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(54) METHOD OF AND A SYSTEM FOR COMBUSTING FUEL IN AN OXYFUEL COMBUSTION BOILER

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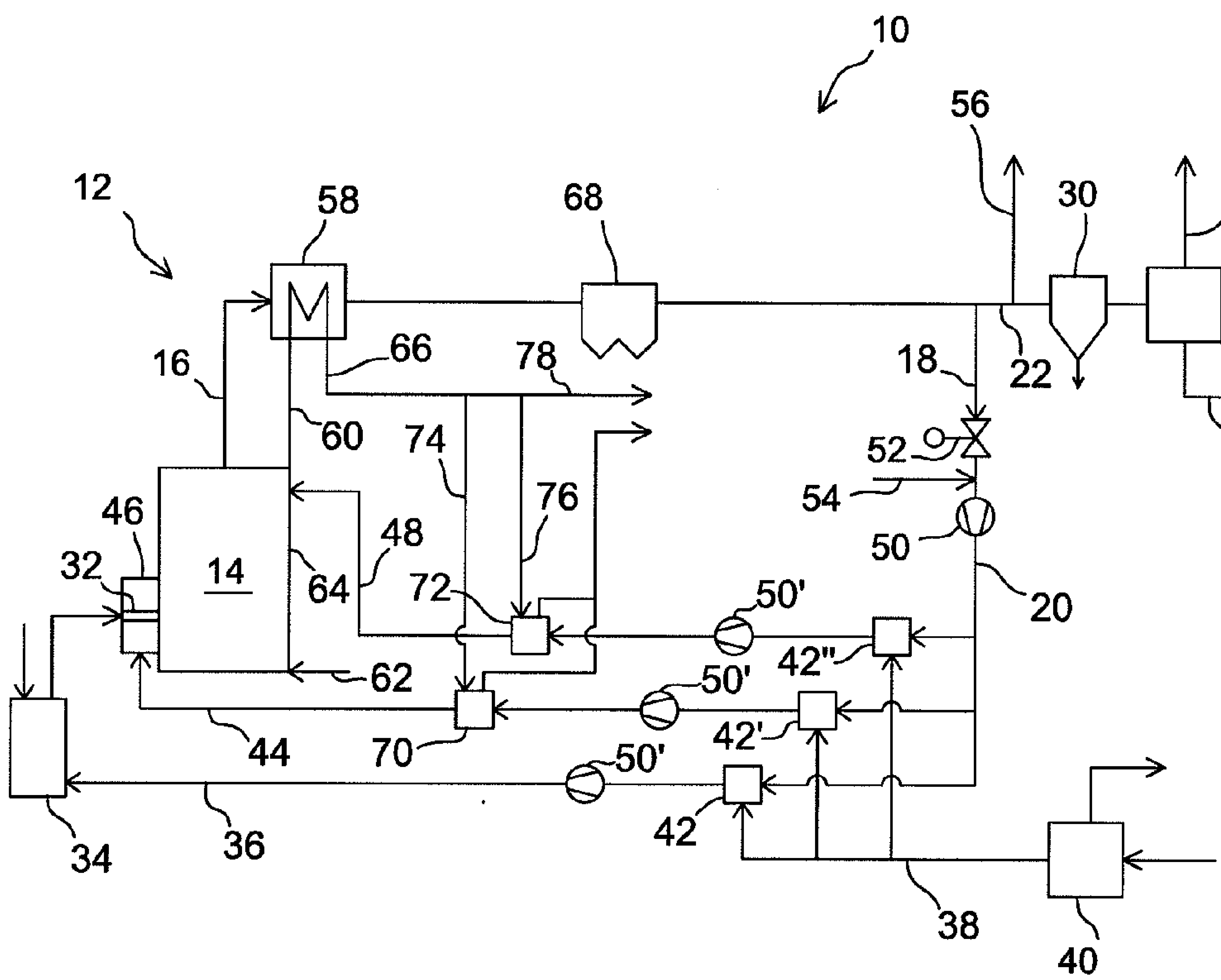
(57) **ABSTRACT**

A method of and a system for combusting fuel in an oxyfuel combustion boiler. Fuel is fed to a furnace of the boiler. Oxidant gas that includes a mixture of substantially pure oxygen and recycled flue gas is fed to the furnace, prior to the feeding of the oxidant gas. At least a portion of the oxidant gas is preheated to generate preheated oxidant gas. The fuel is combusted with the oxidant gas in the furnace so as to generate steam and to produce the flue gas, and at least a portion of the steam is superheated to generate superheated steam. The preheating of the at least a portion of the oxidant gas is performed by using a heat exchanger that transfers heat from a portion of the superheated steam to the oxidant gas.



