(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 June 2016 (23.06.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/096847 A1

(51) International Patent Classification:
F22B 1/18 (2006.01) *F22B 37/02* (2006.01)
F22B 35/08 (2006.01) *F22D 1/12* (2006.01)

(21) International Application Number:
PCT/EP2015/079779

(22) International Filing Date:
15 December 2015 (15.12.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
14199167.9 19 December 2014 (19.12.2014) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

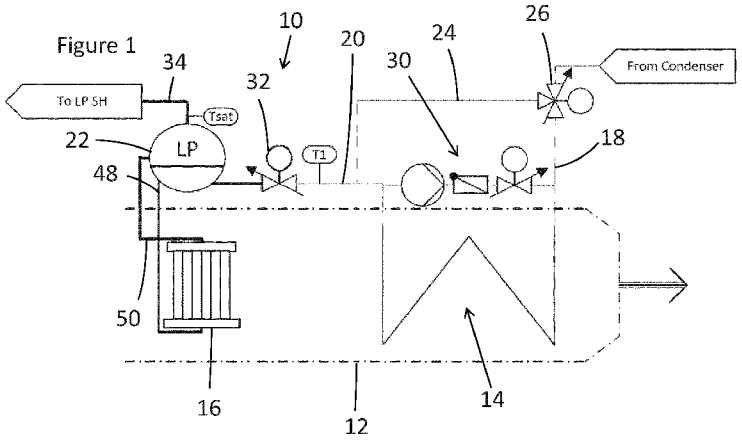
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: SYSTEM AND METHOD FOR FLUID MEDIUM PREHEATING

Figure 1



(57) **Abstract**: A method for operating a feedwater preheating system (10) for a heat recovery steam generator (HRSG) comprising a water separation unit (22), an evaporator (16), and a feedwater preheater (FWPH, 14) attached to a FWPH inlet line (18) and a FWPH outlet line (20) is provided. The method comprises feeding water from a condenser to the FWPH (14) along the FWPH inlet line(18), heating the water in the FWPH (14), feeding the water from the FWPH (14) to the evaporator (16) along an FWPH outlet line (20), boiling water in the evaporator (16) and feeding a resulting steam and water mixture to the water separation unit (22), monitoring an LP approach (ΔT) of the water separation unit (22), setting a set value of the LP approach, when the LP approach is below the set value, directing some water to bypass the FWPH (14) from the FWPH inlet line (18) to the FWPH outlet line (20). Further features of the invention include methods of monitoring the LP approach and apparatus to carry out the method.

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SYSTEM AND METHOD FOR FLUID MEDIUM PREHEATING

TECHNICAL FIELD

This invention relates to gas turbine power plants, and particularly to feedwater preheating systems for gas turbine power plants.

BACKGROUND OF THE INVENTION

In traditional combined cycle power plants (CCPP), low grade (low temperature level) heat is available but not exploited, for example from the HRSG stack or the generator/lubrication cooling.

One method to improve the efficiency of the CCPP is to recover waste heat from the CCPP. The waste heat can, for example, be recovered by decreasing the LP (low pressure) evaporator approach and thereby integrating more low-grade heat from the HRSG. This would increase LP steam production, thereby increasing the power production in the LP steam turbine and increasing the overall efficiency of the CCPP.

Currently, an LP evaporator approach of at least 5 K is used at design conditions. However, even with this LP evaporator approach at design point, the LP evaporator approach may reach 0 K during off-design operation, at which point undesirable flashing and cavitation can occur in the LP feedwater control valve. This can particularly be a problem when conditions are not within the range of conditions for which the CCPP has been designed, such as during part load.

Another limitation with existing designs is that during operating conditions where high feedwater temperature levels are required at the HRSG inlet (such as when sulphur is present in the flue gas during fuel gas or fuel oil operation), the current designs completely bypass the feedwater preheating coil and send cold feedwater directly to the LP drum. This causes a performance reduction in the CCPP.

SUMMARY OF THE INVENTION

The invention is defined in the appended independent claims to which reference should now be made. Advantageous features of the invention are set forth in the dependent claims.

According to a first aspect of the invention, there is provided a method for operating a feedwater preheating system for a heat recovery steam generator (HRSG) comprising a water separation unit, an evaporator, and a feedwater preheater (FWPH) attached to a FWPH inlet line and a FWPH outlet line, the method comprising feeding water from a condenser to the FWPH along an FWPH inlet line, heating the water in the FWPH, feeding the water from the FWPH to the evaporator along an FWPH outlet line, boiling water in the evaporator and feeding a resulting steam and water mixture to the water separation unit, monitoring an LP approach (ΔT) of the water separation unit, setting a set value of the LP approach, when the LP approach is below the set value, directing some water to bypass the FWPH from the FWPH inlet line to the FWPH outlet line. This method improves power plant efficiency and power output. When the operating parameters change, such as when the load level is reduced, the LP approach can be maintained at an appropriate level. In addition, flashing can be minimised or avoided in the LP feedwater control valve.

