107 after heating up the second fluid 105 in the economizer unit 101 should be low in order to provide an efficient overall heat transfer.

[0073] In order provide a low entrance temperature $T_{A,in}$ and a low exit temperature $T_{B,2}$, the bleed section 110 is provided and coupled to the feeding line 106 for bleeding off the part of the first fluid 107 in order to reduce the mass flow of the first fluid 107, specifically before entering the economizer unit 101.

[0074] As can be taken form Fig. 2, a non-linear first fluid temperature curve can be achieved by bleeding off a part of the first fluid 107 at the bleed section 110. Hence, the mass flow of the first fluid 107 differs along the flowing direction when passing the device 100. The bleed section 110 is located between or near the economizer unit 101 and the evaporator unit 102 since the pinch point PP is reached in between these components. The reduced mass flow of the first fluid 107 from the pinch point PP onwards accelerates the temperature decrease of the first fluid 107 during the heat transfer to the feed water (i.e. the second fluid 105) in the economizer unit 101 (see heating section I), thus steepening the gradient of the temperature curve of the first fluid 107 (left of the pinch point PP in Fig. 2).

[0075] The heat flow in the device 100 may not be reduced by these measures, in particular additionally by adapting the heat transfer surfaces of the economizer unit 101.

[0076] In Fig. 2, ΔT_A is the difference between the temperature of the air flowing into the device 100 and the temperature of the first fluid 107 at the pinch point PP. This temperature difference $\Delta T_{A,in}$ is independent from a mass flow reduction occurring downstream. However, the temperature difference $\Delta T_{B,2}$ between the first fluid 107 at the pinch point PP and the temperature $T_{B,out}$ of the first fluid 107 leaving the device 100 through the outlet is much higher with a mass flow reduction (see $\Delta T_{B,2}$) than without a mass flow reduction (see $\Delta T_{B,1}$).

[0077] The heat flow for the entire device 100 may be calculated by this equation:

$$\dot{Q}_{HRSG} = \dot{Q}_A + \dot{Q}_B = \dot{m}_A c_{p,A} \Delta T_A + \dot{m}_B c_{p,B} \Delta T_B$$

[0078] $\dot{Q}_A$ describes the heat flow between the first fluid 107 and the second fluid 105 in the heating sections II,III, i.e. between the bleed section 110 and the input of the first fluid 107 in the device 100. As $\dot{Q}_A$ does not change with the mentioned downstream mass flow reduction at the bleed section 110, the term $\dot{m}_B c_{p,B} \Delta T_B$ has to be constant to have a constant heat flow $\dot{Q}_{HRSG}$ across the complete device 100. While $\dot{m}_B$ is reduced, ΔT_B is increasing, which allows $\dot{Q}_B$ to stay constant. $\dot{Q}_B$ describes the heat flow between the first fluid 107 and the second fluid 105 in the heating section I, i.e. between the bleed section 110 and the output of the first fluid 107 out of the device 100. ΔT_B can be further increased by adapting the heating surface in the economizer 101 to allow the same second fluid 105 (i.e. water/steam) temperature curve with the reduced air mass flow and reduced temperature difference $\Delta T_{B,2}$ between the air (first fluid 107) and the water (second fluid 105) in the economizer unit 101.

[0079] The thermal units 101, 102, 103 comprise respective heat exchangers arranged at the respective thermal coupling sections 108, 109, wherein the heat exchangers extend into the feeding line 106. As shown in Fig. 1, the heat exchanger comprises a plurality of tubes through which the second fluid 105 streams. The respective tubes are arranged within the feeding line 106 and are flushed by the first fluid 105 in order to transfer the thermal energy from the first fluid 107 to the second fluid 105.

[0080] The device 100 further comprises a controllable bleed valve 111 arranged at the bleed section 110 for controlling the mass flow of the part of the first fluid 107 to be bled off the feeding line 106. Hence, the mass flow of the bled off first fluid 107 is adjustable for example in accordance with the respective temperatures of the first fluid 107 and/or the second fluid 105.

[0081] Additionally, the device 100 may comprise a mass flow sensor arranged at the bleed section 110 for measuring the mass flow in the bleed section 110, wherein the mass flow sensor is coupled to the bleed valve 111 for controlling the mass flow of the part of the first fluid 107 to be bled off the feeding line.