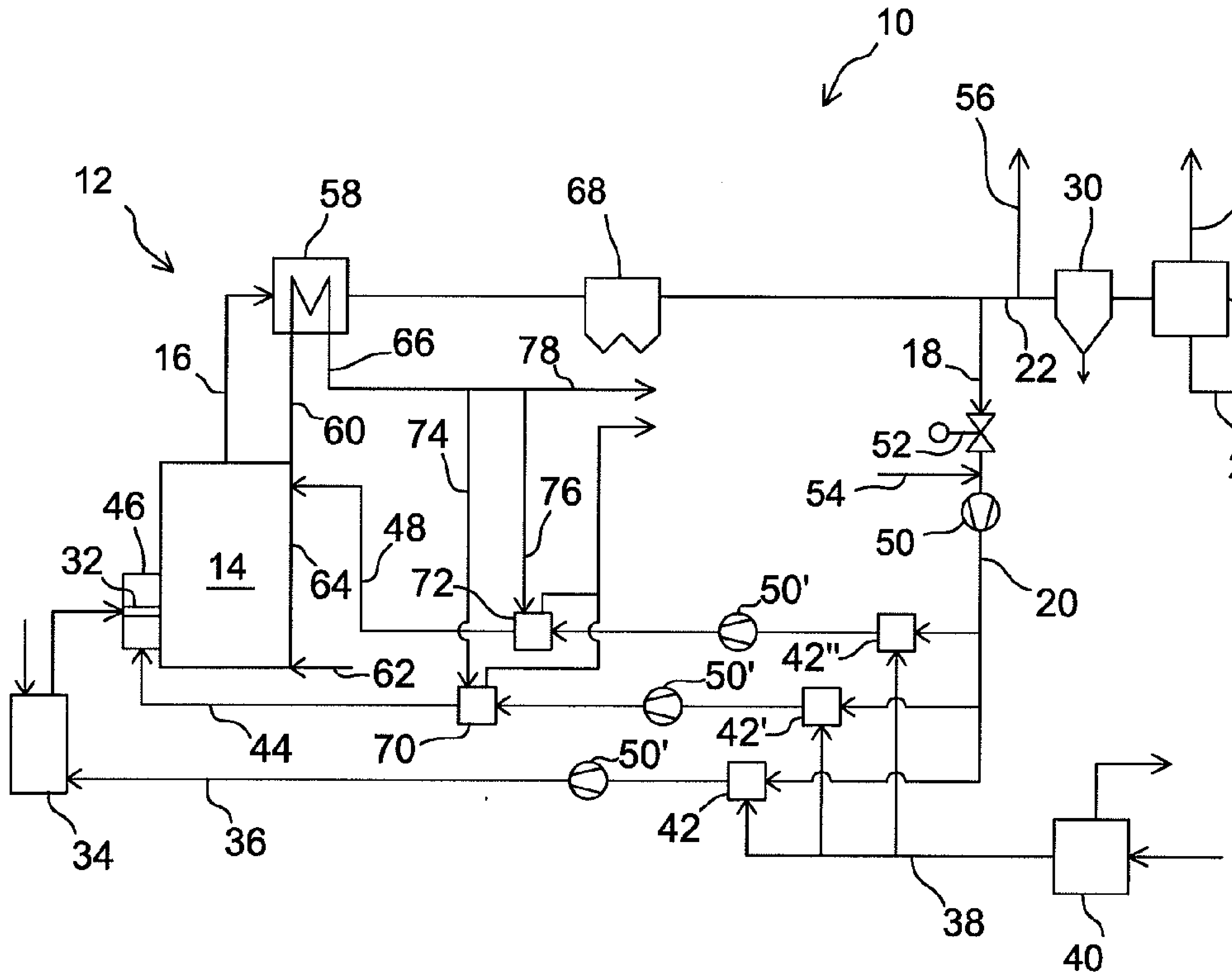

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Fig. 1

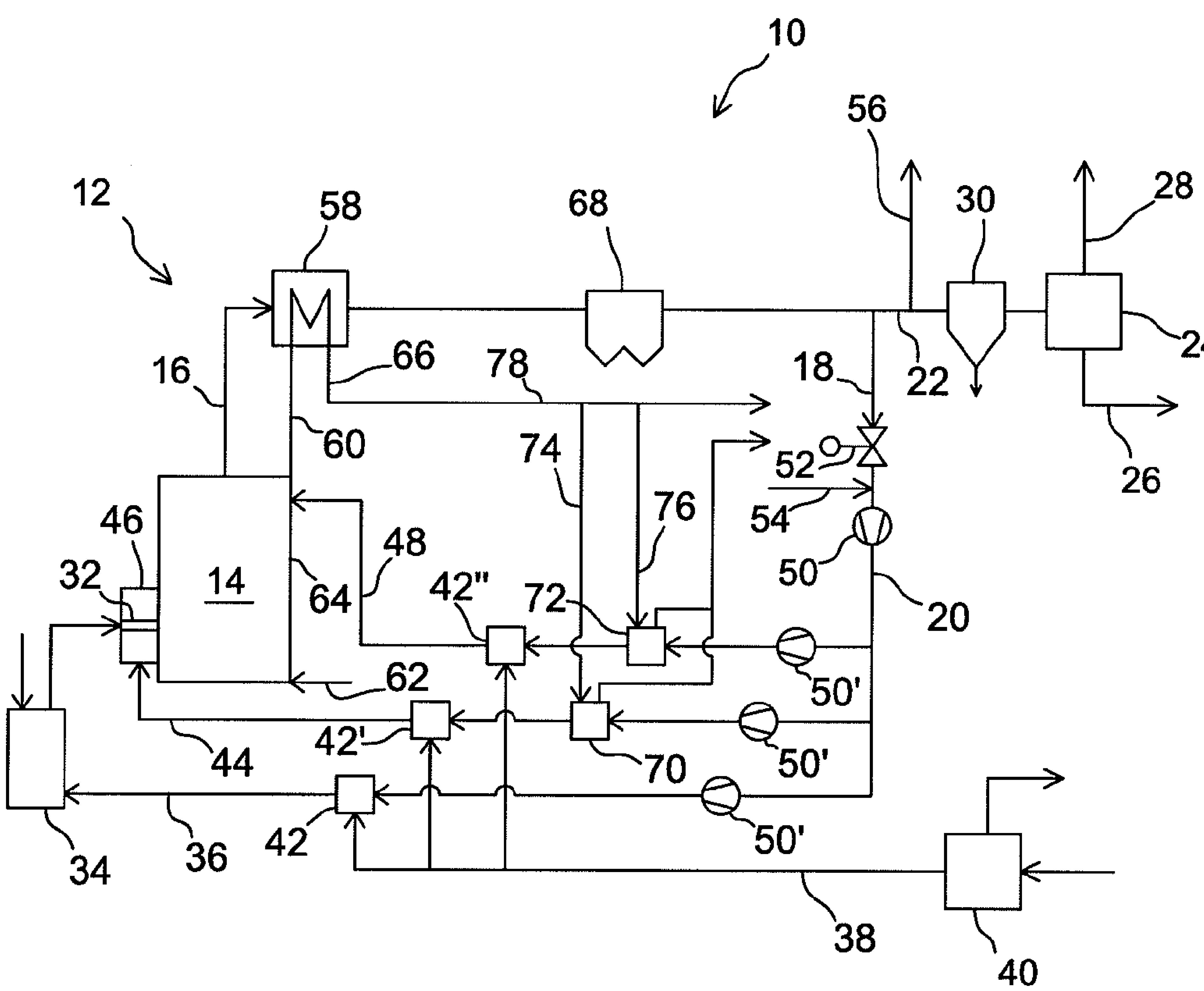
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Fig. 2

METHOD OF AND A SYSTEM FOR COMBUSTING FUEL IN AN OXYFUEL COMBUSTION BOILER

BACKGROUND OF THE INVENTION

[0001] 1. Technical Field of the Invention

[0002] The present invention relates to a method of and a system for combusting fuel in an oxyfuel combustion boiler, especially, in a pulverized coal firing oxyfuel combustion boiler.

[0003] 2. Description of the Background Art

[0004] Oxyfuel combustion is a method of combusting fuel using an oxidant consisting of oxygen and recycled flue gas. The purpose of oxyfuel combustion is to produce a flue gas that predominantly consists of CO_2 and H_2O, with smaller amounts of other gases, such as oxygen, argon and nitrogen. Water vapor can be removed from the flue gas through condensation, after which the flue gas mainly (e.g., 90%), consists of CO_2. Thereby, it is relatively easy to separate, by cooling and compressing, the CO_2 from the flue gas to liquid or supercritical form, which can then be transported to a final storage.

