



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
14.02.2007 Bulletin 2007/07

(51) Int Cl.:
F22B 21/34 (2006.01) **F22B 29/06** (2006.01)
F22B 29/02 (2006.01) **F22B 3/08** (2006.01)
F01K 7/32 (2006.01)

(21) Application number: **06270029.9**

(22) Date of filing: **03.03.2006**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR MK YU

(71) Applicant: **Mitsui Babcock Energy Limited**
Renfrew PA4 8DJ (GB)

(72) Inventor: **Upton, Mark**
Charlwood, Surrey RH6 0DR (GB)

(74) Representative: **Murnane, Graham John**
Murgitroyd & Company
165-169 Scotland Street
Glasgow G5 8PL (GB)

(30) Priority: **10.03.2005 US 660402**

(54) **Supercritical Downshot Boiler**

(57) A downshot boiler for heating water comprising: a first combustion chamber; at least one tube for transporting water, the or each tube being at least partially located at the first combustion chamber; and heating

means for heating the first combustion chamber, the heating means comprising a downshot burner, wherein the boiler is adapted to heat the water to a supercritical condition.

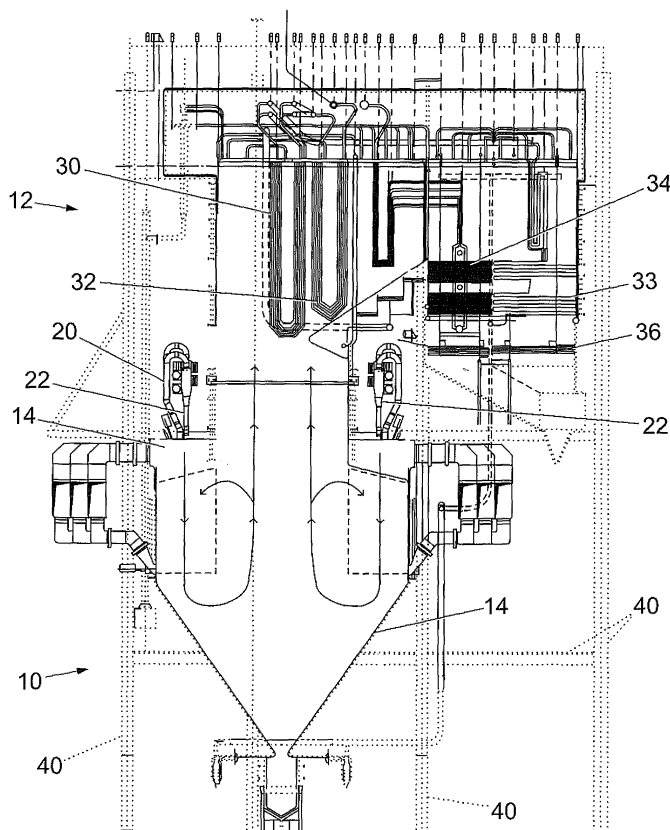


Fig. 4

Description

[0001] The present invention relates to boilers. In particular, but not exclusively, the invention relates to boilers capable of utilising low volatile fuels during supercritical conditions.

[0002] Modern power plants are designed to achieve high efficiency. Aside from the economical advantages, this also has environmental advantages, such as the reducing of fuel usage, the quantity of ash generated, and the levels of pollutants and carbon dioxide emitted.

[0003] Most of the large European thermal power plants that have been commissioned over the last decade and which use fossil fuels have utilised supercritical steam parameters to achieve higher efficiencies. These plants are typically based on pulverized coal (PC) technology. Steam temperatures and pressures have been continuously increasing during this time. However, a limit that is reached is the maximum temperature that the metals used in boiler tubes and turbine blades will allow.

[0004] It is advantageous to utilise low cost fuels in conjunction with high efficiency steam conditions. In addition, emissions will be reduced in comparison with a similar sized unit operating at sub-critical steam conditions.

[0005] There are two types of supercritical boiler design which are presently in use. The first type utilizes vertically orientated tubes and operates at tube mass fluxes of $1500 \text{ kg/m}^2\text{s}$ or greater (high mass flow). The tubes must be appropriately sized, typically between 15 and 45 mm inside diameter, and arranged either in a single pass or in multiple passes in the lower portion of the boiler furnace in which the burners are located and the heat input is high to ensure sufficient cooling.

