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(54) Title: CIRCULATING FLUIDIZED BED BOILER WITH AN AIR PREHEATER SYSTEM

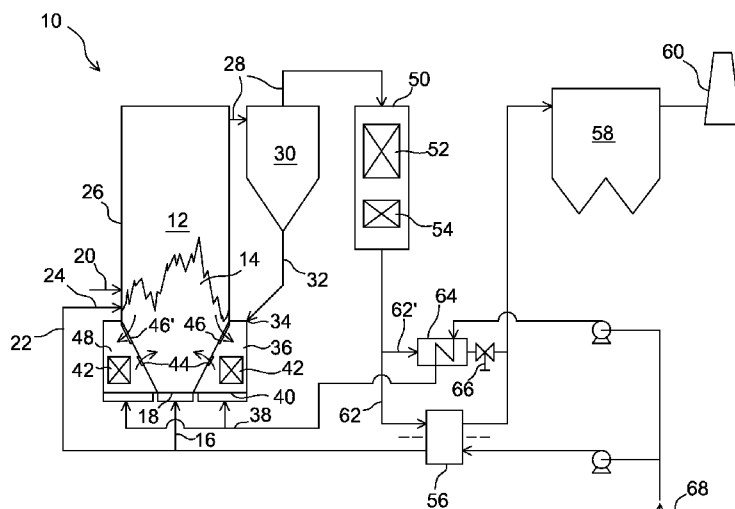


Fig. 1

(57) Abstract: A circulating fluidized bed boiler with an air preheater system, comprising a furnace for combusting particulate solid fuel with primary air injected to the furnace through a bottom grid and secondary air injected to the furnace through walls of the furnace; a flue gas channel connected to the furnace for discharging flue gas and particles entrained therewith from the furnace; a particle separator for separating particles from the flue gas; a return duct for returning separated particles from the particle separator to the furnace; and a fluidized bed heat exchange chamber for recovering heat from particles conducted therein from the furnace, the fluidized bed heat exchange chamber comprising inlet means for conducting particles from the furnace to the fluidized bed heat exchange chamber; outlet means for conducting particles from the fluidized bed heat exchange chamber back to the furnace; and means for injecting second fluidizing gas to the fluidized bed heat exchange chamber, wherein the air preheater system comprises a primary air preheater arranged in a first portion of the flue gas channel for preheating the primary air and secondary air and an air preheater for preheating the second fluidizing air arranged in a second portion of the flue gas channel, which second portion of the flue gas channel is connected in parallel with the first portion of the flue gas channel.

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CIRCULATING FLUIDIZED BED BOILER WITH AN AIR PREHEATER SYSTEM

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[0001] The present invention relates to a circulating fluidized bed boiler with an air preheater system. The invention especially relates to a circulating fluidized bed boiler comprising a primary air preheater and a fluidized bed heat exchange chamber.

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[0002] Fuel, such as coal or biofuel, is combusted with air in the furnace of a circulating fluidized bed (CFB) boiler to form ash and flue gas. In some cases the fuel may be combusted with other oxidant gas than air, such as oxygen enriched air, but, for the sake of simplicity, in the following the oxidant is simply called air. The fluidizing velocity of a particle bed formed in the furnace is so high, typically 4 – 6 m/s, that a portion of the bed material particles and uncombusted fuel particles are entrained with the flue gas and discharged from the furnace. Particles larger than a separation limit are separated from the flue gas in a particle separator and returned back to the furnace through a solids return duct.

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[0003] The solids return duct may comprise a heat exchange chamber with a fluidized bed for recovering heat from the circulating particles. Additional particles may be conducted to the heat exchange chamber directly from the furnace, or the CFB boiler may comprise a heat exchange chamber for recovering heat only from a fluidized bed of particles conducted therein directly from the furnace. All these different types of heat exchange chambers are in the following commonly referred as fluidized bed heat exchange chambers.

