US 20160033128A1

(19) **United States**
(12) **Patent Application Publication**
Stuxberg
(10) **Pub. No.: US 2016/0033128 A1**
(43) **Pub. Date: Feb. 4, 2016**

(54) **POWER GENERATION SYSTEM AND METHOD TO OPERATE**

(71) Applicant: **SIEMENS AKTIENGESELLSCHAFT**, München (DE)

(72) Inventor: **Anders Stuxberg**, Finspong (SE)

(73) Assignee: **SIEMENS AKTIENGESELLSCHAFT**, Munich (DE)

(21) Appl. No.: **14/777,177**

(22) PCT Filed: **Mar. 21, 2013**

(86) PCT No.: **PCT/EP2014/055758**

§ 371 (c)(1),
(2) Date: **Sep. 15, 2015**

(30) **Foreign Application Priority Data**

Mar. 21, 2013 (EP) 13160405.0

Publication Classification

(51) **Int. Cl.**

F23L 7/00	(2006.01)
F01K 9/02	(2006.01)
F01K 7/22	(2006.01)
F23C 9/08	(2006.01)
F01K 7/34	(2006.01)

(52) **U.S. Cl.**
CPC . ***F23L 7/007*** (2013.01); ***F23C 9/08*** (2013.01); ***F01K 7/34*** (2013.01); ***F01K 7/22*** (2013.01); ***F01K 9/02*** (2013.01)

(57) **ABSTRACT**

A method to operate a power generation system and the device itself includes an oxy-fuel burner, a first heat exchanger assembly, and a rankine-cycle. The oxy-fuel burner generates an exhaust fluid submitted to an exhaust fluid line and the rankine-cycle is operated with the working media which is circulating separately from the exhaust fluid. The exhaust fluid line is provided with a recirculation line downstream the first heat exchanger assembly and upstream the working media heat exchanger extracting exhaust fluid from the exhaust fluid line, conducting extracted exhaust fluid to a compression unit to increase pressure and injecting downstream the extracted exhaust fluid into the oxy-fuel burner.