[0006] Typically, a vertical tube arrangement does not require additional support members, other than for structural rigidity.

[0007] This arrangement of once through boiler with vertically orientated tubes operating at high tube mass fluxes ($>1500 \text{ kg/m}^2\text{s}$) is generally the less favoured design for new projects due to operating and other difficulties arising from this design.

[0008] The second type of supercritical boiler utilizes a spiral arrangement of tubes to form the lower portion of the boiler furnace in which the burners are located and the heat input is high to ensure sufficient cooling. This spiral arrangement utilizes fewer tubes to obtain the desired flow per tube by wrapping them around the boiler to create the enclosure. The arrangement also has the benefit of passing all tubes through all heat zones to maintain a substantially even fluid temperature at the outlet of this lower portion of the boiler furnace.

[0009] However, this wrapping of the tubes around the boiler increases the costs and complexity associated with fabrication and erection. Furthermore, additional vertical support bars are typically required. Also, appropriate tube diameter selection is again required since similar thermodynamic conditions prevail.

[0010] Boilers are either natural circulation, assisted circulation or once-through in type. All of these can operate at sub-critical steam conditions but only once-through boilers offer the possibility of operation at supercritical steam conditions. The most commonly used type of once-through boiler is the Benson boiler. It typically operates at power levels of up to 1,300 MWe, steam pressures of up to 350 bar, and steam temperatures of up to 600°C or more. Such boilers can provide an efficient water/steam cycle, high steam temperatures, insensitivity of steam output and steam temperature to fluctuating fuel properties, the capability for rapid load changes due to variable-pressure operation, and short start-up times.

[0011] In once-through boilers, the mass flow is normally too high to allow the flow to naturally redistribute to the tubes having a higher heat input to protect them from overheating. Furthermore, a high mass flow once-through boiler will have a forced circulation characteristic such that the flow decreases with increasing heat input. While a natural circulation boiler tube receiving more heat than the average tube naturally draws more flow, which increases cooling and protects the tube from overheating, in a once-through forced circulation boiler with high mass flow the tube receiving more heat than the average tube receives less flow. This can result in further increasing tube wall temperatures and potential tube failure.

[0012] Therefore, both the vertical tube and the spiral tube supercritical boiler require a relatively high mass flow per tube for cooling.

[0013] Boiler designs with medium mass flow have been attempted in once-through forced circulation boilers. However, these boilers typically have a poorer performance than the high mass flow designs. When the mass flow is reduced during load reduction in a tube receiving more heat than the average, the remaining flow will be less able to provide acceptable cooling.

[0014] It is advantageous to provide a design for a once-through boiler having vertical tubes and a capability to operate with a variable pressure over the load range while exhibiting natural circulation characteristics, thus protecting the tubes from overheating. It is desirable that the mass flow is low to promote natural circulation characteristic, minimize boiler pressure loss, and reduce the pump power required.

[0015] A recent development is to use vertical tubing with a lower mass flow (less than $1300 \text{ kg/m}^2\text{s}$ in the furnace tubes), the tubes being internally ribbed or rifled. Heat transfer in a rifled tube is improved, especially during evaporation, because centrifugal forces transport the water fraction of the wet steam to the tube wall. The resulting wall wetting results in a higher heat transfer from the wall to the fluid. A vertical tube arrangement using rifling allows a design with a lower mass flow which in turn changes the flow characteristics of a once-through system. Increased heat input to an individual tube leads to increased throughput for the tube concerned due to natural circulation or positive flow characteristic.

[0016] The size and geometrical arrangement of the

internal ribs or rifling of the tubing needs to be optimised to allow a sufficient reduction of mass flow to enable a once-through boiler furnace to be cooled successfully in a single vertical pass.

[0017] The majority of once-through boilers in operation today have boiler walls built with plain bore tubes for heat transfer requirements at a high mass flow. Although some once-through boilers utilise rifled tubes, they still typically operate at a high mass flow.