[0082] The bleed sections 110, 114 are arranged in the thermal transfer sections 108, 109 where a temperature difference between the first fluid 107 and the second fluid 105 is minimized. In other words, within a thermal transfer section 108, 109, a local minimum of the temperature difference between the first fluid 107 and the second fluid 105 may occur. However, throughout the feeding line 106, a plurality of local minima and hence a plurality of thermal transfer sections 108, 109 and respective bleed sections 110, 114, respectively, can be arranged in order to control the mass flow of the first fluid 107 within the feeding line 106 precisely.

[0083] Furthermore, within one thermal unit 101, 102, 103 and within one thermal transfer section 108, 109, respectively, a plurality of minima of the temperature differences and a plurality of pinch points PP, respectively, may exist. Hence, respective bleed sections 110, 114 may be arranged, each at a respective pinch point PP. For example, the second thermal unit 102 is a saturated steam unit, wherein in the saturated steam unit a plurality, e.g. three minima (i.e. pinch points PP) of the temperature difference between the first fluid 107 and the second fluid 105 exist. At each of the pinch

points PP, a bleed section 110, 114 may be provided for bleeding off a part of the first fluid 107.

[0084] Fig. 3 shows a schematic view of a device 100 for heat recovery (HRSG) installed in a heat storage system 300 according to an exemplary embodiment of the present invention. The heat storage system 300 comprises at least one blower 306, at least one heater 304 and at least one heat energy storage 305. The blower 306 drives the first fluid 107 such that the first fluid 107 flushes the heat energy storage 305. A fluid line 301 is coupled to the heat storage unit 305 such that heated first fluid 107 is injectable. The fluid line 301 is connected to the feeding 106.

[0085] The heated first fluid 107 may optionally further heated by a heater 304 to increase the thermodynamic efficiency.

[0086] The device 100 is coupled to the heat energy storage 305 such that first fluid 107 transfers respective heat energy to the second fluid 105 of the device 100.

[0087] A bleed line 302 is coupled to the bleed section 110 and to the fluid line 301 for injecting the bled off first fluid 107 back into the fluid line 301. A compressor 303 may be arranged in the bleed line 302 for pumping the bled off first fluid 107 into the fluid line 301.

[0088] The bleed line 302 is in particular coupled to the fluid line 301 between the heater 304 and the feeding line 106 of the device 100 for injecting the bled off first fluid 107 downstream of the heater 304. Hence, the extracted and bled off first fluid 107 is injected again upstream of the device 100 (i.e. the HRSG device). Hence, the temperature at the entrance of the device 100 is reduced as well as the mass flow of the first fluid 107 at the entrance of the device 100 is increased. Optionally, it is also possible to use the remaining thermal energy of the bled of first fluid 107 flowing through the bypass line 302 in another heat consumer by means of a heat exchanger which is situated on the bypass line 302.

[0089] By the present invention, the entrance temperature of the first fluid 107 in the device 100 can be reduced such that also the thermal storage operating temperature may be lower.

[0090] Furthermore, the required volume flow may be lower. Especially the flexibility of the inflow temperature of the first fluid 107 into the device 100 is beneficial. Due to the first fluid 107 extracted from the HRSG device 100, the volume flow and the temperature of the first fluid 107 reaching the (main) blower 306 during discharging is reduced which can lower the complexity for the blower 306. The higher temperature difference between the cold heat transfer fluid entering the storage during discharging and the hot heat storage material increases the capacity ratio which leads to a smaller and therefore cheaper heat energy storage 305 for the same storage capacity. The smaller storage 305 also leads to a smaller pressure loss inside the storage material. With the additional bypass line 302 it is possible to operate the HRSG device 100 even during charging. Up to now the first fluid 107 downstream of the heater 304 reaches temperatures upwards of 700 degrees which may be above the limit for the operation of the HRSG device 100. With the additional bypass line 302, the device inlet temperature of the first fluid 107 can be reduced to a lower temperature with the admixture of the colder bleed first fluid from the bleed line 302.