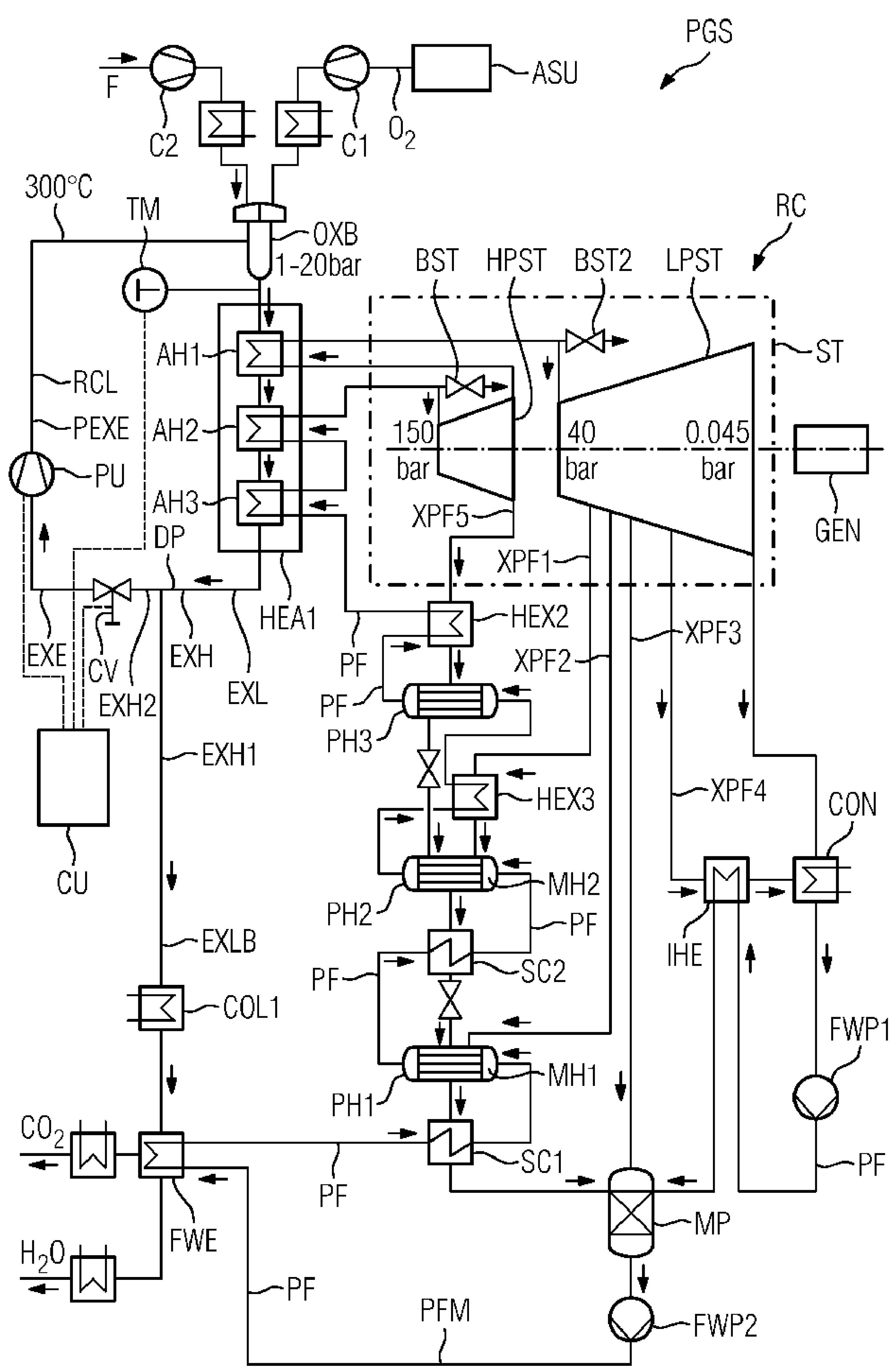


FIG 1

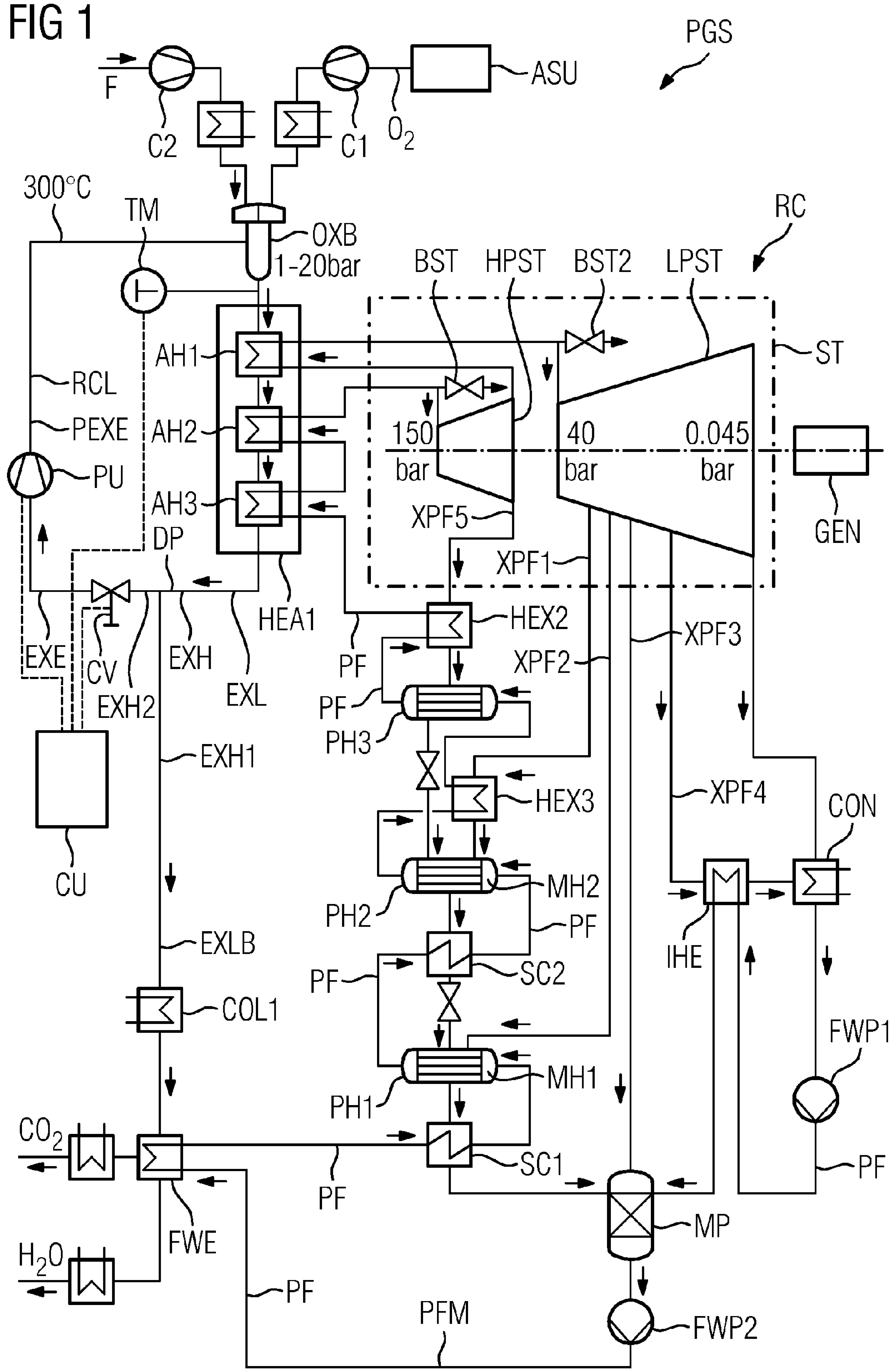
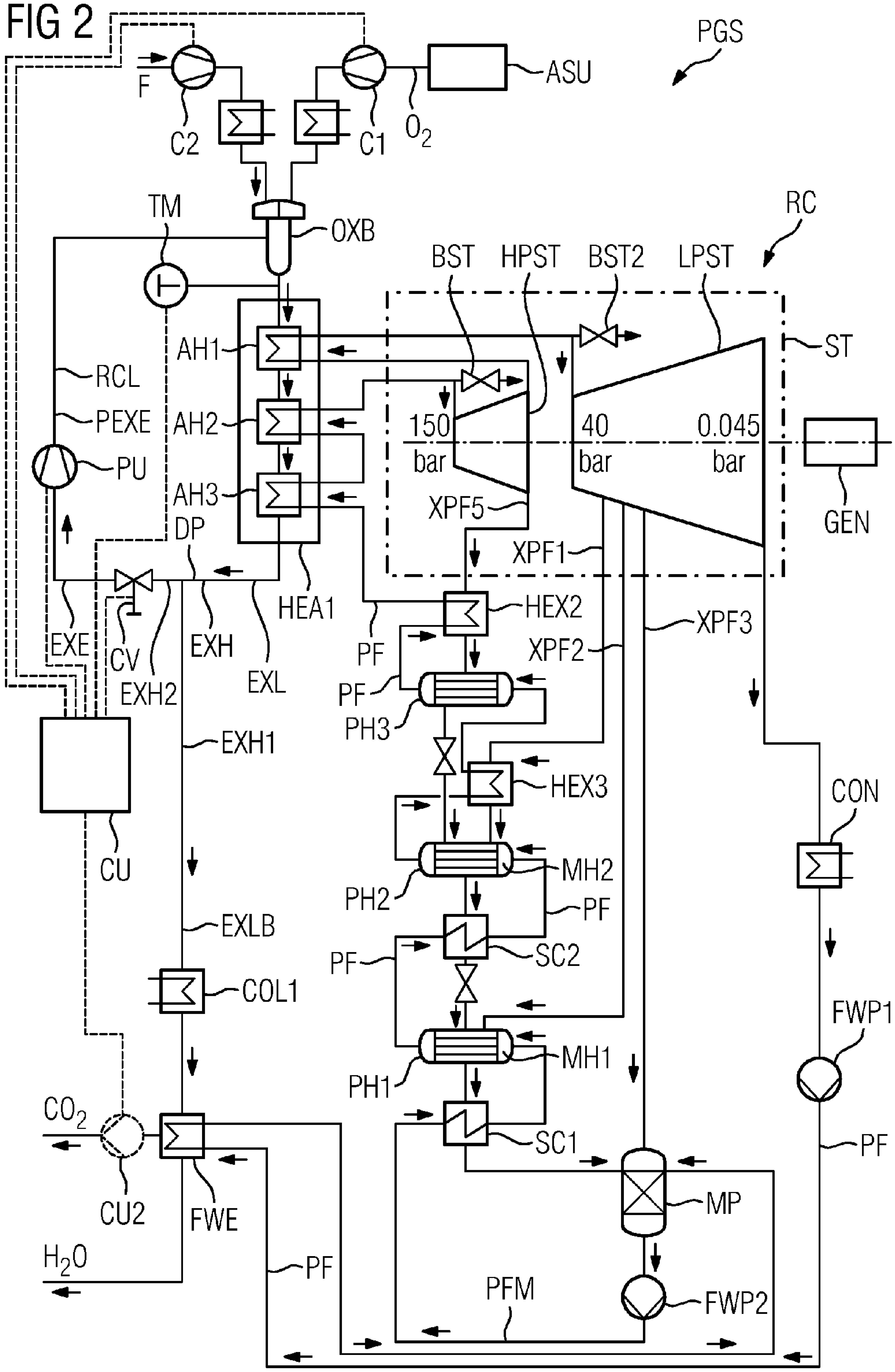

PGS
F
C2
C1
O_2
ASU
300°C
TM
OXB
1-20bar
RC
BST
HPST
BST2
LPST
ST
AH1
AH2
AH3
RCL
PEXE
PU
150
bar
40
bar
0.045
bar
GEN
XPF5
XPF1
DP
HEA1
EXE
CV
EXH2
EXH
EXL
HEX2
PF
XPF3
XPF2
PH3
EXH1
HEX3
XPF4
CON
CU
MH2
PH2
IHE
EXLB
SC2
PF
COL1
FWP1
MH1
PH1
CO_2
SC1
FWE
MP
H_2O
PFM
FWP2

FIG 2



PGS
F
C2
C1
ASU
O_2
TM
OXB
RC
BST
HPST
BST2
LPST
AH1
ST
RCL
PEXE
AH2
150 bar
40 bar
0.045 bar
GEN
PU
AH3
XPF5
DP
XPF1
EXE
CV
EXH
EXL
HEA1
HEX2
PF
XPF3
XPF2
EXH2
PH3
EXH1
HEX3
CON
CU
MH2
PH2
EXLB
SC2
COL1
FWP1
MH1
PH1
CO_2
SC1
CU2
FWE
MP
H_2O
PFM
FWP2

POWER GENERATION SYSTEM AND METHOD TO OPERATE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is the US National Stage of International Application No. PCT/EP2014/055758 filed Mar. 21, 2014, and claims the benefit thereof. The International Application claims the benefit of European Application No. EP13160405 filed Mar. 21, 2013. All of the applications are incorporated by reference herein in their entirety.