In one embodiment, the LP approach is monitored by monitoring a water separation unit water inlet temperature and a water separation unit steam outlet temperature. Preferably, at least one of the water separation unit water inlet temperature and the water separation unit steam outlet temperature is measured using at least one resistance temperature detector (RTD). This can improve measurement accuracy, and multiple RTDs can also provide component redundancy, allowing operation to continue even if one or more sensors fail.

In another embodiment, the set value is less than 5 K, preferably less than 2 K and most preferably less than 1 K. Lower set values are preferable as the efficiency is increased.

In another embodiment, the FWPH comprises an FWPH inlet, additionally comprising the steps of monitoring an FWPH inlet temperature and recirculating water from downstream of the FWPH inlet to the FWPH inlet, and/or directing some water to

bypass the FWPH, when the FWPH inlet temperature is below a set value. Preferably, the FWPH additionally comprises an FWPH outlet, and the water is recirculated from upstream of the FWPH outlet. This allows better efficiency (due to less exergy loss), easier control of the HRSG flue gas exit temperature and higher feedwater extraction temperature for flashing steam (so additional steam for the LP steam turbine) and for gas turbine air preheating.

In another embodiment, the water separation unit is an LP drum and feeding the water from the FWPH includes feeding water to the LP drum and then to the evaporator.

According to a second aspect of the invention, there is provided a feedwater preheating system for a combined cycle power plant (CCPP), comprising a heat recovery steam generator (HRSG) comprising an FWPH and an evaporator, a water separation unit connected to the evaporator and the FWPH, an FWPH inlet line for connection between a condenser and the FWPH, an FWPH outlet line for connection between the FWPH and the evaporator, a bypass connection line between the FWPH inlet line and the FWPH outlet line, a bypass control valve for controlling feedwater flow through the bypass connection line, means for monitoring an LP approach (ΔT) of the water separation unit, a control system configured and arranged to control the bypass control valve and to at least partly open the bypass control valve when the LP approach drops below a set value. This apparatus can provide improved power plant efficiency and power output.

In an embodiment, the means for monitoring an LP approach comprises a sensor for measuring the temperature in the FWPH outlet line, and a sensor for measuring the temperature of the steam in the water separation unit, and the means for monitoring an LP approach is configured and arranged to monitor the LP approach based on the temperature in the FWPH outlet line and the temperature of the steam in the water separation unit. Preferably, the sensor for measuring the temperature of steam in the water separation unit is in an evaporator outlet line.

In another embodiment, the bypass control valve is a three-way valve on the FWPH inlet line.

In another embodiment, the apparatus additionally comprises a recirculation pump attached on a line between a point downstream of the FWPH inlet line and the FWPH inlet line. This can provide further efficiency gains, and can avoid sulphur condensation on the FWPH when sulphur-containing fuels are used.

In another embodiment, at least one of the sensors is a resistance temperature

detector (RTD). Preferably, each of the sensors comprises three RTDs. This can improve measurement accuracy, and multiple RTDs can also provide component redundancy, allowing operation to continue even if one or more sensors fail.

In another embodiment, the water separation unit is an LP drum and the LP drum is interposed on the FWPH outlet line between the FWPH and the evaporator.

According to a third aspect of the invention, there is provided a combined cycle power plant comprising one of the feedwater preheating systems described above.

BRIEF DESCRIPTION OF THE DRAWINGS

An embodiment of the invention will now be described by way of example only and with reference to the accompanying drawings in which:

Figure 1 shows a feedwater preheating system according to the present invention;

Figure 2 shows an alternative feedwater preheating system according to the present invention; and

Figure 3 shows an alternative feedwater preheating system according to the present invention, in which RTDs (resistance temperature detectors) are used to monitor the temperature.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows a feedwater preheating system 10 for a heat recovery steam generator (HRSG) 12 for a combined cycle power plant (CCPP). The system encompasses a feedwater preheater (FWPH) 14 and an evaporator 16 (a low pressure evaporator in this example). An evaporator inlet line 48 and an evaporator outlet line 50 lead to and from the evaporator. An FWPH inlet line 18 is provided for connection between a condenser (not shown) and the feedwater preheater 14, and an FWPH outlet line 20 is provided for connection the between the feedwater preheater 14 and a water separation unit, which is a low pressure (LP) drum 22 in this example. A bypass connection line 24 is provided for connection between the FWPH outlet line 20 and the FWPH inlet line 18, and a bypass control valve (CV)(in this case three-way control valve 26) is provided at the connection point between the FWPH outlet line 20 and the FWPH inlet line 18.