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[0004] Three kinds of combustion air are typically introduced into a fluidized bed boiler: primary air that is used for fluidizing the particle bed in the furnace; secondary air that is fed to the furnace through wall nozzles to ensure

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complete combustion of the fuel; and second fluidizing air, so called high pressure (HP) air, that is used for fluidizing a particle bed in a fluidized bed heat exchange chamber. The pressure of the HP air is higher than that of the primary or secondary air because there is a relatively high pressure drop in the slow fluidized bed formed in the fluidized bed heat exchange chamber. Fluidizing velocity of the particle bed in the fluidized bed heat exchange chamber is typically less than 0.5 m/s.

[0005] The streams of primary and secondary air are typically preheated by flue gas in a tubular air preheater or in a regenerative air preheater, also called rotating air preheater, arranged in the flue gas channel between a feed water preheater (economizer) and means for flue gas cleaning, such as a dust separator. Preheating the streams of primary and secondary air, thus, reduces the flue gas exit temperature and, therefore, increases the thermal efficiency of the boiler. Typically a change of 10 °C in flue gas exit temperature results in an approximately 0.6 % change in the boiler efficiency.

[0006] Primary and secondary air streams may be separated from each other downstream of a common air preheater or the streams may be preheated separately, for example, in two tubular air preheaters or in two sectors of a regenerative air preheater. Because, in view of the present invention, the preheating of primary air and secondary air correspond to each other, the means for preheating both primary and secondary air are in the following commonly called as a primary air preheater.

[0007] Due to the relatively low flow rate of the HP air, HP air is typically led to the furnace without preheating. However, in some cases the amount of HP air may be relatively large, up to 5-10% of total combustion air. Especially in large CFB boilers of today, the flow rate of HP air may be of the order of 10 – 15 m³/s.

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Therefore, it is possible to transfer several MW of heat from the flue gas to the HP air, and, thus, further decrease the end temperature of the flue gas and thereby increase the boiler efficiency.

5 [0008] U.S. Patent No. 4,470,255 discloses a CFB boiler, in which primary air, secondary air, and fluidizing air of a fluidized bed heat exchanger (HP air) are all preheated by a single air preheater arranged in the flue gas channel. The air preheater appears to be a tubular air preheater, but the patent does not specify the type or operation of the air preheater. In spite of the versatile air heat system
10 shown in U.S. Patent No. 4,470,255, the thermal efficiency of the boiler may be less than optimal.

[0009] An object of the present invention is to provide an air preheater system improving the thermal efficiency of the boiler.

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[0010] In order to obtain the above mentioned object and other objects of the invention, a circulating fluidized bed boiler with an air preheater system is provided, the circulating fluidized bed boiler comprising a furnace for combusting particulate solid fuel with primary air injected to the furnace through a bottom grid and secondary air injected to the furnace through walls of the furnace; a flue gas
20 channel connected to the furnace for discharging flue gas and particles entrained therewith from the furnace; a particle separator for separating particles from the flue gas; a return duct for returning separated particles from the particle separator to the furnace; and a fluidized bed heat exchange chamber for recovering heat
25 from particles conducted therein from the furnace, the fluidized bed heat exchange chamber comprising inlet means for conducting particles from the furnace to the fluidized bed heat exchange chamber; outlet means for conducting particles from the fluidized bed heat exchange chamber back to the furnace; and means for injecting second fluidizing gas to the fluidized bed heat exchange

chamber, wherein the air preheater system comprises a primary air preheater arranged in a first portion of the flue gas channel for preheating the primary air and secondary air and an air preheater for preheating the second fluidizing air arranged in a second portion of the flue gas channel, which second portion of the
5 flue gas channel is connected in parallel with the first portion of the flue gas channel.

[0011] The primary air preheater and the air preheater for preheating the second fluidizing air, so called high pressure (HP) air, being arranged in a portion
10 of the flue gas channel means that heat is transferred in the air preheaters from the flue gas flowing in the portion of the flue gas channel in question to the respective stream of air. The air preheaters are in practice usually rotary (rotating ja rotary ovat yhtä oikein. Nyt käytiin keksintöilmoituksessa käytettyä sanaa rotating), or regenerative, air preheaters or tubular air preheaters. An air
15 preheater can in some applications even be a heat exchanger in which heat is transferred from the flue gas to a stream of air by a heat transfer medium, such as water. According to a preferred embodiment of the present invention, the primary air preheater is a rotary air preheater. Correspondingly, according to a preferred embodiment of the present invention, the HP air preheater is a tubular air
20 preheater.