FIELD OF INVENTION

[0002] The invention relates to a power generation system comprising an oxy-fuel burner, a first heat exchanger assembly, and a rankine-cycle, wherein said rankine-cycle comprises at least one turbine expanding a working media or process fluid, downstream said turbine at least one condenser condensing said process fluid, downstream said condenser at least one first working media pump (or feed water pump) delivering said process fluid to a higher pressure level, downstream said working media pump at least one first working media pre-heater (or feed water pre-heater) heating said process fluid by extracted process fluid or extracted working media from said turbine, and downstream said working media pre-heater said process fluid passes said first heat exchanger assembly to be boiled and superheated. The oxy-fuel burner will be provided with recirculated and compressed exhaust fluid from said oxy-fuel burner.

BACKGROUND OF INVENTION

[0003] Power generation systems and respective methods to operate such systems are known for a long time since mechanical power or electrical power is generated especially by burning a fuel with an oxygen containing gas. Recently concerns came up about carbon-dioxide content in air increasing up to an amount where a so called green-house effect might occur. Since such awareness is rising several projects are initiated to reduce the emission of carbon-dioxide. One of those projects is burning a fuel with an oxygen containing gas other than air to avoid the generation of NOx (nitrogen oxides) and to avoid the mixing of essential inert components with the carbon-dioxide generated during combustion to more easily enable the separation of carbon-dioxide from the exhaust gas generated. This easy separation simplifies storage of pure carbon-dioxide in a final storage capacity. Essentially pure carbon-dioxide can further better be used for subsequent chemical processes.

[0004] The oxygen containing gas is basically pure oxygen with minor impurities generated by for example an air separation unit, which can be of conventional membrane type. In the context of this invention an oxy-fuel burner is characterized by burning basically a fuel with an oxygen containing gas wherein said oxygen containing gas has significant higher oxygen content than ambient air and wherein oxygen is its main component and wherein said oxygen containing gas is preferably pure oxygen with some impurities. This oxygen containing gas may contain some further additives but its main component is preferably oxygen. In other words, the oxygen containing gas is a gas with an elevated oxygen content compared to ambient air.

[0005] One known power generation system is disclosed in U.S. Pat. No. 7,021,063 B2, which deals with an oxy-fuel burner respectively gas generator comprising a recuperative heat exchanger for reheating of steam that has passed a first expansion machine stage, which heat exchanger is heated by outlet steam respectively exhaust from said gas generator.

[0006] The total efficiency of a conventional power generation system with an oxy-fuel burner is significantly below the efficiency of an ordinary power generation system if the energy consumption of the air separation unit is considered. The efficiency is therefore to be improved to make this technology economically feasible and to have a positive effect on the environment.

SUMMARY OF INVENTION

[0007] It is one object of the invention to improve the efficiency of the known power generation system comprising an oxy-fuel burner.

[0008] The object of enhancing the efficiency of the incipiently defined power generation system is achieved by a power generation system according the claims. Further the object is achieved by a method according to the claims. Embodiments can be found in the dependent claims.

[0009] One essential aspect of the proposed improvement of the power generation system respectively the method according to the invention is the combination of oxy-fuel combustion principle with a boiler design separating the carbon dioxide-steam cycle from the steam-water cycle. This unique feature enables the operation of the exhaust fluid—i.e. a heat carrying media—at elevated pressure above atmospheric pressure. Further high efficiency is achieved by taking the recirculation of exhaust fluid from upstream economizers in the boiler such that as little heat as possible is moved from high temperature to a low temperature parts of the cycle.

[0010] Said oxy-fuel burner according to the invention is basically a gas generator generating an exhaust gas respectively exhaust fluid from a fuel burned with essentially pure oxygen. This exhaust gas is referred to as exhaust-fluid since it might contain liquid components or parts of the fluid might condense to a liquid.

[0011] A further beneficial efficiency improvement of the process according to the invention or an embodiment thereof is obtained by providing said turbine as a combination of at least a high pressure turbine and a low pressure turbine, wherein between these two turbines the working media or process fluid—both terms will be used to identify the closed loop fluid or medium of the steam cycle—is led through a reheater, wherein said reheater is part of said first heat exchanger assembly, so that said process fluid is reheated by said exhaust fluid downstream said high pressure turbine and upstream said low pressure turbine.

[0012] Another beneficial improvement of the invention is given by providing at least one adjustable valve and/or one adjustable pump—which can be a multiphase pump or might as well be a compressor—to control the flow through said recirculation line. When gases are recirculated—which may be a particular embodiment —, then the pump may be replaced by a compressor or fan. This control feature allows maintaining the desired exhaust-fluid temperature downstream said oxy-fuel burner respectively before said heat exchanger assembly. Advantageously a control unit controls the position of said adjustable valve or pump in the recirculation line according to a temperature measurement located advantageously upstream said heat exchanger assembly. This control unit is designed such that it receives the measurement results from temperature measurement and submits control signals to said control valve. The control method in particular is designed such that the valve opens further when exceeding a temperature limit is recognized. Further the valve control can be designed such that upper limits of temperature increases respectively steep temperature transients in a turbine of the power generation system are avoided.

[0013] Another embodiment is given by a mixing pre-heater is provided upstream of said at least one first working media pre-heater (or first feed water pre-heater). Said mixing pre-heater mixes a third extracted process fluid (or extracted working media) from said turbine with said process fluid downstream said condenser.

[0014] Another embodiment of the invention provides an air separation unit upstream of said oxy-fuel burner to advantageously separate oxygen from ambient air to be burned with a fuel in said oxy-fuel burner. This air separation unit can be of a membrane type.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The above mentioned attributes and other features and advantageous of this invention and the manner of attaining them will become more apparent and the invention itself will be understood by reference to the following description of the currently known best mode of carrying out the invention taken in conjunction with the accompanying drawings, wherein

[0016] FIG. **1** shows a schematic flow diagram of an oxy fuel power plant comprising the arrangement according to the invention and depicting the method according to the invention;

[0017] FIG. **2** shows a schematic flow diagram of an oxy fuel power plant comprising the arrangement according to a second embodiment of the invention and depicting the method according to the invention.

DETAILED DESCRIPTION OF INVENTION

[0018] FIG. **1**—and also FIG. **2** later on—is a schematic depiction of a simplified flow diagram showing a power generation system and illustrating a method according to the invention.

[0019] According to FIG. **1**, fuel F and oxygen O_2 from an air separation unit ASU are both elevated to a higher pressure level by compressors C**1**, C**2**, which compressors C**1**, C**2** might be provided with not shown intercoolers before both fluids (F and O_2) are injected in an oxy-fuel burner OXB at a pressure of around 20 bar. In said oxy-fuel burner OXB—which can also be considered as a gas generator—combustion takes place of said fuel F with said oxygen O_2 generating exhaust gas hereinafter referred to as exhaust-fluid EXH.

[0020] It has to be noted when the term said oxygen O_2 or "pure oxygen" is used, a gas with an elevated content of oxygen is meant, e.g. of 95% oxygen content.

[0021] The exhaust fluid EXH—or more generally called heat carrying media—exits said oxy-fuel burner OXB and enters a first heat exchanger assembly HEA**1**.

[0022] Downstream said first heat exchanger assembly HEA**1** said exhaust fluid EXH is divided at a division point DP into recirculated exhaust fluid EXE stream and the remaining exhaust fluid (referred to as first part EXH**1** which it is diminished by recirculated exhaust fluid stream EXE, which is also called second part EXH**2**) being conducted through a continued exhaust fluid line EXLB. Alternatively, the division of fluids can be performed even inside the first heat exchanger assembly HEA**1**.