Optionally, a recirculation pump 30 (comprising in this example a pump, a non-return valve and a control valve) is connected on a line from a tapping point at the exit of the feedwater preheater to a point at the entry of the feedwater preheater.

In this example, water temperature sensor T1 and saturation temperature sensor Tsat (measuring saturated steam temperature in the LP drum) are shown, with the water temperature sensor T1 placed on the FWPH outlet line 20. The saturation temperature sensor Tsat is placed on a steam line 34 leading from the LP drum to a low pressure superheater (LP SH). A control system (not shown) can control the control valve 26 based on the output of sensors T1 and Tsat, with the difference between these two outputs known as the LP approach. More formally, the LP approach is the difference in temperature (ΔT) between the saturated steam leaving the LP drum and the water entering the LP drum.

A further control valve 32 (LP drum control valve) to control LP drum water level is provided on the FWPH outlet line 20.

By control of the control valve in recirculation pump 30, some of the heated feedwater passing along FWPH outlet line 20 may be passed back to the FWPH inlet line 18, where it will then pass through the FWPH again. This can be carried out to increase the temperature of the feedwater at the inlet to the FWPH.

Figure 2 shows an alternative feedwater preheating system, and many of the components are as described in Figure 1. In Figure 2, a feedwater preheater 14 is provided and the recirculation pump 30 tapping point is connected to the line 41 between two parts of the FWPH.

Instead of three-way control valve 26, the embodiment of Figure 2 provides a (two-way) control valve 40. This is provided on the bypass connection line 24 between the condenser (not shown) and the FWPH outlet line 20.

A control system 42 is shown in Figure 2. Water temperature sensor T is equivalent to water temperature sensor T1 in Figure 1, and pressure sensor P is used to derive the saturation temperature (to replace saturation temperature sensor Tsat in Figure 1). Control unit 44 is also shown; this control unit monitors the pressure sensor P and the water temperature sensor T and adjusts the control valve 40 based on these inputs. Further details on methods of using the systems described in Figures 1 and 2 are provided below.

One option for measuring the LP approach is to measure the temperature of the feedwater using a thermocouple (at T, T1) and to measure the temperature of the drum by

calculating the saturation temperature correspondent to the pressure measured (Tsat, P). Another option is shown in Figure 3. To measure the inlet temperature of the LP drum, three resistance temperature detectors (RTDs) are placed in the FWPH outlet line 20 before the LP drum. To obtain the temperature, the average of these three devices is taken. To measure the LP drum steam temperature, three RTDs are placed on the evaporator outlet line 50 leading from the evaporator back to the LP drum (e.g. in the return header from the evaporator), and again the average temperature of the three RTDs is taken.

An advantage of multiple RTDs is that in the event that one or even two RTDs fail, the temperature can still be measured and operation of the system can continue. In such a case, the LP approach may be increased to account for the reduced accuracy of the temperature reading.

The input of pressure sensor P may also be used in control unit 44, as a cross-check for the temperature and/or for pressure control.

In a method of use of the apparatus shown in the Figures, feedwater enters from the condenser (not shown). The feedwater passes along FWPH inlet line 18 through three-way control valve 26 and into FWPH 14. In the FWPH 14 it is heated by heat transfer from the exhaust gas flow in the HRSG 12. The heated feedwater then passes along FWPH outlet line 20 through control valve 32 into the LP drum. From the LP drum, steam is passed to the LP SH (not shown) along steam line 34. Any water in the LP drum is fed to evaporator 16 through evaporator inlet line 48, and heat transfer from the flow in the HRSG 12 heats the water to produce further steam, with this steam being fed to the LP drum via evaporator outlet line 50.

The LP approach can be monitored using water temperature sensor T1 and saturation temperature sensor Tsat. The LP approach is the difference in temperature (ΔT) between the feedwater entering the LP drum and the saturation temperature at the drum pressure, with the feedwater temperature having the lower value. Based on the LP approach temperature, the state of the bypass CV is altered. If the LP approach drops below a set value (i.e. the minimum LP approach), the bypass CV (three-way CV 26 in Figure 1) will open and spray cold water to reduce the temperature T1 in FWPH outlet line 20. The set value is an LP approach of less than 5 K, preferably less than 2 K and most preferably less than 1 K.

Controlling the temperature T1 reduces the risk of flashing within the LP drum

control valve 32, even during deep part load (low or very low load) operation.