[0091] It should be noted that the term "comprising" does not exclude other elements or steps and "a" or "an" does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

Claims

1. Device (100) for heat recovery of a thermal system (300), the device (100) comprising
 - a feeding line (106) through which a first fluid (107) of the thermal system (300) is streamable, wherein the first fluid (107) streams along a first streaming direction,
 - a first thermal unit (101) for transforming a state of a second fluid (105) by thermal energy from the first fluid (107),
 - a second thermal unit (102) which is arranged adjacent to the first thermal unit (101) with respect to the first streaming direction of the first fluid (107),
 - wherein the second thermal unit (102) is configured for receiving the second fluid (105), wherein the second thermal unit (102) is adapted for transforming a further state of the second fluid (105) by thermal energy from the first fluid (107),
 - wherein the first thermal unit (101) and/or the second thermal unit (102) are installed at least partially in a thermal transfer section (108) in the feeding line (106),
 - wherein in the thermal transfer section (108) thermal energy is transferrable from the first fluid (107) to the second fluid (105), and
 - a bleed section (110) coupled to the feeding line (106) at the thermal transfer section (108) for bleeding off a part of the first fluid (107) out of the feeding line (106).
2. Device (100) according to claim 1
 - wherein the bleed section (110) is arranged in the thermal transfer section (108) at the location where a temperature difference between the first fluid (105) and the second fluid (107) is minimized.

3. Device (100) according to claim 2,
wherein the bleed section (110) is arranged in the thermal transfer section (108) at the location where the minimum temperature difference between the first fluid (105) and the second fluid (107) is below 50K, in particular below 20K, further in particular below 10K.
4. Device (100) according to one of the claims 1 to 3, further comprising
a controllable bleed valve (111) arranged at the bleed section (110) for controlling the mass flow of the part of the first fluid (107) to be bled off the feeding line (106).
5. Device (100) according to claim 4, further comprising
a mass flow sensor arranged at the bleed section (110) for measuring the mass flow bled off the feeding line (106).
6. Device (100) according to one of the claims 1 to 5, further comprising
a first sensor arranged in the thermal transfer section (108) for determining the temperature of the second fluid (105), and
a second sensor arranged in the thermal transfer section (108) for determining the temperature of the first fluid (107), such that a temperature difference between the second fluid (105) and the first fluid (107) at the thermal transfer section (108) is determinable.
7. Device (100) according to one of the claims 1 to 6, wherein the first fluid (107) is flowable along the flow path passing the first thermal unit (101) between a first fluid connection (104) and a second fluid connection (112) of the first thermal unit (101),
wherein the flow path between the first fluid connection (104) and the second fluid connection (112) of the first thermal unit (101) has a total length (x),
wherein the second fluid (105) flows between the first fluid connection (104) and the second fluid connection (112),
wherein the bleed section (110) is arranged 30 % or less of the total length (x) of the flow path upstream or downstream with respect to the first flow direction of the first fluid connection (104), or
wherein the bleed section (110) is arranged 30 % or less of the total length (x) of the flow path upstream or downstream with respect to the first flow direction of the second fluid connection (112).
8. Device (100) according to one of the claims 1 to 7, wherein the first thermal unit (101) and/or the second thermal unit (102) is selected from one of the group consisting of an economizer unit (101), an evaporator unit (102), a superheater unit (104) and a reheater unit.
9. Device (100) according to one of the claims 1 to 8, further comprising
a further bleed section (114) coupled to the feeding line (106) at the thermal transfer section (108) for bleeding off a further part of the first fluid (107) out of the feeding line (106).
10. Device (100) according to one of the claims 1 to 9, further comprising
a third thermal unit (103) which is arranged adjacent to the second thermal unit (102) with respect to the first streaming direction of the first fluid (107),
wherein the third thermal unit (103) is configured for receiving the second fluid (105),
wherein the third thermal unit (103) is adapted for transforming a further state of the second fluid (105) by thermal energy from the first fluid (107),
wherein the second thermal unit (102) and/or the third thermal unit (103) are installed at least partially in a further thermal transfer section (109) in the feeding line (106), and
a further bleed section (114) coupled to the feeding line (106) at the further thermal transfer section (109) for bleeding off a further part of the first fluid (107) out of the feeding line (106).
11. Device (100) according to one of the claims 1 to 10, further comprising
a coupling section for feeding the second fluid (105) to a steam turbine (113) for driving the steam turbine (113), and/or
an injection section coupled to the feeding line (106) for injecting a part of the first fluid (107) into the feeding line (106).
12. Thermal system (300) for providing thermal energy, comprising
the device (100) according to one of the claims 1 to 11, a fluid line (301) coupled to the feeding line (106) such that heated first fluid (107) is providable from the fluid line (301) to the feeding line (106).
13. Thermal system (300) according to claim 12, further comprising