[0023] The temperature of said first part EXH**1** of the exhaust fluid stream EXH is adjusted by controlling said flow of recirculated exhaust fluid EXE (as said also called the second part EXH**2** after the branch off) to the oxy-fuel burner OXB to be mixed with the fuel F and oxygen containing gas OCG and thus cool the exhaust fluid EXH (i.e. the second part EXH**2**) to the right temperature to subsequently enter said heat first exchanger assembly HEA**1**. This control is done by a control unit CU controlling a compression unit PU and/or a control valve CV. Optionally only one of the compression unit PU or the valve CV can be provided. The compression unit PU can be a pump can as well be a multiphase pump or a compressor or fan depending on the phase of the recirculated exhaust fluid EXE. The pump or multiphase pump will be used for liquid content, the compressor or fan for gaseous content. In a further embodiment, gases will be guided through the recirculating line RCL, so a compressor or fan will be used for the compression unit PU.

[0024] Past the compression unit PU the fluid in the recirculating line RCL may be called pressurized recirculating fluid PEXE which then is delivered to the oxy-fuel burner OXB.

[0025] Downstream said division point DP said exhaust fluid EXH passes a first cooler COL**1** before it enters a feed water heat exchanger FWE (or working media heat exchanger) transferring thermal energy to said process fluid PF (also called working media) of said rankine cycle RC. This additional sub-cooling effect further separates carbon dioxide CO_2 from water H_2O of the exhaust fluid EXH. Said feed water heat exchanger FWE provides further the feature of separating the gaseous phase from the liquid phase so that said carbon dioxide CO_2 is divided from the water H_2O to be stored or to be recycled separately.

[0026] The stream of carbon dioxide CO_2 and water H_2O are respectively compressed and cooled by a respective intercooled compressor assembly (which will be called CCCO2, CCH2O).

[0027] Said first exchanger assembly HEA**1** comprises several single heat exchangers designed for different temperature levels of heat exchange. FIG. **1** shows three of these heat exchangers: a first assembly heat exchanger AH**1** (or first reheater), a second assembly heat exchanger AH**2** (or second reheater) and a third assembly heat exchanger AH**3** (or third reheater).

[0028] The first heat exchanger AH**1** is also identified as reheater for the process fluid between two turbine stages.

[0029] A fourth reheater (not shown) may optionally be present within the oxy-fuel burner OXB to pre-heat the working media PF to be provided to the third assembly heat exchanger AH**3**.

[0030] Said rankine cycle RC comprises a high pressure turbine HPST and a low pressure turbine LPST, which are basically designed as steam turbines, wherein said turbines respectively said rankine cycle are/is operated using in particular water as a process fluid PF.

[0031] Said first exchanger assembly HEA**1** works as the boiler of said rankine cycle RC boiling the water and superheating the steam generated to be expanded first in said high pressure turbine HPST starting from an entrance pressure level of around 150 bar.

[0032] Upstream of said high pressure turbine HPST a full capacity first bypass station BST**1** is provided to allow full operation flexibility especially during start-up and shut-down. Said high pressure turbine receives its steam respectively process fluid PF not from the most upstream first assembly heat exchanger AH**1** but from said second assembly heat exchanger AH**2** and is therefore not using the highest temperature level available from the exhaust fluid line EXL. After said process fluid PF as passed the high pressure turbine HPST it is conducted to the first assembly heat exchanger AH**1** for being reheated to further downstream pass a second full capacity bypass station BST**2** and to further downstream enter a low pressure turbine LPST to be expanded from 40 bar down to around 0.045 bar.

[0033] Both turbines HPST, LPST are driving a generator GEN but can as well be used to drive a different consumer.

[0034] During this expansion a first extracted process fluid stream XPF**1** (also called first extracted working media stream), a second extracted process fluid stream XPF**2** (also called second extracted working media stream), a third extracted process fluid stream XPF**3** (also called third extracted working media stream) and a fourth extracted process fluid stream XPF**4** (also called fourth extracted working media stream) are separated from the process fluid PF to provide thermal energy to downstream process steps of the rankine cycle RC. The process fluid exiting said low pressure turbine LPST enters a condenser CON, where it is condensed to liquid together with said fourth extracted process fluid stream XPF**4**, which is recycled into the main process fluid PF.

[0035] Water or steam may be a advantageous process fluid PF. Therefore in the following the term "feed water" is also used, also in combination with devices like "feed water pump" or "feed water pre-heater" or "feed water heat exchanger". Nevertheless also different media can be used in the cycle, not only water. Therefore the general term instead of "feed water" would be "working media" and therefore the devices "feed water pump" or "feed water pre-heater" or "feed water heat exchanger" or the like may be called more generally "working media pump" or "working media pre-heater" or "working media heat exchanger". Thus, even though the embodiment will use feed water as an example, this should not be considered limiting in respect of the used working media.

[0036] The term "working media pump" stands for example for a feed water pump but also for a condensate pump.

[0037] Downstream said condenser CON said process fluid PF enters a first feed water pump FWP**1** (or first working media pump) before receiving thermal energy from said fourth extracted process fluid stream XPF**4** in an intermediated heat exchanger THE. Further downstream said process fluid PF enters a mixing pre-heater MP and is mixed with said third extracted process fluid stream XPF**3** directly coming from the extraction point of said low pressure turbine LPST. Said first and second extracted process fluid streams XPF**1**, XPF**2** and said fifth extracted process fluid stream XPF**5** (also called fifth extracted working media stream) are injected into said mixing pre-heater MP, too, after they respectively were used to preheat said process fluid PF. Downstream said mixing pre-heater MP said process fluid PF enters a second feed water pump FWP**2** (or second working media pump) increasing the pressure well above 150 bar before said process fluid enters downstream said feed water heat exchanger FWE. Subsequently said process fluid PF enters a preheating assembly PAS comprising a sequence of three feed water pre-heaters (or working media pre-heaters), a first feed water pre-heater PH**1** (or first working media pre-heater), a second feed water pre-heater PH**2** (or second working media pre-heater), a third feed water pre-heater PH**3** (or third working media pre-heater).

[0038] Said first feed water pre-heater PH**1** includes a first sub-cooler SC**1** and a first main heat exchanger MH1.

[0039] Said second feed water pre-heater PH**2** includes a second sub-cooler SC**2** and a second main heat exchanger MH2, wherein said first feed water pre-heater PH**1** receives said second extracted process fluid stream XPF**2** and said second feed water pre-heater PH**2** receives said first extracted process fluid stream XPF**1**. The respective sub-coolers are located upstream of the main heat exchangers with regard to said process fluid PF stream.

[0040] Said third feed water pre-heater PH**3** is heated by a fifth extracted process fluid stream XPF**5** extracted from said high pressure turbine HPST, wherein said process fluid PF first passes a third heat exchanger HEX**3** of said third feed water pre-heater PH**3** before it enters said third feed water pre-heater PH**3** and downstream enters said second heat exchanger HEX**2** also heated by said fifth extracted process fluid stream XPF**5**. Downstream said second heat exchanger HEX**2** said process fluid PF enters said third assembly heat exchanger AH**3**. Downstream said second assembly heat exchanger AH**2** said process fluid PF passes said first bypass station BST**1** and further downstream enters said high pressure turbine HPST.