Preferably, the LP approach is continuously monitored (for example once every second). With continuous monitoring, the amount that the bypass CV is open can be changed as and when conditions change.

Examples of situations in which monitoring of the LP approach is valuable include during a change of turbine load and during part load, particularly deep part load. Under part load conditions, the heat is shifted to the cold end of the boiler (HRSG in this example) and therefore without adjustment of the bypass control valve to allow more water through the bypass connection line compared to normal conditions, the LP approach would normally drop and flashing would occur in the LP drum control valve.

The embodiments of the feedwater preheating system 10 described in the Figures may be incorporated into a gas turbine system. In particular, they may be incorporated into the system upstream of a steam turbine. The examples shown are upstream of a low pressure steam turbine, although the feedwater preheating system may also be used with a medium or high pressure steam turbine.. Downstream of the water separation unit, the feedwater preheating system may feed to a superheater (SH) or directly to a steam turbine (ST).

To enable greater heating of the feedwater, the HRSG 12 may have a greater surface (greater heat transfer area) than that provided in previous feedwater systems.

The bypass connection line 24 is connected at one end to the FWPH outlet line 20. The bypass connection line may be connected at any point between the exit of the FWPH and the water separation unit inlet temperature sensor. At the other end, the bypass connection line may be connected to the FWPH inlet line at any point between the condenser and the FWPH. Although the recirculation pump is shown as connected closer to the FWPH than the bypass connection line in the Figures, the bypass connection line may be closer than the recirculation pump line at one or both ends. A control valve is included (e.g. control valves 26, 40) to control the flow of water in the bypass connection line. The control valve shown in Figure 2 could also be used in the embodiments shown in Figures 1 and 3, and the control valve of Figures 1 and 3 could be used in the embodiment of Figure 2.

A temperature sensor may be placed near the inlet point where the FWPH inlet line joins the FWPH. This sensor monitors the FWPH inlet flow. In embodiments where the

fuel contains sulphur (such as during oil or fuel gas operation), the FWPH inlet flow temperature should preferably remain high, ideally above the condensation temperature of sulphur, to minimise or avoid build-up of sulphur on the outside of the FWPH. The recirculation pump 30 may be controlled based on the output of this temperature sensor, to maintain the feedwater inlet temperature for the FWPH above a set value. The set value may be the condensation temperature of sulphur.

Alternatively or additionally, the bypass connection line flow, as controlled by a control valve, can be modified based on the temperature at the FWPH inlet (HRSG inlet, the point where the FWPH enters the HRSG). When the temperature of the FWPH inlet drops below a set value, such as the condensation temperature of sulphur, some of the feedwater flow from the condenser is diverted through the bypass connection line. This reduces the feedwater flow through the FWPH. Once again, this method may be of use when a high FWPH inlet temperature is needed, for example to alleviate the problem of sulphur condensation. If the feedwater provided through the bypass connection line means that the water entering the LP drum is not sufficiently hot, LP steam production and/or extra steam (pegging steam) may be used to increase the water temperature. Additionally, a steam condenser, a condensate heat exchanger, a direct steam injection (DSI) or an electric heater can be used to further increase the LP feedwater temperature before the water is fed to the HRSG.

The recirculation pump 30 may either be connected (tapped) downstream of the feedwater preheater (e.g. Figure 1)(that is, after the FWPH outlet, i.e. the point where the FWPH leaves the HRSG), or it may also be connected part-way through a feedwater preheater (e.g. Figure 2). In cases where tapping occurs upstream of the feedwater preheater outlet (intermediate tapping) (upsteam of the last feedwater preheater outlet, when multiple feedwater preheaters are provided), a comparatively higher mass flow of lower temperature preheated water is recirculated when compared to tapping at or downstream of the feedwater preheater outlet. The remaining water downstream of the tapping point is then heated to a relatively higher temperature than if no water was recirculated, and this provides better efficiency (due to less exergy loss) and easier control of the HRSG flue gas exit temperature. It can also provide a higher feedwater extraction temperature for flashing steam (so additional steam for the LP steam turbine) and/or for gas turbine air preheating.

A control valve 32 is provided on the FWPH outlet line between the bypass line

and the water separation unit. The LP CV 32, the LP drum and the piping between them can all be designed for flashing conditions, such as by making them of hardened steel. This would allow further improvements in efficiency (further reduction in the LP approach) as flashing would be less detrimental to these components. Alternatively the flashing-hardened parts could be included as a backup, so that these parts are resistant to damage in case of flashing due to a failure of temperature measurements or control elements.

The saturation temperature sensor Tsat may be a pressure sensor, with a steam reference table used to calculate temperature from the pressure.