[0012] According to the present invention, the primary air preheater is arranged in a first portion of the flue gas channel and the HP air preheater is arranged in a second portion of the flue gas channel, which second portion of the
25 flue gas channel is connected in parallel with the first portion of the flue gas channel. This means that the flue gas channel is divided, typically at a point downstream of a feed water preheater, into two parallel channel portions, wherein the primary air preheater is arranged in one of the parallel channel portions, and the HP air preheater is arranged in the other of the parallel channel portions.

Typically the channel portions comprise dampers to control the flue gas flows or they are dimensioned so that preferably about 90 – 98 % of the flue gas flows through the primary air heater, and the rest through the HP air preheater.

- 5 [0013] An advantage of the present invention is that when the HP air is preheated by flue gas in a separate air preheater, arranged in the flue gas stream parallel to the primary air preheater, the flue gas end temperature can be lowered, and thereby the boiler efficiency is improved. In the following, a simple explanation is given for the effect, in which complications due to possible air
10 leakage in the primary air preheater are ignored.

[0014] Thermal effectiveness ε of a primary air preheater is defined as

$$\varepsilon = (T_{ao} - T_{ai}) / (T_{fgi} - T_{ai}), \quad (1)$$

15 where

T_{ao} = air outlet temperature from the primary air preheater,

T_{ai} = air inlet temperature to the primary air preheater, and

T_{fgi} = flue gas inlet temperature to the primary air preheater.

- 20 [0015] The thermal effectiveness is in practice bound to be less than one because the air outlet temperature T_{ao} is always lower than the flue gas inlet temperature T_{fgi} . Typically it is possible to obtain for an air preheater, especially for a large rotating air preheater, a maximum thermal effectiveness of about 0.89 – 0.92.

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[0016] Total amount of heat Q_{fg} transferred from the flue gas in the primary air preheater is

$$Q_{fg} = dm_{fg}/dt * c_{fg} (T_{fgi} - T_{fgo}), \quad (2)$$

where

dm_{fg}/dt = mass flow rate of the flue gas in the primary air preheater,

c_{fg} = specific heat of the flue gas, and

T_{fgo} = flue gas outlet temperature to the primary air preheater.

5

[0017] Assuming that there is no loss of heat, the amount of heat Q_{fg} transferred from the flue gas in the primary air preheater is as large as the amount of heat Q_a received therein by the air

$$10 \quad Q_a = dm_a/dt * c_a (T_{ao} - T_{ai}) \quad (3)$$

where

dm_a/dt = mass flow rate of air, and

c_a = specific heat of air.

15 [0018] Equations (1), (2) and (3) lead to flue gas outlet temperature from the primary air preheater

$$T_{fgo} = T_{fgi} - \varepsilon * (dm_a/dt * c_a) / (dm_{fg}/dt * c_{fg}) * (T_{fgi} - T_{ai}). \quad (4)$$

20 [0019] As can be seen from equation (4), if the thermal effectiveness ε is constant, the flue gas outlet temperature T_{fgo} can be decreased by decreasing the mass flow rate dm_{fg}/dt of the flue gas flowing through the primary air preheater. The present invention is based on the observation that if the mass flow rate of the flue gas through the primary air preheater is decreased by a relatively small
25 amount, it is possible to increase the size of the primary air preheater so that the maximum value for the effectiveness ε is again obtained.