[0018] Particular problems exist when using low volatile fuels such as coal. The ignition of the fuel, and also low unburned carbon levels, becomes more difficult to attain as the volatile content reduces. To overcome these difficulties, it is necessary to ensure a longer residence time of the fuel in the boiler. Other requirements are a fine fuel grading, careful admission of air, and optimised boiler refractory cover.

[0019] Downshot, or 'W' flame, boiler technology is the most widely used for burning low volatile coals. These boiler types are especially suitable for use with anthracite coals, which are coals containing less than 10% volatile matter (dry, ash free). However, the geometric configuration of the downshot 'W' flame boiler does not lend itself to the adoption of once-through supercritical steam conditions for reasons of complicated manufacturing, erecting and supporting this downshot arrangement of boiler with the preferred spiral arrangement of tubing.

[0020] It is common to use bifurcations in the tubes of downshot boilers. This is to enable all tubes in the boiler to be supported and to have a flow of water for cooling.

[0021] Pressure losses in all boilers arise from two principal sources: static pressure and dynamic pressure losses. Static pressure is due to the weight of a column of steam and water and therefore depends on the density and height involved. The total static pressure drop can be obtained from integrating the heights and densities over the circuit height. The greater the heat input, the more steam will be generated, and this lower density entails a lower static pressure. However, a higher heat input requires sufficient cooling.

[0022] Dynamic pressure losses arise from friction between the fluid and the tube wall, from turbulence and by accelerating the flow. These losses are functions of the specific volume, *tube geometry* and the mass flow. The greater the heat input, the more steam will be generated and so the greater the dynamic losses.

[0023] Having the correct pressure loss in the appropriate location is fundamental to the success of a low mass flow boiler design utilising vertical tubes.

[0024] High mass flow rates lead to high dynamic losses. Circuits designed with low mass flow rates are dominated by static pressure drops. When extra heat is applied, the overall pressure drop falls. The flow in the affected tube must increase to match the overall circuit pressure drop (therefore, a positive flow characteristic). The positive flow response continues to improve as water mass flow rates reduce.

[0025] According to a first aspect of the present inven-

tion, there is provided a downshot boiler for heating water comprising:

a first combustion chamber;

at least one tube for transporting water, each tube being at least partially located at the first combustion chamber;

heating means for heating the first combustion chamber, the heating means comprising a downshot burner;

wherein the boiler is adapted to heat the water to a supercritical condition.

[0026] Preferably each tube includes a substantially linear portion. Preferably each tube includes a substantially vertical portion.

[0027] Preferably the downshot boiler includes a plurality of tubes.

[0028] Preferably the boiler includes a plurality of support members. Preferably one or more support member is provided at the front wall of the boiler. Preferably one or more support members are provided at the rear wall of the boiler.

[0029] Preferably each tube has a single inlet and a single outlet.

[0030] According to a second aspect of the present invention, there is provided a method of heating water comprising:

transporting the water within at least one tube to a first combustion chamber provided in a downshot boiler;

heating the first combustion chamber using a downshot burner such that the water within each tube is heated to a supercritical condition.

[0031] An embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 is a front view of a supercritical boiler having (a) a vertical tube and (b) a spiral tube arrangement;

Fig. 2 is a diagrammatic view of (a) a vertical tube boiler, (b) a spiral tube boiler and (c) a boiler according to the invention;

Fig. 3 is a graph of the mass flow response of a typical boiler; and

Fig. 4 is a front view of a boiler according to the present invention.

[0032] Fig. 1 (a) and (b) show a vertical tube and a spiral tube supercritical boiler respectively, and a flow diagram for these boilers is shown in Fig. 2 (a) and (b) respectively. Each of the boilers 100, 102 has a lower portion 110, or first combustion chamber, and an upper

portion 112.

[0033] Each of the boilers 100, 102 has a number of vertically orientated tubes 120 at the upper portion 112, but the spiral boiler 102 has a helical arrangement of tubes 122 in the lower portion of the boiler 102.

[0034] In both boilers 100, 102, the tubes typically have an inside diameter of around 15 to 45 mm, and a sufficiently high mass flow per tube must be used to ensure sufficient cooling.

[0035] Fig. 3 shows the tube flow response ratio plotted against the mass flow rate. The figure shows that a higher mass flow rate leads to a negative flow response.