[0041] One feature to mention one more time is that the rankine-cycle RC is operated with the working media (the process fluid PF) and that this working media is circulating separately from the exhaust fluid EXH. "Separately" means in this respect that the two media do not mix with each other. The rankine cycle is a closed cycle without input or output during normal operation. Particularly no exhaust fluid EXH is transferred into the rankine cycle RC as or to mix with working media of the rankine cycle RC. The exhaust fluid EXH and the working media PF are kept separate or unmixed. The exhaust fluid EXH is also rerouted back to the oxy-fuel burner but a part of the fluid may be extracted, but not to enter the rankine cycle RC.

[0042] Different to what is shown in FIG. **1**, there may not be a common output port of the first heat exchanger assembly HEA**1** for outputting the exhaust fluid EXH with a later element to branch off into a first part EXH**1** and a second part EXH**2**. Possibly the first heat exchanger assembly HEA**1** may have two output ports included into the first heat exchanger assembly HEA**1**. As a further alternative the complete recirculation via recirculation line RCL and the compression unit PU may also be incorporated into the first heat exchanger assembly HEA**1**.

[0043] The system according to FIG. **1** can also be explained in slightly different terminology:

[0044] A power generation system (PGS) is shown comprising an oxy-fuel burner (OXB), a first heat exchanger assembly (HEA**1**), and a rankine-cycle (RC),—wherein said rankine-cycle (RC) comprises at least one turbine (ST) expanding a process fluid (PF), downstream said turbine (ST) at least one condenser (CON) condensing said process fluid (PF),—wherein said rankine-cycle (RC) comprises downstream said condenser (CON) at least one first feed water pump (FWP) delivering said process fluid (PF) to a higher pressure level,—wherein said rankine-cycle (RC) comprises downstream said feed water pump (FWP) at least one first feed water pre-heater (PH) heating said process fluid (PF) by extracted process fluid (XPF**1**, XPF**2**) from said turbine (ST),—wherein downstream said feed water pre-heater (PH**1**, PH**2**, PH**3**) said process fluid (PF) passes said first heat exchanger assembly (HEA**1**) to be boiled and superheated, wherein,—said oxy-fuel burner (OXB) generates an exhaust fluid (EXH) submitted to an exhaust fluid line (EXL),—said rankine-cycle (RC) is operated with said process fluid (PF) which is circulating separately from said exhaust fluid (EXH),—wherein downstream said first heat exchanger assembly (HEA**1**) at least one feed water heat exchanger (FWE) is provided to heat up said process fluid (PF) of said rankine-cycle (RC) downstream said feed water pump (FWP) and upstream said feed water preheater (PH) by said exhaust fluid (EXH), —wherein said exhaust fluid line (EXL) is provided with a recirculation line (RCL) downstream said first heat exchanger assembly (HEA**1**) and upstream said feed water heat exchanger (FWE) extracting exhaust fluid (EXH) from said exhaust fluid line (EXL), conducting extracted exhaust fluid (EXE) to a pump (PU) to increase pressure and injecting downstream said extracted exhaust fluid (EXE) into said oxy-fuel burner (OXB).

[0045] By such a system a following method can be performed:

[0046] Method to operate a power generation system (PGS) comprising the following steps: —providing an oxy-fuel burner (OXB), a first heat exchanger assembly (HEA**1**), a rankine-cycle (RC),—generating an exhaust fluid (EXH) by said oxy-fuel burner (OXB) submitted to an exhaust fluid line (EXL) by burning oxygen O2 and fuel F,—expanding a process fluid (PF) in said rankine-cycle (RC) comprising at least one turbine (ST) of said rankine-cycle (RC), —condensing said process fluid (PF) downstream said turbine (ST) by at least one condenser (CON) of said rankine-cycle (RC),—delivering said process fluid (PF) to a higher pressure level downstream said condenser (CON) by least one first feed water pump (FWP) of said rankine-cycle (RC),—heating said process fluid (PF) by extracted process fluid (XPF**1**, XPF**2**) from said turbine (ST) downstream said feed water pump (FWP) by at least one first feed water pre-heater (PH) of said rankine-cycle (RC),—boiling and superheating said process fluid (PF) downstream said feed water pre-heater (PH**1**, PH**2**, PH**3**) by said first heat exchanger assembly (HEA**1**) of said rankine-cycle (RC),—operating said rankine-cycle (RC) with said process fluid (PF) which is circulating separately from said exhaust fluid (EXH),—providing at least one feed water heat exchanger (FWE) downstream said first heat exchanger assembly (HEA**1**) and heating up said process fluid (PF) of said rankine-cycle (RC) downstream said feed water pump (FWP) and upstream said feed water preheater (PH) by said exhaust fluid (EXH),—providing said exhaust fluid line (EXL) comprising a recirculation line (RCL) downstream said first heat exchanger assembly (HEA**1**) and upstream said feed water heat exchanger (FWE) extracting exhaust fluid (EXH) from said exhaust fluid line (EXL), —conducting said extracted exhaust fluid (EXE) to a pump (PU) to increase pressure and —injecting downstream said extracted exhaust fluid (EXE) into said oxy-fuel burner (OXB).

[0047] It has to be mentioned that in the power generation system it is fired externally to the power cycle in a boiler where the exhaust gas side may be pressurized. Exhaust gas may be recirculated to reduce firing temperature. This is advantageous to increase plant reliability by decreased complexity and avoidance of risks inherent in known cycles where exhaust from a gas generator is led through next burner platelet narrow channels and through blade cooling. The solution provides a better performance. Further, it is less sensitive to combustion disturbances or fuel quality variations and also less sensitive to corrosion as the exhaust gases are kept outside the power cycle.

[0048] In general, FIG. **1** is directed to a process for production of power via combustion by combining a fuel gas stream and an oxygen rich stream in burner(s) in a steam generating boiler. The resulting exhaust gas, mainly comprising CO_2 and steam is cooled to a desired temperature by adding a recirculated exhaust flow. The process is based on steam turbine technology and the configuration is similar to a reheat steam cycle seen in known applications. The steam generating boiler according to FIG. **1** is different to a conventional boiler in that it is closed at the exhaust gas side to deliver carbon dioxide CO_2 produced to a compressor and that it has a large recirculation of exhaust gas. Water formed in the combustion is condensed before the remaining carbon dioxide CO_2 rich exhaust is led to a compressor and clean-up for delivery to a carbon dioxide consumer or injection in ground.

[0049] The process separates the exhaust gas from the power cycle working media (water/steam circuit) such that turbo-machinery of known existing type can be selected and will run in an environment as designed for. By separating the exhaust from the water/steam circuit the process will also be relatively insensitive to soot or emissions resulting from the fuel or combustion.

[0050] The boiler can be operated at an exhaust gas pressure of about atmospheric pressure but can also be designed to be operated at an exhaust gas pressure elevated above atmospheric pressure in order to save boiler size, reduce size of burners, reduce size of recirculation duct and fan and to reduce size of final carbon dioxide (CO_2) compressor. The elevated pressure may also lead to marginally better cycle performance due to less expansion of delivered fuel gas and oxygen and less compression work for delivered carbon dioxide CO_2, however depending on specific project pre-requisites. Boiler elevated exhaust pressure may also enable modularization of boiler supply to enable road transport of boiler proper where an atmospheric boiler would be constructed at site or be divided in a number of modules. Boiler type may be a traditional drum type boiler or a once-through (Benson) type. Steam cycle may be with or without reheat and high pressure main steam pressure below of above critical.

[0051] A special feature of the process is the combination of oxy-fuel combustion principle with a boiler design separating the CO_2/steam from the steam/water cycle (and optionally by operation of the exhaust gas at elevated pressure above atmospheric). High efficiency is achieved by taking the recirculation of exhaust from upstream economizers in the boiler such that as little heat as possible is moved from high temperature to low temperature parts of the cycle.