[0020] According to the present invention, the air preheater system differs from a conventional air preheater system in that the mass flow rate of the flue gas

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flowing through the primary air preheater is decreased by letting a portion of the flue gas bypass the primary air preheater and flow through a separate HP air preheater. The size of primary air heater is simultaneously increased from that of a conventional design so that a typical maximum value of the thermal

5 effectiveness ε is obtained, resulting in a lower flue gas temperature after the primary air heater. Because an amount of heat is recovered from the flue gas also in the HP air preheater, the temperature of the flue gas obtained by combining the streams of flue gas from primary air preheater and the HP heater is lower than that of the flue gas without a HP heater. Therefore, the thermal efficiency of the
10 boiler is increased.

[0021] 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 presently preferred, but nonetheless
15 illustrative, embodiments in accordance with the present invention, when taken in conjunction with the accompanying drawing, wherein:

[0022] Fig. 1 is a schematic diagram of a circulating fluidized bed boiler with an air preheater system according to the present invention.
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[0023] Fig. 1 schematically shows a circulating fluidized bed boiler 10, comprising a furnace 12 with a bed of particles 14 fluidized by primary air 16 which is introduced to the furnace through a bottom grid 18. Fuel, such as biofuel or coal, is fed to the boiler through fuel feeding means 20. The fuel is combusted
25 by the primary air 16 and secondary air 22, which is fed to the furnace through secondary air feeding means 24 at the walls 26 of the furnace. 12. Flue gas generated in the combustion, which is discharged from the furnace through a flue gas channel 28, entrains bed particles and uncombusted fuel, a portion of which

is separated from the flue gas in a particle separator 30 and returned back to the furnace by a return duct 32.

[0024] Particles separated in the particle separator are conducted through the return duct and an inlet opening 34 to a fluidized bed heat exchanger 36 comprising a bed of particles fluidized by second fluidizing air 38, so called high pressure (HP) air. Means 40 for injecting the second fluidizing gas to the fluidized bed heat exchange chamber preferably comprise a conventional wind box and a second bottom grid. The fluidized bed heat exchanger 36 comprises heat exchange surfaces 42 to cool the particles before they are returned back to the furnace 12 through an outlet opening 44. The fluidized bed heat exchanger 36 may comprise also another inlet 46 to conduct particles directly from the furnace 12 to the fluidized bed heat exchanger 36.

[0025] The boiler in Fig. 1 comprises also another fluidized bed heat exchanger 48, fluidized with the HP air 38, which comprises only an inlet opening 46' for feeding particles directly from the furnace 12 to the heat exchanger 48. Actually the number of the different types of the heat exchangers is often larger than one, or the boiler may comprise one or more heat exchangers of one of these types only.

[0026] Cleaned flue gas is conducted from the particle separator 30 via a back pass 50, comprising heat exchange units, such as superheaters 52 and economizers 54 to a primary air preheater 56. The primary air preheater 56 is here shown as a rotary, or regenerative, air preheater, but it may alternatively be a tubular air preheater. The flue gas flows from the primary air preheater via a dust separator 58 and possible other gas cleaning units (not shown) to a stack 60. Primary air and secondary air are typically heated in the primary air preheater 56 to a temperature of about 300 °C.

[0027] In accordance with the present invention, the primary air preheater 56 is arranged in a flue gas channel portion 62, so called first flue gas channel portion, and an air preheater 64 for preheating the second fluidizing air 38, or HP air, is arranged in another flue gas channel portion 62', so called second flue gas channel portion, which is connected in parallel with the first flue gas channel portion 62. Thus, the air preheater system comprises the primary air preheater 56 and the HP air preheater 64, which are connected in parallel. One or both of the parallel flue gas channel portions 62, 62' may advantageously comprise a damper 66, by which the rate of flue gas flowing through the HP air preheater 64 can be adjusted to, for example, 3 – 4 % of the total flue gas flow rate. Downstream of the primary air preheater 56 and the HP air preheater 64, the flue gas channel portions 62 and 62' are again combined to a single flue gas channel, which leads to the dust separator 58. The HP air preheater 64 is typically a tubular air preheater and dimensioned for heating, for example, 4 – 5 % of the total stream of air 68 introduced to the boiler 10.