[0005] An oxyfuel combustion boiler plant is complicated, when compared to a conventional boiler plant that uses air for combustion, by having an air separation unit (ASU) for producing oxygen and a CO_2 processing unit (CPU) for separating CO_2 from the flue gas. The boiler itself can be designed so that it largely resembles a normal air-fired boiler and can also be operated in an air firing mode. In an oxyfuel combustion mode, a large portion of the flue gas is recirculated back to the furnace, in order to replace the nitrogen in the oxidant gas of the air firing mode. Thereby, the combustion temperature and heat transfer efficiency can be maintained nearly unchanged. As a major difference to combustion with air, the flow rate of flue gas led out from the boiler plant in the oxyfuel combustion mode is, due to recycling of the flue gas, only a fraction, typically, 25-35%, of the flow rate of the flue gas as discharged from the furnace.

[0006] In order to obtain a high thermal efficiency in an oxyfuel combustion boiler, different oxidant streams, such as a secondary oxidant stream and an overfire oxidant stream of the boiler, are advantageously preheated prior to being introduced to the furnace. This generally corresponds to the process used in conventional air firing, wherein the oxidant stream, i.e., a stream of relatively cold air, is usually preheated by the flue gas in a gas-gas heat exchanger. Conventional oxidant gas preheating systems and methods used in air firing boilers are, however, not always suitable for oxyfuel combustion. Because the oxidant stream of an oxyfuel combustion boiler is a mixture of substantially pure oxygen and recycled flue gas, there are several possibilities to perform the preheating of the oxidant.

[0007] An alternative for preheating the oxidant of an oxyfuel combustion boiler is to preheat the stream of substantially pure oxygen from an ASU, which is originally at a relatively low temperature. U.S. Pat. No. 6,505,567 discloses a method of preheating the stream of substantially pure oxygen by the flue gas in a gas-gas heater. U.S. Pat. No. 6,202,574 discloses a method of preheating both the stream of substantially pure oxygen and the stream of recycled flue gas by the flue gas in two separate gas-gas heaters. Due to the very high reactivity of oxygen, the preheating of the oxygen stream by the flue gas in a gas-gas heat exchanger may create, in the case of a leak, a risk of an explosion.

[0008] Another alternative to preheat the oxidant stream is to use the flue gas for heating, instead of the stream of substantially pure oxygen, the stream of recycled flue gas in a gas-gas heat exchanger. However, this method may be inefficient due to the relatively small temperature difference between the two gas streams. A third possibility is to preheat the mixture of oxygen and recycled flue gas by the flue gas in a gas-gas heat exchanger. However, even in this method may involve a risk of explosion in a case in which the mixing of gases is not complete. All of the oxidant heating methods described above may also suffer from not being able to heat the oxidant gas streams to a sufficiently high temperature.

[0009] U.S. Patent Application Publication No. US 2008/0302107 discloses preheating a mixture of oxygen and recycled flue gas by the flue gas in a gas-gas heat exchanger. U.S. Patent Application Publication No. US 2009/0293782 shows a relatively complicated system, in which a gas-gas heat exchanger is arranged for preheating recycled flue gas by the flue gas, and a separate system for preheating an oxygen stream by circulating a fluid medium between heat transfer surfaces in the flue gas channel and oxygen channel, respectively.

SUMMARY OF THE INVENTION

[0010] An object of the present invention is to provide a method and a system for combusting fuel in an oxyfuel combustion boiler, wherein at least some of the drawbacks of the prior art mentioned above are minimized.

[0011] In order to attain the object mentioned above, and other objects, the present invention provides a method of combusting fuel in an oxyfuel combustion boiler. The method comprises the steps of (a) feeding fuel to a furnace of the boiler, (b) feeding oxidant gas consisting of a mixture of substantially pure oxygen and recycled flue gas to the furnace, (c) prior to the feeding of the oxidant gas, preheating at least a portion of the oxidant gas to generate preheated oxidant gas, (d) combusting the fuel with the oxidant gas in the furnace so as to generate steam and to produce the flue gas, and (e) superheating at least a portion of the steam to superheated steam, wherein the preheating of the at least a portion of the oxidant gas is performed by using a heat exchanger that transfers heat from a portion of the superheated steam to the oxidant gas.