[0052] Fuel gas and oxygen are supplied to a boiler where combustion takes place in burners(s) at atmospheric pressure or at increased pressure (in order to reduce size and cost). A recirculation of exhaust gas is applied to reduce the firing temperature.

[0053] The exhaust passes a superheater, a reheat superheater and evaporator coils. Finally the exhaust is split in two streams, one recirculation back to the burner section and one exit stream which is led through a heat recovery section. The pressure resistant boiler casing is protected from hot gases by water cooling either combined in the shell design or by internal separate water cooled lining. Internal insulation may be applied instead of water cooling or as a complement.

[0054] The steam generation side of the boiler may be a conventional single pressure drum type or a once through (e.g. Benson) type. The heat recovery section downstream the main boiler cools the exhaust stream which is not re-circulated back to the burner section. This heat recovery is anticipated to comprise heat exchange utilized for preheating of oxygen and fuel to the burners and a condenser transferring the heat to the feed water preheat section in the closed steam cycle. The condenser condenses only the steam in the exhaust gas resulting from the combustion of the hydrogen in the fuel, i.e. a rather small heat load. The rest of the exhaust gas, comprising mainly carbon dioxide CO_2, extracted from the condenser is compressed and cleaned. The pressure in the condenser and thus also the CO_2-extraction is as in the boiler minus some pressure drop, i.e. atmospheric or increased depending on design.

[0055] High pressure (HP) steam generated and superheated in the boiler is admitted to the high pressure steam turbine and is expanded to an intermediate pressure, producing power. The steam is then returned to the boiler to pass a second superheat (reheat) and then forwarded to a low pressure (or intermediate pressure) steam turbine where it is further expanded to the near vacuum condition in the condenser producing more power.

[0056] The condenser is in particular to be water cooled. However an air cooled condenser may be used as well. Cooling water may come from an open source or a cooling tower. Condensate collected in the condenser is pumped through a sequence of pre-heaters to the deaerator/feed water tank (i.e. the mixing pre-heater MP). Feed water is taken from the deaerator (mixing pre-heater MP) and is pumped through further pre-heaters before being introduced in the boiler again. The pre-heaters are supplied by steam taken from steam turbine extractions or other source. Some heat for the feed water preheating is also recovered from cooling and condensing water from the exhaust stream exiting the boiler.

[0057] In case of using drum type boiler, water chemistry is managed by reject of about 1% of the flow rate as boiler blow down. In case of a Benson type a smaller bleed rate is applied but then there is a requirement of inline water polish. In case an alternative burner should be used the oxygen may be blended into re-circulated exhaust prior to introduction to the burner.

[0058] To allow full flexibility the cycle may be equipped with turbine full capacity bypasses and startup vents both at high pressure and low pressure. By running steam in bypass mode the CO_2 production can be maintained even if one or both turbines are stopped. Since the boiler provides a thermal storage capacity turbine trips can be managed without disturbing the O_2 production.

[0059] If an increased efficiency is desired the steam conditions may be increased. As an example, high pressure steam at supercritical condition 250 bars and 600 degrees would provide an increased net efficiency compared to examples given in figure above. However a third steam turbine module would then be installed. If double reheat is introduced in a supercritical cycle even a further improvement would be possible. By pressurizing the exhaust gas side of the boiler a significant reduction in size and hopefully in cost could be gained. This is a difference of this cycle compared to existing boilers where pressurization would require a turbine for pressure recovery when letting the exhaust to a stack. In this case there is no stack but instead a requirement to further compress. The largest cost and space saving would be gained by a pressure of about 5 to 8 bars. Up to 20 bars may be advantageous but above that the benefit can in some cases be overruled by pressure vessel issues which may need to be considered. To save in design efforts scalability may best be handled by designing a pressurized boiler as a standard module to be put in parallel for scalability but with a common drum, e.g. 100 MW fired per module. Road transport limits would probably dictate the sizing.

[0060] The previous configuration can be operated with exhaust fluids with atmospheric pressures, but possibly also with elevated pressure up to 20 bar.

[0061] In the following a configuration is explained in which the exhaust fluid is operated with elevated pressure, for example above 5 bar or above 10 bar, particularly between 10 to 40 bar, advantageously between 15 to 30 bar. A further configuration is operated with 20 bar (plus/minus 10%). Thus, the pressure is significantly above atmospheric pressure. This is further explained in relation to FIG. **2**.

[0062] Basically FIG. **2** shows almost all components as already explained in conjunction with FIG. **1**. Therefore only the differences will be discussed. All previously said still applies also for FIG. **2**.

[0063] What is different to FIG. **1** is that FIG. **2** is designed so that the exhaust fluid is operated on elevated pressure level. A further control unit or the existing control unit CU is arranged to control a pressure level for said pressurized recirculating fluid (PEXE), particularly by balancing supplied fluids and extracted fluids such that the wanted pressure level is reached. Said supplied fluids comprise the fluids that are provided to said oxy-fuel burner (OXB) and/or to said recirculation line (RCL). Said extracted fluids comprise the fluids that are separated or extracted from said recirculation line (RCL).

[0064] So the pressure level within the recirculation line can be set-up by controlling an amount of fuel (F) provided to said oxy-fuel burner (OXB) and/or by controlling an amount of oxygen (O2) provided to said oxy-fuel burner (OXB) and/or by controlling a ratio between said first part (EXH**1**) of said exhaust fluid (EXH) and said second part (EXH**2**) and/or by controlling the outtake of CO2. The pressure level specifically can be set by controlling valves—e.g. said control valve CV—and/or compressors and/or fans—e.g. said compression unit PU and/or an additional compression unit CU**2** and/or compressors C**1**, C**2**.

[0065] The pressure for the exhaust fluid of the oxy-fuel burner (OXB) elevated above atmospheric pressure (typical magnitude of 10 to 40 bar) increases exhaust fluid water gaseous phase partial pressure and thereby enable recovery of latent heat of condensation of said water, particularly at temperature level for efficient use within the rankine cycle RC.

[0066] To use this effect, some modifications in the system may be beneficial. Particularly it may to provide the working media PF when first feed water pump FWP**1** is guided to the feed water heat exchanger FWE to be able to use the heat of the first part EXH**1** of the exhaust fluid EXH and to use also its latent heat. Past the feed water heat exchanger FEW the working media PF now has an increased temperature and will be provided to the mixing pre-heater MP, which has—as before—a further source from the first sub-cooler SC**1** and is also provided with working media via the third extracted process fluid stream XPF3 from the low pressure turbine LPST. The mixing pre-heater MP can provide working media via the second feed water pump FWP2 directly to the first sub-cooler SC1 to be further guided to the first feed water pre-heater PH1.

[0067] Compared to FIG. 1, an extraction of the fourth extracted process fluid stream XPF4 from the low pressure turbine LPST may become superfluous and can be omitted. This again improves the effectiveness of the cycle.

[0068] Downstream the division point DP said exhaust fluid EXH passes the first cooler COL1 before it enters the feed water heat exchanger FWE. The first cooler COL1 may be upstream or downstream of the feed water heat exchanger FWE, or may even be incorporated into a common vessel with the feed water heat exchanger FWE. The first cooler COL1 can be connected to a heat exchanger in a branch that is providing the fuel F. Alternatively the first cooler COL1 can be connected to a heat exchanger in a branch that is providing the oxygen O_2 to preheat the oxygen O_2. As a further alternative, the feed water heat exchanger FWE can provide heat to the working media stream in the rankine cycle RC in various positions.

[0069] Fuel F provided by a pipeline may already be provided at an elevated pressure level, often of about 30 bar. In this case the compressor C2 may be superfluous. So the system can be simplified. Even more, possibly the pressure of the fuel F from the pipeline way need to be reduced—e.g. if the pipeline is operated by for example 85 bar. The reduction would then in particular take place in an expander replacing the compressor C2.