[0028] To verify the effect of the present invention, a calculation was made, in which a 500 MWe CFB boiler plant is equipped with a rotating air preheater (primary air preheater) dimensioned for a flue gas inlet temperature, i.e., a flue gas temperature after economizer, of 338°C, and a flue gas mass flow rate of 538 kg/s. In the calculation, the average temperature of the primary and secondary air after fans was 55°C, and their mass flow rate to combustion was 445 kg/s. The temperature of the HP air after fan was 100°C, and its mass flow rate to combustion was 19 kg/s. Air leakage to flue gas in the primary air preheater was assumed to cause a 1.5 % rise of the O₂ content in dry flue gas. In practice, the primary air preheater has a maximum size that limits the flue gas end temperature and, therefore, the boiler efficiency.

[0029] In case 1, the plant did not comprise an HP air preheater. On the basis of equation 1, practical maximum air outlet temperature is 306.9 °C. This corresponds to an end temperature of diluted flue gas of 142.6 °C and a boiler efficiency of 92.70% (DIN 1942-Feb94).

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[0030] In case 2, an HP air preheater is installed. By leading a small part, 3%, of the total flue gas flow to an HP air preheater installed parallel to the primary air preheater, the average diluted flue gas end temperature was lowered to 136.6 °C without exceeding primary air preheater air side effectiveness value of 0.89. The corresponding boiler efficiency was then 93.06%, i.e., 0.36% better than in the case without an HP air preheater. On the basis of the calculation, an HP air preheater renders possible a clear increase of the boiler efficiency.

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[0031] 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 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.

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WHAT IS CLAIMED IS:

1. A circulating fluidized bed boiler (10) with an air preheater system, the circulating fluidized bed boiler comprising a furnace (12) for combusting
5 particulate solid fuel with primary air (16) injected to the furnace through a bottom grid (18) and secondary air (22) injected to the furnace through walls (26) of the furnace; a flue gas channel (28) connected to the furnace for the discharge of flue gas and particles entrained therewith from the furnace; a particle separator (30) for separating particles from the flue gas; a return duct (32) for returning
10 separated particles from the particle separator to the furnace; and a fluidized bed heat exchange chamber (36, 48) for recovering heat from particles conducted therein from the furnace, the fluidized bed heat exchange chamber comprising inlet means (34, 46, 46') for conducting particles from the furnace to the fluidized bed heat exchange chamber; outlet means (44) for conducting particles from the
15 fluidized bed heat exchange chamber back to the furnace; and means (40) for injecting second fluidizing gas to the fluidized bed heat exchange chamber, wherein the air preheater system comprises a primary air preheater (56) arranged in a first portion (62) of the flue gas channel for preheating the primary air and secondary air, **characterized** in that the air preheater system comprises also an
20 air preheater (64) for preheating the second fluidizing air arranged in a second portion (62') of the flue gas channel, which second portion of the flue gas channel is connected in parallel with the first portion of the flue gas channel.
2. The circulating fluidized bed boiler according to claim 1, **characterized** in
25 that the inlet means (34) and outlet means (44) are in flow connection to the return duct (32).

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3. The circulating fluidized bed boiler according to claim 2, **characterized** in that the fluidized bed heat exchange chamber (36) comprises additional inlet means (46) in direct flow connection with the furnace (12).

5 4. The circulating fluidized bed boiler according to claim 1, **characterized** in that the inlet means (46, 46') are in direct flow connection with the furnace.

5. The circulating fluidized bed boiler according to claim 1, **characterized** in that the first portion (62) of the flue gas channel and the second portion (62') of
10 the flue gas channel are dimensioned so that 90 – 98 % of the flue gas flows through the first portion of the flue gas channel.

6. The circulating fluidized bed boiler according to claim 1, **characterized** in that at least one of the first portion (62) of the flue gas channel and the second
15 portion (62') of the flue gas channel comprises a damper (66) to control the flue gas flow so that 90 – 98 % of the flue gas flows through the first portion of the flue gas channel.

7. The circulating fluidized bed boiler according to claim 1, **characterized** in
20 that the preheater (64) for preheating the second fluidizing air is a tubular air preheater.