[0012] Also, the invention provides a system for combusting fuel in an oxyfuel combustion boiler, wherein the system comprises a feed for feeding fuel to a furnace of the boiler, a feed for feeding oxidant gas consisting of a mixture of substantially pure oxygen and recycled flue gas to the furnace, a preheater for preheating at least a portion of the oxidant gas, arranged upstream of the feed for feeding the oxidant gas to the furnace, to generate preheated oxidant gas, a combustor for combusting the fuel with the oxidant gas in the furnace so as to generate steam and to produce the flue gas, and a superheater for superheating at least a portion of the steam to generate superheated steam, wherein the preheater for preheating the at least a portion of the oxidant gas comprises a heat exchanger for preheating the portion of the oxidant gas by transferring heat from a portion of the superheated steam to the oxidant gas.

[0013] The present invention thus relates to a method of and a system for combusting fuel in an oxyfuel combustion boiler, especially, a pulverized coal firing boiler. The invention is based on a surprising observation that, in order to guarantee a sufficiently high efficiency of an oxyfuel combustion boiler, especially, a pulverized coal firing boiler, it is advantageous to preheat at least a portion of the oxidant stream, before feeding the oxidant to the furnace, to such a high temperature that cannot be safely and efficiently obtained by the methods conventionally used in air combustion. The desired final temperature of the oxidant depends on the type of fuel used, but, especially for pulverized coal, the required temperature increase can be so high that, for example, a conventional steam-coil oxidant preheater, which works mainly with the latent heat of steam, is not sufficient.

[0014] Steam is typically superheated in an oxyfuel combustion boiler to a temperature of about 500° C., and, thus, it is possible to preheat the oxidant gas, in accordance with the present invention, by using a heat exchanger that transfers heat from a portion of the superheated steam to the oxidant gas. When using anthracite or pet-coke as a fuel, i.e., a low volatile fuel, the oxidant is preferably preheated in a pulverized coal firing oxyfuel combustion boiler to a temperature of at least about 300° C. to about 350° C., and, in some cases, to about 400° C. The superheated steam leaving the heat exchanger may correspondingly be cooled down to about 400° C. to about 450° C., but the steam is still superheated, and it can be used for thermal purposes.

[0015] The heat exchanger, a so-called steam-oxidant heater (SOH), thus works as a reverse superheater. The SOH is preferably of a similar construction as that of a conventional gas-gas heat exchanger, i.e., for example, it may be constructed of conventional finned tubes. The exact geometry, materials, tube thicknesses and performance of the heat exchanger can be optimized by using conventional procedures. It is also possible that the heat exchanger has a construction, which is specially designed for the purpose.

[0016] According to a first preferred embodiment of the present invention, the preheating of the oxidant gas is performed by preheating at least a portion of the stream of recycled flue gas, by superheated steam, prior to mixing the recycled flue gas with substantially pure oxygen. By using this embodiment, the size of the steam-oxidant heater is relatively small, and the risk of corrosion inside the SOH is minimized. Downstream of the SOH, the recycled flue gas is mixed with the stream of substantially pure oxygen, and a final mixture of substantially pure oxygen and recycled flue gas is obtained. The mixture is then at a suitable temperature, such as about 350° C., for being fed to the furnace.

[0017] According to a second preferred embodiment of the present invention, the preheating of the oxidant gas is performed by transferring heat from a portion of the superheated steam to a mixture of substantially pure oxygen and recycled flue gas. Thus, a preheated mixture of substantially pure oxygen and recycled flue gas is readily obtained. By this method, the mixture to be fed to the furnace can be heated to a relatively high temperature, such as about 400° C.

[0018] The oxidant gas stream, comprising a mixture of substantially pure oxygen and recycled flue gas and being preheated according to the first or second preferred embodiment of the present invention, as described above, can then advantageously be fed, for example, as a secondary oxidant or as an overfire oxidant to the furnace.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The above brief description, as well as further objects, features, and advantages of the present invention will be more fully appreciated by reference to the following detailed description of the at present preferred, but nonetheless illustrative, embodiments in accordance with the present invention, when taken in conjunction with the accompanying drawings, wherein:

[0020] FIG. **1** is a schematic diagram of an oxyfuel combustion boiler in accordance with a preferred embodiment of the present invention; and

[0021] FIG. **2** is a schematic diagram of an oxyfuel combustion boiler in accordance with another preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0022] FIG. **1** shows a schematic diagram of an oxyfuel combustion boiler plant **10** having a boiler **12**, in accordance with a preferred embodiment of the present invention. The boiler comprises a furnace **14**, and a flue gas channel **16** for discharging flue gas from the furnace. A portion of the flue gas, so-called recycled flue gas **18**, is recycled through a flue gas recycling channel **20** back to the furnace **14**, the rest of the flue gas being discharged through a flue gas discharge channel **22** from the boiler **12**.