In Figure 3, the three RTDs are shown on the evaporator outlet line, but they can also be placed on the steam line (LP outlet line) or the LP drum, as shown with the sensors in Figures 1 and 2. Similarly, the sensor Tsat in Figure 1 and the sensor P in Figure 2 could be placed on the evaporator outlet line, at the LP drum exit, or in the LP drum above the water level. These steam temperature measuring sensors are placed in a place where they measure only the temperature of the steam in the LP drum, and are not directly influenced by the temperature of the water in the LP drum.

In Figure 3, three RTDs are used for each measurement for greater accuracy, but in general one or more RTD can be used, with the number depending for example on cost considerations and the level of accuracy required.

Deaeration of the feedwater may be carried out in the condenser (e.g. a water cooled condenser) and/or deaeration may be carried out in the LP drum. The set value may be adjusted to allow adequate LP approach for deaeration in an LP drum. This provides additional deaeration capacity.

Various modifications to the embodiments described are possible and will occur to those skilled in the art without departing from the invention which is defined by the following claims.

REFERENCE SIGNS

10	combined cycle power plant (CCPP)	34	steam line
12	heat recovery steam generator (HRSG)	40	control valve
14	feedwater preheater (FWPH)	41	line
16	evaporator	42	control system
18	FWPH inlet line (feedwater line)	44	control unit
20	FWPH outlet line (outlet line)	48	evaporator inlet line (inlet line)
22	low pressure (LP) drum	50	evaporator outlet line (outlet line)
24	bypass connection line	P	pressure sensor
26	bypass control valve	T	water temperature sensor
30	recirculation pump	T1	water temperature sensor
32	control valve (LP drum control valve)	Tsat	saturation temperature sensor

LP evaporator = low pressure evaporator
LP CV = low pressure control valve
LP ST = low pressure steam turbine
LP SH = low pressure super heater
FWPH = feedwater preheater
HRSG = heat recovery steam generator
CCPP = combined cycle gas turbine
RTD = resistance temperature detector

CLAIMS

1. A method for operating a feedwater preheating system (10) for a heat recovery steam generator (HRSG, 12) comprising a water separation unit (22), an evaporator (16), and a feedwater preheater (FWPH, 14) attached to a FWPH inlet line (18) and a FWPH outlet line (20), the method comprising
   - feeding water from a condenser to the FWPH (14) along the FWPH inlet line(18),
   - heating the water in the FWPH (14),
   - feeding the water from the FWPH (14) to the evaporator (16) along an FWPH outlet line (20),
   - boiling water in the evaporator (16) and feeding a resulting steam and water mixture to the water separation unit (22),
   - monitoring an LP approach (ΔT) of the water separation unit (22),
   - setting a set value of the LP approach,
   - when the LP approach is below the set value, directing some water to bypass the FWPH (14) from the FWPH inlet line (18) to the FWPH outlet line (20).

2. The method of claim 1, wherein the LP approach is monitored by monitoring a water separation unit inlet temperature and a water separation unit outlet temperature.

3. The method of claim 2, wherein at least one of the water separation unit inlet temperature and the water separation unit outlet temperature is measured using at least one resistance temperature detector (RTD).

4. The method of claim 1, wherein the set value is less than 5 K, preferably less than 2 K and most preferably less than 1 K.

5. The method of any previous claim wherein the FWPH (14) comprises an FWPH inlet, additionally comprising the steps of
   - monitoring an FWPH inlet temperature and
   - recirculating water from downstream of the FWPH inlet to the FWPH inlet,

and/or directing some water to bypass the FWPH (14), when the FWPH inlet temperature is below a set value.

6. The method of claim 5, wherein the FWPH (14) additionally comprises an FWPH outlet, and the water is recirculated from upstream of the FWPH outlet.

7. The method of any of claims 1 to 6, wherein the water separation unit is an LP drum and feeding the water from the FWPH (14) includes feeding water to the LP drum (22) and then to the evaporator (16).

8. A feedwater preheating system (10) for a heat recovery steam generator (HRSG, 12) for a combined cycle power plant (CCPP), comprising
   - a feedwater preheater (FWPH, 14) and an evaporator (16),
   - a water separation unit (22) connected to the evaporator (16) and the FWPH (14),
   - an FWPH inlet line (18) for connection between a condenser and the FWPH (14),
   - an FWPH outlet line (20) for connection between the FWPH (14) and the evaporator (16),
   - a bypass connection line (24) between the FWPH inlet line (18) and the FWPH outlet line (20),
   - a control valve (32) on the FWPH outlet line (20) downstream of the bypass connection line (24),
   - a bypass control valve (26) for controlling feedwater flow through the bypass connection line (24),
   - means for monitoring an LP approach (ΔT) of the water separation unit (22),
   - a control system configured and arranged to control the bypass control valve (26) and to at least partly open the bypass control valve (26) when the LP approach drops below a set value.