a bleed line (302) coupled to the bleed section (110) and the fluid line (301) for injecting the bled off first fluid (107) into the fluid line (301),

a compressor (303) which is arranged in the bleed line (302) for feeding the first fluid (107) into the fluid line (301), and/or

a heater (304) coupled to the fluid line (301) for heating the first fluid (107).

14. Thermal system (300) according to claim 13,

wherein the bleed line (302) is coupled to the fluid line (301) between the heater (304) and the feeding line (106) of the device (100) for injecting the bled off first fluid (107) downstream of the heater (304), and

wherein the thermal system (300) in particular further comprises a heat energy storage unit (305) for storing heat energy,

wherein the fluid line (301) is coupled to the heat storage unit such that heated first fluid (107) is injectable into the fluid line (301).

15. Method for heat recovery of a thermal system (300), the method comprising

streaming a first fluid (107) of the thermal system (300) through a feeding line (106),

wherein the first fluid (107) streams along a first streaming direction,

transforming in a first thermal unit (101) a state of a second fluid (105) by thermal energy from the first fluid (107),

wherein a second thermal unit (102) is arranged adjacent to the first thermal unit (101) with respect to the first streaming direction of the first fluid (107) for receiving the second fluid (105),

transforming in the second thermal unit (102) a further state of the second fluid (105) by thermal energy from the first fluid (107),

wherein the first thermal unit (101) and/or the second thermal unit (102) are installed at least partially in a thermal transfer section (108) in the feeding line (106),

wherein in the thermal transfer section (108) thermal energy is transferrable from the first fluid (107) to the second fluid (105), and

bleeding off a part of the first fluid (107) out of the feeding line (106) at a bleed section (110) coupled to the feeding line (106) at the thermal transfer section (108).