[0023] The flue gas discharge channel **22** is equipped with a carbon dioxide processing unit (CPU) **24** for cooling, cleaning and compressing the end portion of the flue gas, so as to separate a cleaned carbon dioxide stream **26** therefrom. The CPU **24** usually comprises a dryer for completely drying all water from the flue gas, and a separator for separating a stream of non-condensable gases **28**, such as oxygen, and possibly other impurities, from the carbon dioxide. The stream of carbon dioxide **26** is typically captured in a liquid or a supercritical state, at a pressure of, for example, about one hundred ten bar, so that it can be transported for further use or to be stored in a suitable place. FIG. **1** shows, separately, a condensing gas cooler **30**, located upstream of the carbon dioxide capture unit (CPU) **24**, for removing water from the flue gas.

[0024] FIG. **1** shows a burner **32** attached to the furnace **14** for combusting pulverized coal conducted from a coal mill **34**. In practice, there are usually several burners attached to the furnace **14**, but, for the sake of simplicity, only one burner **32** is shown here. The pulverized coal is conducted from the coal mill **34** to the furnace **14** with a stream of primary oxidant **36**, which consists of substantially pure oxygen **38**, obtained from an air separation unit (ASU) **40**, mixed with recycled flue gas **18**, in a mixer **42**.

[0025] Secondary oxidant **44**, consisting of substantially pure oxygen **38** mixed with recycled flue gas **18** in another mixer **42'**, is fed to the furnace **14** adjacent to each of the burners **32** through a wind box **46**. Correspondingly, overfire oxidant **48**, consisting of substantially pure oxygen **38** mixed with recycled flue gas **18** in a third mixer **42"**, is fed to the upper portion of the furnace **14**.

[0026] The flue gas recycling channel **20** advantageously comprises a flow controller, such as a controllable fan **50** and/or a damper **52**, for controlling the flue gas recycling rate. The recycling rate of the flue gas is advantageously adjusted such that the average O_2 content of the oxidant gas is close to that of air, preferably, from about 18% to about 28%. The branches of the flue gas recycling channel **20** for the streams of overfire oxidant **48**, secondary oxidant **44** and primary oxidant **36**, respectively, advantageously comprise controllers, such as fans **50'**, for separately controlling the flow rates and/or oxygen contents of the corresponding oxidant streams.

[0027] The system may also comprise an air intake **54**, which is preferably arranged in the flue gas recycling channel **20**. The purpose of the air intake **54** is to enable switching from oxyfuel combustion to air-firing combustion. Thus, when introducing air to the gas recycling channel **20**, the oxygen supply is stopped, and the recycling of flue gas is minimized or, preferably, totally stopped, by the damper **52**. The flue gas comprises, in the air-firing mode, carbon dioxide and water mixed with a large amount of nitrogen, whereby, it is not possible to easily capture the carbon dioxide from the flue gas, which is, thus, in this case, released to the environment through a stack **56**.

[0028] An upstream portion of the flue gas channel **16** comprises a heat exchange unit **58**, wherein saturated steam **60**, generated from feed water **62** in evaporation surfaces **64** in the furnace **14**, is superheated to superheated steam **66**. The superheated steam, typically having a temperature of about 500° C., is conducted to thermal purposes, typically, to steam turbines, not shown in FIG. **1**, to generate power.

[0029] The flue gas channel **16** usually comprises other heat exchange surfaces, for example, reheaters and economizers. However, for the sake of simplicity, they are not shown in FIG. **1**. The flue gas channel **18** may also comprise different gas cleaning units, such as an NO_x catalyst and an SO_2 scrubber, but, because they are not relevant for the present invention, only a dust separator **68** is shown in FIG. **1**.