9. The feedwater preheating system (10) of claim 8, wherein the means for monitoring an LP approach comprises
   - a sensor (T1, T, RTD) for measuring the temperature in the FWPH outlet line

(20), and

- a sensor (Tsat, P, RTD) for measuring the temperature of steam in the water separation unit (22), and
- the means for monitoring an LP approach is configured and arranged to monitor the LP approach based on the temperature in the FWPH outlet line (20) and the temperature of the steam in the water separation unit (22).

10. The feedwater preheating system of claim 9, wherein the sensor (RTD) for measuring the temperature of steam in the water separation unit (22) is in an evaporator outlet line (50).

11. The feedwater preheating system (10) of any of claims 8 to 10, wherein the bypass control valve is a three-way valve (26) on the FWPH inlet line (18).

12. The feedwater preheating system (10) of claim 8, additionally comprising a recirculation pump (30) attached on a line between a point downstream of the FWPH inlet line (20) and the FWPH inlet line (18) .

13. The feedwater preheating system (10) of any of claims 9 to 12, wherein at least one of the sensors is a resistance temperature detector (RTD).

14. The feedwater preheating system (10) of claim 13, wherein each of the sensors comprises three RTDs.

15. A combined cycle power plant comprising the feedwater preheating system (10) of any of claims 8 to 14.

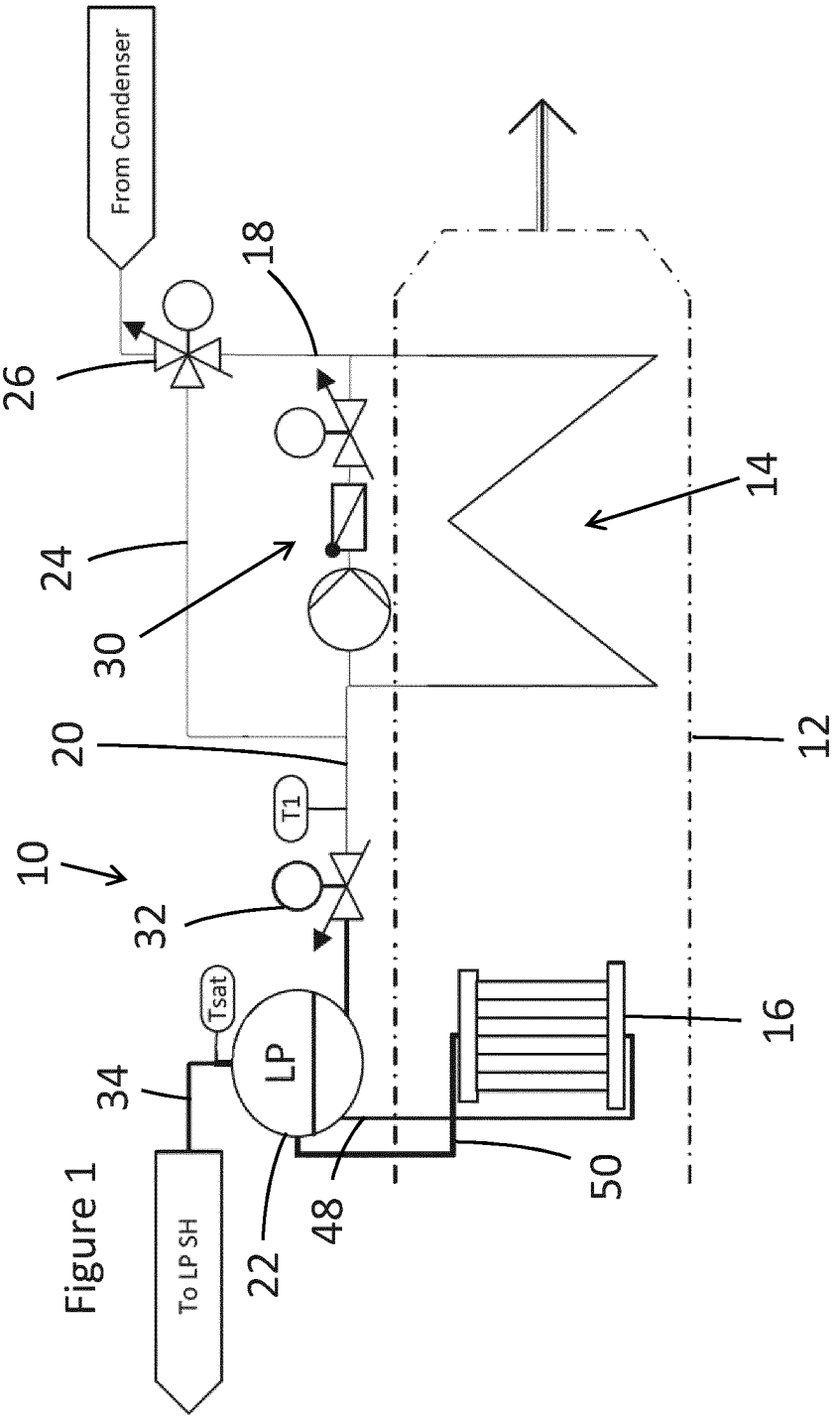