FIG 1

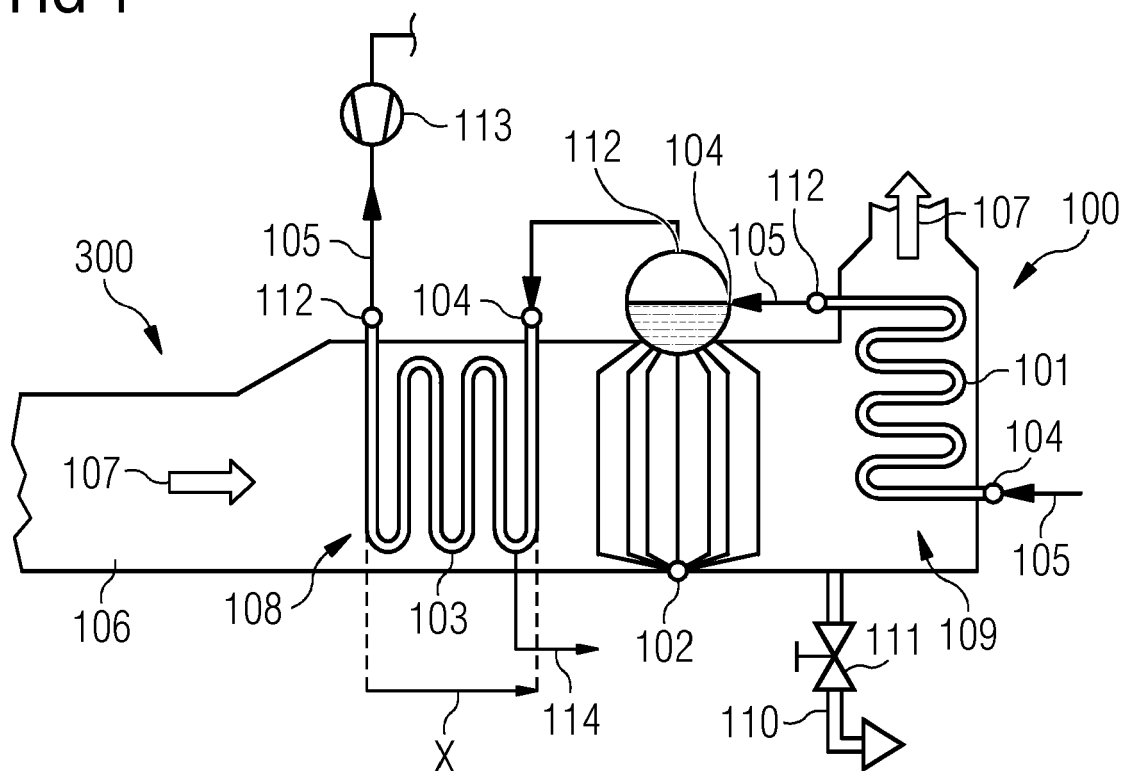


FIG 2

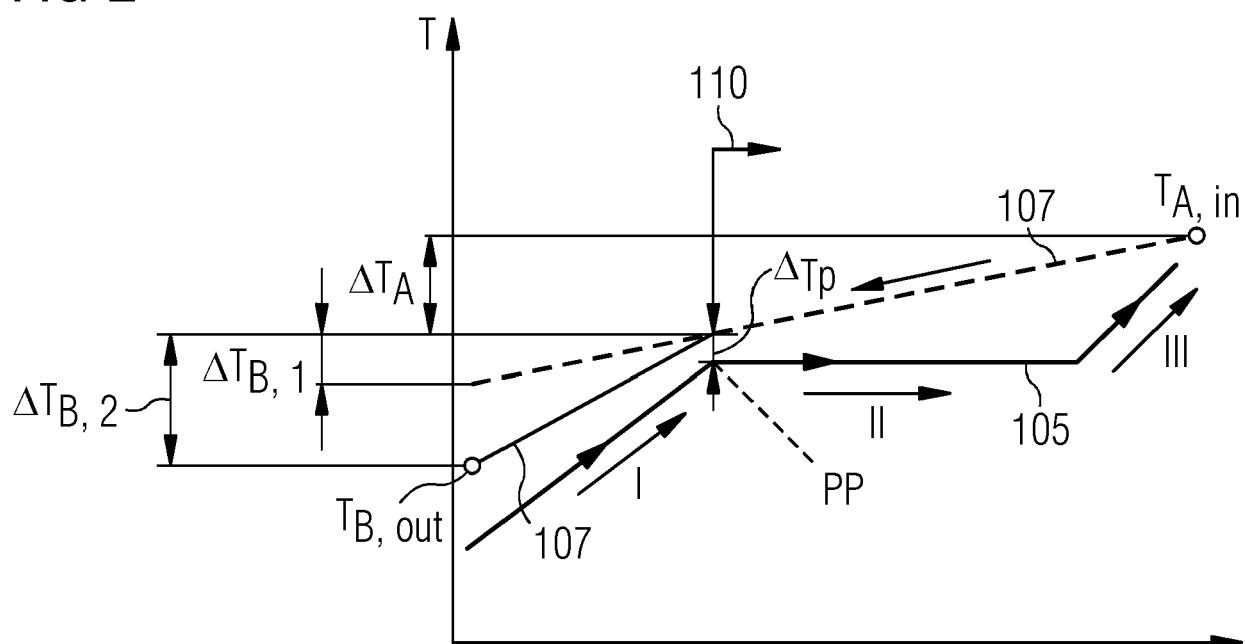


FIG 3

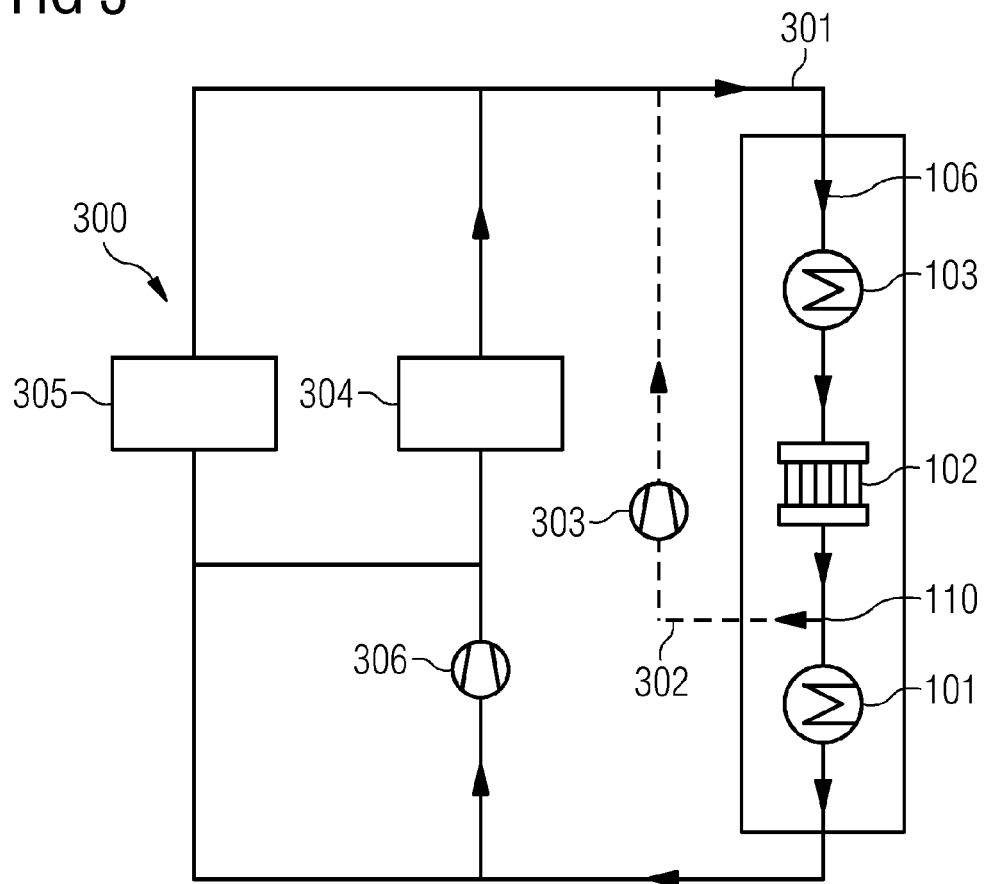