[0030] In order to preheat the streams of secondary oxidant **44** and overfire oxidant **48**, FIG. **1** shows preheaters **70**, **72**, so-called steam-oxidant heaters (SOH), for the secondary oxidant **44** and the overfire oxidant **48**, respectively. The steam-oxidant heaters **70**, **72** are advantageously arranged in the corresponding branches of the flue gas recycling channel **20** downstream of the mixers **42'** and 42". In accordance with the present invention, the steam-oxidant heaters **70**, **72** are heat exchangers, wherein heat is transferred from a portion of the superheated steam **66** to secondary oxidant **44** and overfire oxidant **48**, respectively.

[0031] The secondary oxidant **44** and overfire oxidant **48** are advantageously heated in the steam-oxidant heaters **70**, **72** to a relatively high temperature, such as about 300° C. to about 350° C. At the same time, the portion of superheated steam flowing through one of the steam-oxidant heaters **70**, **72** is cooled to a temperature of about 400° C. to about 450° C. Thus, the steam remains superheated after flowing through the steam-oxidant heaters **70**, **72**, and it can still advantageously be used for suitable thermal purposes, such as for power generation.

[0032] In FIG. **1**, the steam-oxidant heaters **70**, **72** are connected to two parallel lines **74**, **76**, branching off from a main line **78** of superheated steam. It may, however, in some embodiments of the present invention, be possible to connect the steam-oxidant heaters **70**, **72** differently, for example, in series in a single branch line of the main line **78** of superheated steam.

[0033] FIG. **1** shows steam-oxidant heaters **70**, **72** for heating the streams of secondary overfire oxidant **44**. It may, however, in some embodiments of the present invention, be possible to preheat only one of these oxidant streams in a steam-oxidant heater. Alternatively, it may also be useful to preheat other oxidant streams, such as the primary oxidant stream **36**, alone, or in combination with other oxidant streams, in a steam-oxidant heater.

[0034] FIG. **2** shows another embodiment of the present invention, which differs from the embodiment shown in FIG. **1**, only in that the steam-oxidant heaters **70**, **72** are connected to respective branches of the flue gas recycling line **20** upstream of the mixers **42'**, **42"**. This may be practical in some embodiments of the present invention, for example, for layout reasons. However, usually, the arrangement of FIG. **1** is preferable, because, due to the mixing of oxygen, which is originally at a relatively low temperature, upstream of the steam-oxidant heaters **70**, **72**, the oxidant stream is in the steam-oxidant heaters **70**, **72** at a lowered temperature, and the heat exchange is more effective.

[0035] Another advantage of the embodiment shown in FIG. **1** is that, for example, due to a relatively long distance from the mixers **42**, **42'**, **42"**, the fans **50'** improve the mixing, and the required mixing efficiency of the mixers **42**, **42'**, **42"** is reduced. The mixers **42**, **42'**, **42"** can then be, for example, simple pipe connecting pieces, wherein the flow of oxygen and recycled flue gas are just merged together.

[0036] An advantage of the embodiment of FIG. **2**, i.e., of mixing the streams of oxygen with the streams of recycled flue gas only downstream of the steam-oxidant heaters **70**, **72**, is that, in this case, the flow of gas to be heated is lower than that in the embodiment of FIG. **1**, and the size of the steam-oxidant heaters **70**, **72** can be correspondingly smaller. Another advantage of the embodiment of FIG. **2** is that the risk of corrosion in the steam-oxidant heaters **70**, **72**, caused by the streams of oxygen, is avoided.

[0037] As described above, in some embodiments of the present invention, the oxidant streams can be preheated with, in addition to the steam-oxidant heaters **70**, **72**, other types of oxidant preheaters, such as conventional oxidant preheaters. Because the steam-oxidant heaters **70**, **72** according to the present invention have the special advantage that the oxidant stream can be heated to a relatively high temperature, other possible oxidant preheaters are preferably arranged upstream of the steam-oxidant heaters **70**, **72**.

[0038] Examples of using steam-oxidant heaters in pulverized coal firing boilers have been described above, but it may be advantageous to use steam-oxidant heaters, in accordance with the present invention, in other types of boilers, for example, in fluidized bed boilers, especially, when a high temperature of oxidant being fed to the furnace is required.

[0039] While the invention has been described herein by way of examples in connection with what are at present considered to be the most preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments, but it is intended to cover various combinations or modifications of its features and several other applications included within the scope of the invention as defined in the appended claims.