[0070] If natural gas is provided a fuel F, it has to be noted that natural gas typically anyhow is provided pressurized so it is advantageous if also the exhaust fluid is pressurised.

[0071] The oxygen O_2 may even be provided in liquid form, e.g. when provided as liquid oxygen if no air separation unit ASU is used on site. A then needed regasification of the liquid oxygen can be integrated in the system such that the heat reaction can be utilized in the system, particularly via a further heat exchanger unit.

[0072] If preheating of fuel F and oxygen O_2 is wanted, then the preheating operation can utilize heat from the rankine cycle RC.

[0073] As an output to the exhaust stream carbon dioxide CO_2 and water H_2O is extracted. With the pressurization of the exhaust stream a further compressor CU2 may be superfluous as the CO_2 is already delivered at a wanted pressure level. Alternatively the further compressor CU2 may be present to elevate CO_2 to a wanted pressure level.

[0074] As an option, a catalyst unit for cleaning of said exhaust fluid EXH from residual content of oxygen may be provided—e.g. removing oxygen content that was not burned or removing unburned hydrocarbons —, particularly in the exhaust fluid line branch EXLB. The catalyst unit is operated by adding of further fuel and/or other combustible media to the first part EXH1 exhaust fluid EXH. The catalyst unit may particularly be connected in such way that heat of a catalyst process running in the catalyst unit is recovered for use in said rankine cycle RC and/or for preheating of fuel F or said oxygen enriched gas O_2. This allows to facilitate efficient use of generated heat in the cleanup process by the catalyst unit.

[0075] The catalyst unit can be place at several positions in the exhaust fluid stream. It may be upstream or downstream of a condensation occurring in the feed water heat exchanger FEW. The catalyst unit may even be incorporated in the oxy-fuel boiler OXB.

[0076] Furthermore other refinery components may be incorporated in the exhaust fluid line branch EXLB or in the recirculating line RCL for gas filtration.

[0077] The system according to FIG. 2 provides improvement of performance and reduction of component sizes for the oxyfuel boiler process. This may improve the previously explained oxyfuel cycle, in which the cycle configuration is based on the boiler exhaust side operating at atmospheric pressure or slightly above atmospheric. The condensation of water from exhaust gas is typically not fully utilised to benefit from water condensation latent heat.

[0078] Boiler exhaust pressure is increased to increase the temperature level of water condensation in the exhaust gas water separation and thereby enable usage of the latent heat in the power cycle at beneficial temperature level. The feed water preheating heat exchanger sequence may then be adapted to fit with the changed recovery in the exhaust cooling, also some related changes to fuel and oxygen preheating may be made to suit the new configuration.

[0079] By the increased temperature level for water condensation the latent heat in steam phase in the exhaust gas formed by combustion is utilized in the power cycle, i.e. the power cycle makes use of the fuel higher heating value instead of the normal practice of only use of lower heating value (minus certain loss). This may be seen as achieving boiler efficiency above 100% when referring to the normal efficiency definition based on lower heating value. A number of other positive effects are also gained in equipment size and cost by the reduced gas volumes and increased heat convection factors resulting from increased pressure.

[0080] By increasing gas side pressure in the boiler, the size of downstream equipment (heat exchangers, water separation unit and CO_2 compressor, is reduced and parasitic load for the CO_2 compression is reduced. Since the supplied fuel gas normally is at a positive pressure in the order of 25 to 30 bars the boiler exhaust pressure may be increased to about 20 bars without any additional fuel compression.

[0081] By also changing the exhaust stream cooling section and changing the adaption of boiler feed water preheaters the following positive effects are gained:

[0082] 1) The increased exhaust pressure results in increased dew point for the water phase in the exhaust gas since the water steam partial pressure is increased to the same rate as the increase in total pressure. As an example when firing natural gas with 95% CH4 content and operating the boiler at 20 bar the dew point is 190° C. Water condensation will thus begin at 190° C. when cooling the exhaust gas.

[0083] 2) By connecting boiler feed water, to be heated, at the secondary side of the heat exchange in the exhaust gas cooling (element FEW in the Figures), both the convective (sensible) heat of cooling the exhaust gas and the latent heat of condensation from the water phase is utilised in the power cycle.

[0084] 3) By moving the mixing preheater/feed water tank to a position downstream the feed water heat exchanger FWE and deleting the condensate preheater—i.e. said intermediated heat exchanger IHE—more heat is recovered from the exhaust cooling as the original final CO_2 cooler cannot utilise the added latent heat from the exhaust stream efficiently.

[0085] 4) The feed water heat exchanger FWE may be divided in two or more sections and the mixing preheater may be integrated between sections.

[0086] 5) Fuel F and oxygen 02 preheating may be integrated with the FWE as part of the heat recovery to achieve a more efficient use of available exergy (energy related to temperature level).

[0087] 6) The higher the boiler pressure is, the higher the temperature level is for the said recovery of latent heat.

[0088] 7) The increased heat recovery in the exhaust gas cooling is used to reduce the steam extraction from the steam turbine. This implies higher power production from the steam turbine as more steam is allowed to pass through the turbine all way down to the cold condenser. Also less number of steam extraction points and less number of steam driven boiler feed water preheaters are required.

[0089] Generally, the pressurization of the exhaust fluid benefits from that a fluid under higher pressure has a higher density. Furthermore, under pressure condensation starts at a higher temperature level (e.g. at 190° C. when operating with 20 bar instead of 90° C. when operating under atmospheric conditions). As a secondary effect, sizes of components can be reduced due to pressurising the fluid, e.g. the size of the oxy-fuel burner OXB or the size of the feed water heat exchanger FWE.

[0090] It may be advantageous to set up the power generation system PGS such that temperature level at design working conditions for said second part EXH**2** of said exhaust fluid EXH is at least two third (⅔) of saturation temperature measured in Celsius of boiling occurring in said first heat exchanger assembly HEAL It is advantageous to have a temperature level being particularly above 200° C.

[0091] The recirculation line RCL according to FIGS. **1** and **2** may be implemented as shown. Alternatively the recirculated exhaust fluid EXE may even be kept internally to the first heat exchanger assembly HEA**1**. So no external piping may be required (particularly when even the compression unit PU is integrated within the first heat exchanger assembly HEA**1**) or may be limited to just exit the first heat exchanger assembly HEA**1** to provide the recirculated exhaust fluid EXE to the compression unit PU and then provided to the oxy-fuel burner OXB.

[0092] Valid for both embodiments of FIGS. **1** and **2**, it may be advantageous to directly drive rotating equipment (like the compressors or pumps in the power generation system) by the steam turbine ST. Gear boxes may be used to operate the driven rotating equipment at a needed speed. This may increase the effectiveness as a conversion in electrical energy and reconversion in rotational energy can be omitted.

[0093] For startup or purging the oxy-fuel burner OXB, a further air supply may be present to guide air into the oxy-fuel burner OXB.

[0094] The at least one working media heat exchanger FWE may comprise more than one element to allow a heat transfer from a hot exhaust fluid EXH—i.e. the first part EXH**1**—to a cooler medium. E.g. a first heat transfer element operates with the first part EXH**1** in gas phase and further heat transfer elements operate with the first part EXH**1** in liquid state.