8. The circulating fluidized bed boiler according to claim 1, **characterized** in that the primary air preheater (56) is a rotary air preheater.

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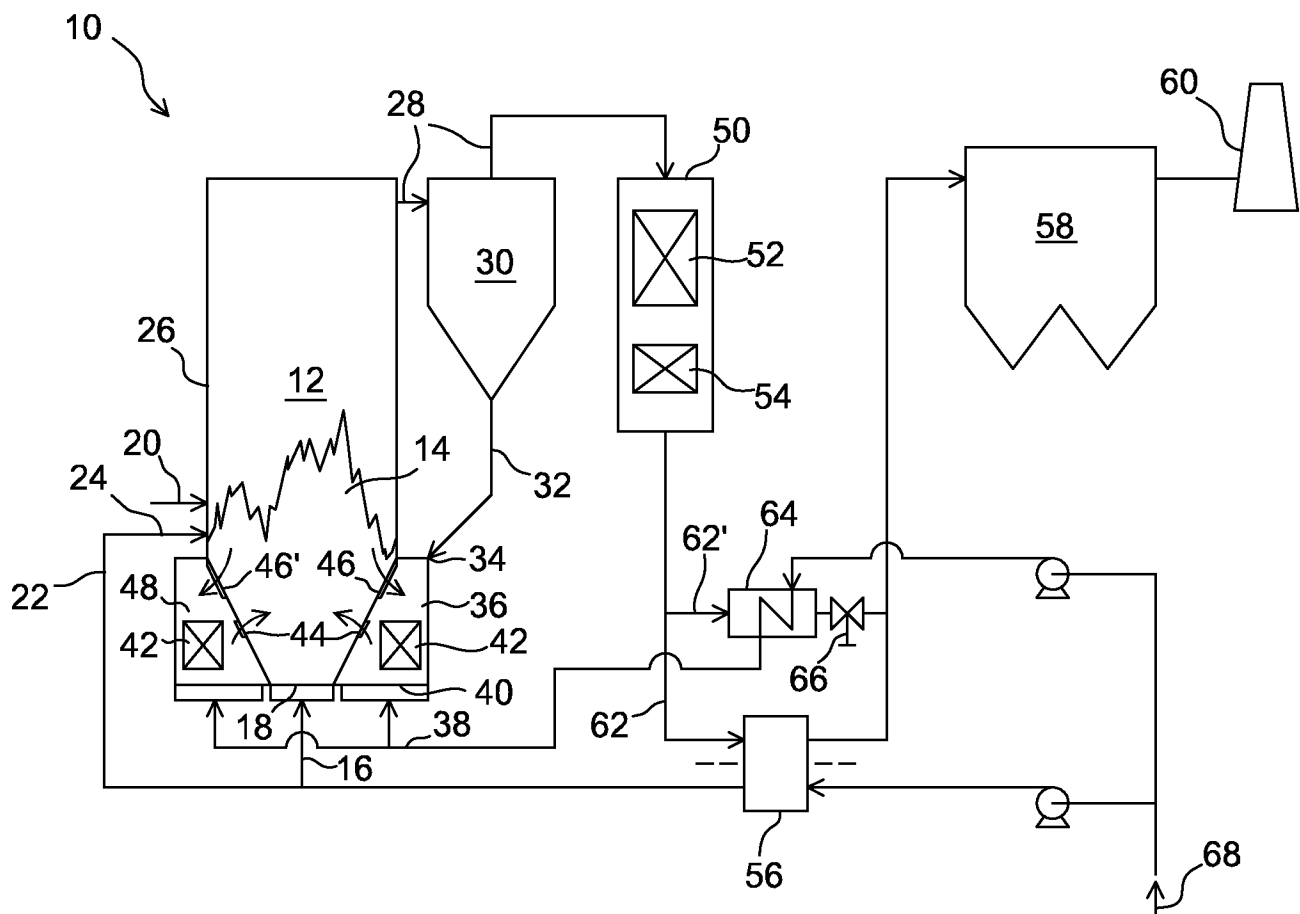


Fig. 1