We claim:

1. A method of combusting fuel in an oxyfuel combustion boiler, the method comprising the steps of:

(a) feeding fuel to a furnace of the boiler;

(b) feeding oxidant gas consisting of a mixture of substantially pure oxygen and recycled flue gas to the furnace;

(c) prior to the feeding of the oxidant gas, preheating at least a portion of the oxidant gas to generate preheated oxidant gas;

(d) combusting the fuel with the preheated oxidant gas in the furnace so as to generate steam and to produce the flue gas; and

(e) superheating at least a portion of the steam to produce superheated steam, wherein the preheating of the at least a portion of the oxidant gas is performed by using a heat exchanger that transfers heat from a portion of the superheated steam to the oxidant gas.

2. The method of claim **1**, wherein the preheating of the oxidant gas is performed by preheating at least a portion of the recycled flue gas to produce preheated recycled flue gas, prior to mixing the preheated recycled flue gas with substantially pure oxygen, to generate the mixture of substantially pure oxygen and recycled flue gas.

3. The method of claim **2**, wherein the step of feeding the preheated oxidant gas to the furnace comprises introducing a portion of the mixture of substantially pure oxygen and recycled flue gas as a secondary oxidant to the furnace.

4. The method of claim **2**, wherein the step of feeding the preheated oxidant gas to the furnace comprises introducing a portion of the mixture of substantially pure oxygen and recycled flue gas as an overfire oxidant to the furnace.

5. The method of claim **1**, wherein the preheating of the oxidant gas is performed by preheating at least a portion of the mixture of substantially pure oxygen and recycled flue gas.

6. The method of claim **5**, wherein the step of feeding the oxidant gas to the furnace comprises introducing a portion of the mixture of substantially pure oxygen and recycled flue gas as a secondary oxidant to the furnace.

7. The method of claim **5**, wherein the step of feeding the oxidant gas to the furnace comprises introducing a portion of the mixture of substantially pure oxygen and recycled flue gas as an overfire oxidant to the furnace.

8. The method of claim **1**, wherein the oxidant gas is preheated in the heat exchanger to a temperature of at least 300° C.

9. The method of claim **1**, wherein the oxidant gas is preheated in the heat exchanger to a temperature of at least 350° C.

10. A system for combusting fuel in an oxyfuel combustion boiler, the system comprising:

a feed for feeding fuel to a furnace of the boiler;

a feed for feeding oxidant gas consisting of a mixture of substantially pure oxygen and recycled flue gas to the furnace;

a preheater for preheating at least a portion of the oxidant gas, arranged upstream of the feed for feeding the oxidant gas to the furnace, to generate preheated oxidant gas;

a combustor for combusting the fuel with the oxidant gas in the furnace so as to generate steam and to produce the flue gas; and

a superheater for superheating at least a portion of the steam to generate superheated steam,

wherein the preheater for preheating the at least a portion of the oxidant gas comprises a heat exchanger for preheating the portion of the oxidant gas by transferring heat from a portion of the superheated steam to the oxidant gas.

11. The system of claim **10**, wherein the preheater for preheating the oxidant gas comprises a preheater for preheating at least a portion of the recycled flue gas to generate preheated recycled flue gas, prior to mixing the preheated recycled flue gas with substantially pure oxygen, so as to generate the mixture of substantially pure oxygen and recycled flue gas.

12. The system of claim **11**, wherein the feed for feeding preheated oxidant gas to the furnace comprises a supply for introducing a portion of the mixture of substantially pure oxygen and recycled flue gas as a secondary oxidant to the furnace.

13. The system of claim **11**, wherein the feed for feeding preheated oxidant gas to the furnace comprises a supply for introducing a portion of the mixture of substantially pure oxygen and recycled flue gas as an overfire oxidant to the furnace.

14. The system of any claim **10**, wherein the preheater for preheating the oxidant gas comprises a preheater for preheating at least a portion of the mixture of substantially pure oxygen and the recycled flue gas.

15. The system of claim **14**, wherein the feed for feeding the preheated oxidant gas to the furnace comprises a supply for introducing a portion of the mixture of substantially pure oxygen and recycled flue gas as a secondary oxidant to the furnace.

16. The system of claim **14**, wherein the feed for feeding the preheated oxidant gas to the furnace comprises a supply for introducing a portion of the mixture of substantially pure oxygen and recycled flue gas as an overfire oxidant to the furnace.

17. The system of claim **10**, wherein the heat exchanger preheats the oxidant gas to a temperature of at least 300° C.

18. The system of claim **10**, wherein the heat exchanger preheats the oxidant gas to a temperature of at least 350° C.

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