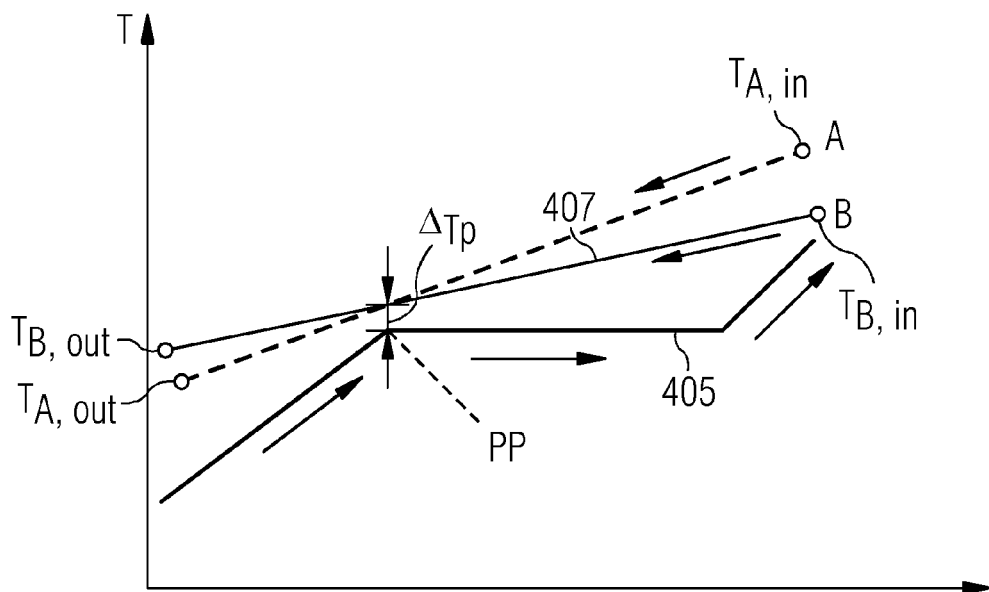


FIG 4 PRIOR ART





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