From Condenser
18
26
14
24
30
20
12
T1
10
32
Tsat
LP
16
34
50
48
22
To LP SH

Figure 1

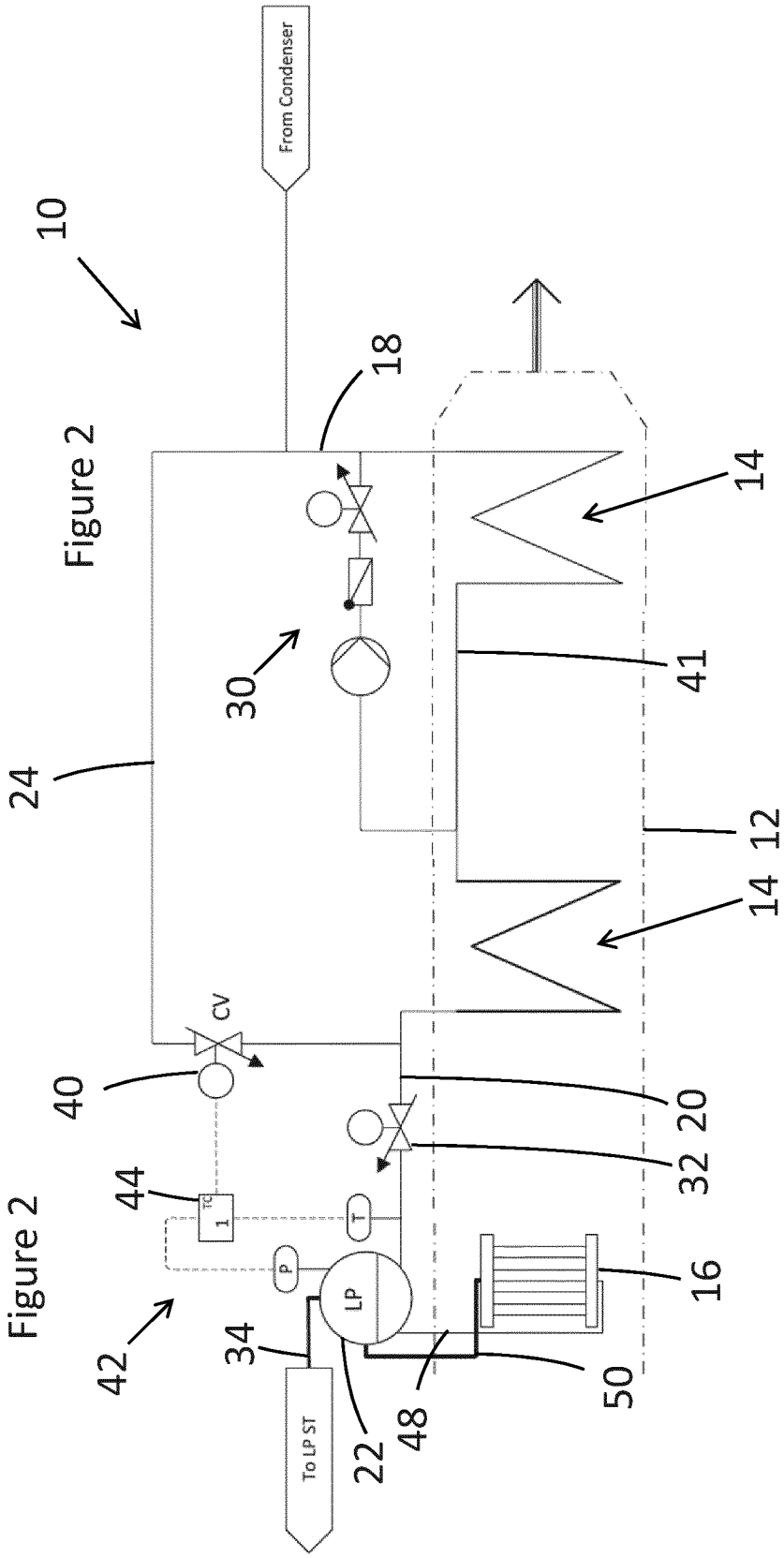


Figure 2

Figure 2

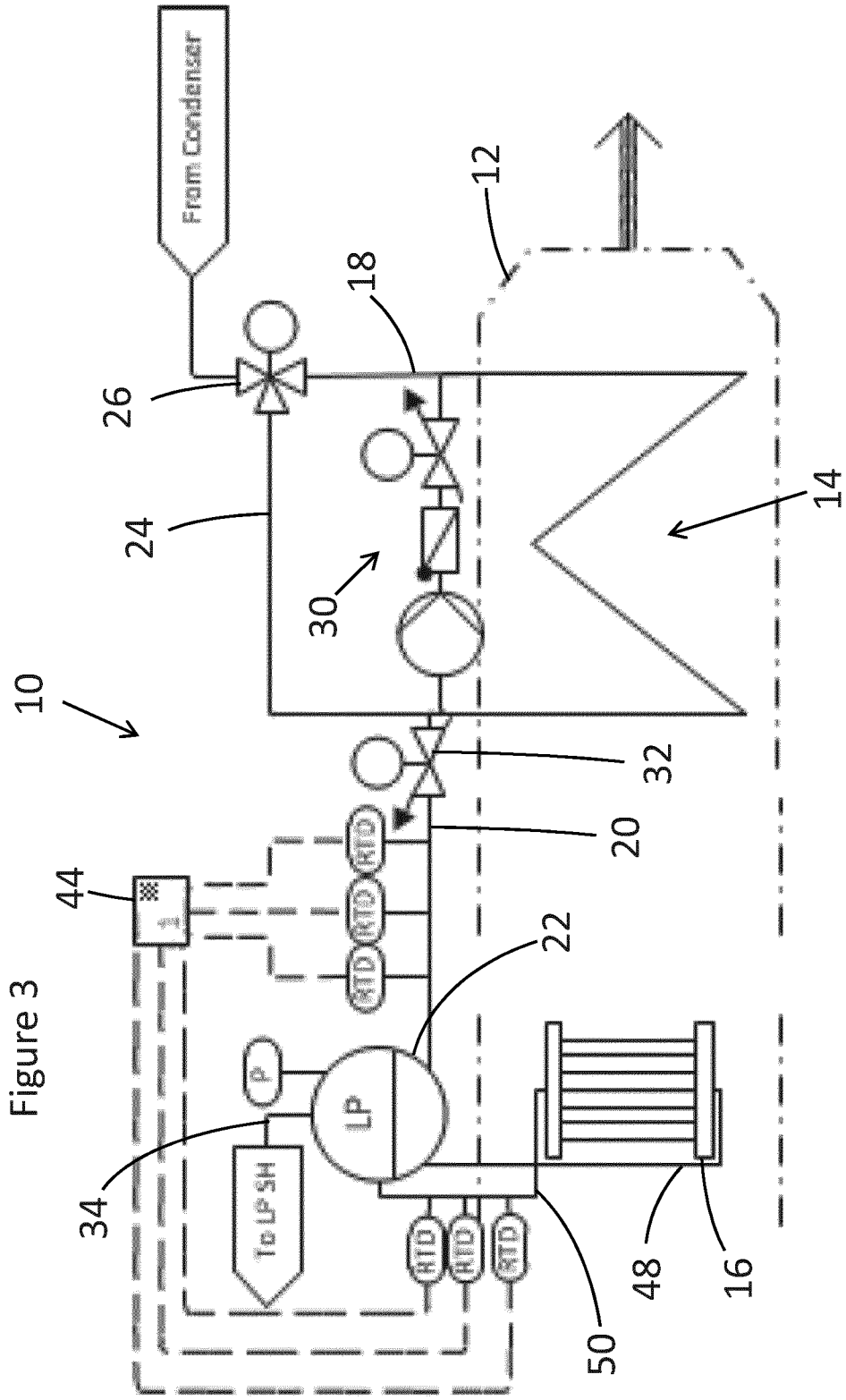

From Condenser
12
18
26
24
14
30
10
32
20
RTD
RTD
RTD
44
22
P
LP
34
To LP SH
RTD
RTD
RTD
48
16
50

Figure 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/079779

A. CLASSIFICATION OF SUBJECT MATTER
INV. F22B1/18 F22B35/08 F22B37/02 F22D1/12
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F22B F22D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 099 558 A (GEN ELECTRIC) 8 December 1982 (1982-12-08) page 1, line 79 - page 3, line 34; figures -----	1-15
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