1. A power generation system (PGS) comprising

an oxy-fuel burner (OXB),

a first heat exchanger assembly (HEA**1**),

a rankine-cycle (RC),

wherein said rankine-cycle (RC) comprises at least one turbine (ST) for expansion of a working media (PF), downstream said turbine (ST) at least one condenser (CON) for condensing of said working media (PF),

wherein said rankine-cycle (RC) comprises downstream said condenser (CON) at least one first working media pump (FWP**1**) delivering said working media (PF) to a higher pressure level,

wherein said rankine-cycle (RC) comprises downstream said first working media pump (FWP**1**) at least one first working media pre-heater (PH**1**) heating said working media (PF) by extracted working media (XPF**2**) from said turbine (ST),

wherein downstream said first working media pre-heater (PH**1**) said working media (PF) passes said first heat exchanger assembly (HEA**1**) to be boiled and superheated,

wherein said oxy-fuel burner (OXB) generates an exhaust fluid (EXH) by combustion of fuel (F) and oxygen enriched gas (O2), wherein a first part (EXH**1**) of said exhaust fluid (EXH) is provided to an exhaust fluid line branch (EXLB) and a second part (EXH**2**) of said exhaust fluid (EXH) is provided for recirculation to said oxy-fuel burner (OXB),

wherein said rankine-cycle (RC) is operated with said working media (PF) which is circulating separately from said exhaust fluid (EXH),

wherein said first part (EXH**1**) of said exhaust fluid (EXH) is provided to at least one working media heat exchanger (FWE) that is provided to heat up said working media (PF) of said rankine-cycle (RC) downstream said first working media pump (FWP**1**) and upstream said first working media pre-heater (PH**1**) by said first part (EXH**1**) of said exhaust fluid (EXH),

wherein said second part (EXH**2**) of said exhaust fluid (EXH) is provided downstream of heat exchangers of said first heat exchanger assembly (HEA**1**) to a compression unit (PU) to increase pressure of said second part (EXH**2**) in order to re-inject said second part (EXH**2**) into said oxy-fuel burner (OXB).

2. The power generation system (PGS) according to claim **1**,

wherein said power generation system (PGS) is operated at a pressure level for said exhaust fluid (EXH) of several bar above atmospheric.

3. The power generation system (PGS) according to claim **1**, further comprising

a catalyst unit for cleaning of said exhaust fluid (EXH) from residual content of oxygen by addition of further fuel and/or other combustible media.

4. The power generation system (PGS) according to claim **1**,

wherein said turbine (ST) is a combination of at least a high pressure turbine (HPST) and a low pressure turbine (LPST),

wherein between said high pressure turbine (HPST) and said low pressure turbine (LPST) said working media (PF) is led through a reheater (AH**1**),

wherein said reheater (AH**1**) is part of said first heat exchanger assembly (HEA**1**), so that said working media (PF) is reheated by said exhaust fluid (EXH) downstream said high pressure turbine (HPST) and upstream said low pressure turbine (LPST).

5. The power generation system (PGS) according to claim 1, further comprising
at least one adjustable valve (CV) or a capacity control of said compression unit (PU) to control the flow of said second part (EXH2) of said exhaust fluid (EXH).

6. The power generation system (PGS) according to claim 1, further comprising
in respect of a fluid flow of a mixed working media (PFM), upstream of said at least one first working media pre-heater (PH1), a mixing pre-heater (MP) for mixing a third extracted working media (XPF3) from said turbine (ST) with said working media (PF) downstream said condenser (CON) to result in said mixed working media (PFM).

7. The power generation system (PGS) according to claim 1, further comprising
upstream said oxy-fuel burner (OXB), an air separation unit (ASU) as part of said power generation system (PGS) to purify ambient air to generate said oxygen enriched gas (O2).

8. The power generation system (PGS) according to claim 1,
wherein said power generation system (PGS) is set up such that temperature level at design working conditions for said second part (EXH2) of said exhaust fluid (EXH) is at least ⅔ of saturation temperature measured in Celsius of boiling occurring in said first heat exchanger assembly (HEA1).

9. The power generation system (PGS) according to claim 1,
wherein said feed water heat exchanger (FWE) comprises an output port to release gaseous carbon dioxide (CO2) and other output port to release water (H2O), said carbon dioxide (CO2) and said water (H2O) separated from said first part (EXH1) of said exhaust fluid (EXH) within said feed water heat exchanger (FWE).

10. A method to operate a power generation system (PGS) comprising:
providing an oxy-fuel burner (OXB), a first heat exchanger assembly (HEA1), a rankine-cycle (RC),
generating an exhaust fluid (EXH) by said oxy-fuel burner (OXB) by burning oxygen enriched gas (O2) and fuel (F), wherein a first part (EXH1) of said exhaust fluid (EXH) is provided to an exhaust fluid line branch (EXLB) and a second part (EXH2) of said exhaust fluid (EXH) is provided for recirculation to said oxy-fuel burner (OXB),
expanding a working media (PF) in said rankine-cycle (RC) comprising at least one turbine (ST) of said rankine-cycle (RC),
condensing said working media (PF) downstream said turbine (ST) by at least one condenser (CON) of said rankine-cycle (RC),
delivering said working media (PF) to a higher pressure level downstream said condenser (CON) by at least one first working media pump (FWP1) of said rankine-cycle (RC),
heating said working media (PF) by extracted working media (XPF2) from said turbine (ST) downstream said first working media pump (FWP1) by at least one first working media pre-heater (PH1) of said rankine-cycle (RC),
boiling and superheating said working media (PF) downstream said first working media pre-heater (PH1) by said first heat exchanger assembly (HEA1) of said rankine-cycle (RC),
operating said rankine-cycle (RC) with said working media (PF) which is circulating separately from said exhaust fluid (EXH),
providing at least one working media heat exchanger (FWE) for heating up said working media (PF) of said rankine-cycle (RC) downstream said first working media pump (FWP1) and upstream said first working media pre-heater (PH1) by said first part (EXH1) of said exhaust fluid (EXH),
routing said second part (EXH2) to a compression unit (PU) to increase pressure of said second part (EXH2) in order to inject said second part (EXH2) into said oxy-fuel burner (OXB).

11. The method according to claim 10, further comprising:
providing said turbine (ST) as a combination of at least a high pressure turbine (HPST) and a low pressure turbine (LPST),
conducting said working media (PF) is through a reheater (AH1) located downstream of said high pressure turbine (HPST) and upstream of said low pressure turbine (LPST),
wherein said reheater (AH1) is part of said first heat exchanger assembly (HEA1), so that said working media (PF) is reheated by said exhaust fluid (EXH) downstream said high pressure turbine (HPST) and upstream said low pressure turbine (LPST).

12. The method according to claim 10, further comprising:
controlling the flow through said recirculation line (RCL) by at least one adjustable valve (CV) or by speed control of said compression unit (PU).

13. The method according to claim 10, further comprising:
mixing a third extracted working media (XPF3) from said turbine (ST) with said working media (PF) downstream said condenser (CON) to a mixed working media (PFM) by a mixing pre-heater (MP), and providing the mixed working media (PFM) to said at least one first working media pre-heater (PH1).

14. The method according to claim 10, further comprising:
providing an air separation unit (ASU) as part of said power generation system (PGS) to purify ambient air to generate said oxygen enriched gas (O2).

15. The power generation system (PGS) according to claim 1,
wherein said power generation system (PGS) is operated at a pressure level for said exhaust fluid (EXH) of more than 5 bar above atmospheric.

16. The power generation system (PGS) according to claim 1, further comprising
a catalyst unit for cleaning of said exhaust fluid (EXH) from residual content of oxygen by addition of further fuel and/or other combustible media, connected such that heat of a catalyst process running in the catalyst unit is recovered for use in said rankine-cycle (RC) and/or for preheating of fuel (F) or said oxygen enriched gas (O2).

* * * * *