[0036] Fig. 2(c) shows an ideal flow diagram in which the flow response allows a single pass in the lower portion 110 without the need for a complex arrangement of tubes and where there is sufficient cooling of the tubes.

[0037] Fig. 4 shows a boiler according to the present invention. Typically, the boiler is used to generate steam for a dedicated turbo-alternator set. A number of support members 40 provide structural support to the boiler.

[0038] The boiler is a downshot boiler and has a lower portion 10 defining a first combustion chamber and an upper portion 12. Heating means is provided in the form of a number of downshot burners 22 which are mounted on arches 14 of the boiler to apply heat to the lower portion 10. In a downshot boiler, combusted fuel from the burner 22 is directed to the base of the boiler. Subsequently, the profile of the boiler causes the combusted fuel to be conveyed upwards, resulting in a 'w' shaped flame. Downshot boilers are widely used for burning low volatile coals as they provide a longer residence time for the fuel in the boiler.

[0039] For smaller size units a half section of the 'W' shaped furnace may be used. This is called a 'U' fired shape.

[0040] The fuel used is coal, which is first dried and milled to form a pulverised fuel. This is conveyed through pipes 20 to the downshot burners 22 using a heated air stream. The fuel is blown into the lower portion 10 of the boiler to be combusted.

[0041] The heat released is absorbed in the boiler walls 14 which are water-cooled. The tubes are provided within the boiler wall and are substantially vertical in orientation. The internal bore of the tubes is rifled or ribbed. The heat absorbed converts the water within the tubes to steam.

[0042] The tubes are arranged such that the number of bends in the tubes are minimised. This is partly achieved using the vertical arrangement. This tube arrangement results in the correct pressure loss at the appropriate location, which is important to boilers using a low mass flow.

[0043] The internal diameter of the tubes is between 15 and 45 mm which is considerably less than for natural circulation sub critical 'W' firing downshot boilers. This reduces the load bearing capacity but assists in allowing the use of a lower mass flow rate.

[0044] It has been found that the combination of the smaller diameter tubes, a rifled or ribbed internal tube

bore, a reduced number of tube bends and the vertical arrangement of the tubes all allow the use of a low mass flow. This low mass flow promotes natural circulation, improves cooling, and reduces the risk of tube failure.

[0045] A lower mass flow tends to decrease cooling of the tube walls and so an optimum mass flow rate exists. Such optimum conditions can be derived from corresponding tube wall metal temperature calculations for a specific application.

It has been found that a boiler design according to the invention can readily provide such optimum conditions.

[0046] Other advantages of a boiler according to the invention include that the boiler pressure loss is minimized and the pump power required is reduced.

[0047] The boiler heats the water to a supercritical condition. The steam generated is superheated in the upper portion 12 of the boiler and superheater sections, shown typically as a primary superheater 33, a platen superheater 30 and a final superheater 32 before being transported to the turbine.

[0048] Following expansion of the steam in a high power turbine cylinder, the steam is returned to the boiler to be reheated using a reheater 34, before final expansion within intermediate power and low power turbine cylinders. The condensate is pumped back to the boiler for reuse.

[0049] The products of combustion are cooled using an economiser 36 which receives water being fed to the boiler. The gases are then cleaned using a number of downstream processes to remove particulates or unwanted gases such as a sulphur monoxide or nitrogen monoxide.

[0050] Various modifications and improvements can be made without departing from the scope of the present invention.

Claims

1. A downshot boiler for heating water comprising:

a first combustion chamber;
at least one tube for transporting water, the or each tube being at least partially located at the first combustion chamber; and
heating means for heating the first combustion chamber, the heating means comprising a downshot burner,

wherein the boiler is adapted to heat the water to a supercritical condition.

2. A downshot boiler as claimed in Claim 1, wherein the or each tube includes a substantially linear portion.

3. A downshot boiler as claimed in Claim 1 or 2, wherein the or each tube includes a substantially vertical por-

tion.

4. A downshot boiler as claimed in any preceding claim,
wherein the diameter of the or each tube is less than
38 mm. 5
5. A downshot boiler as claimed in any preceding claim,
wherein the diameter of the or each tube is around
25 mm. 10
6. A downshot boiler as claimed in any preceding claim,
wherein the internal bore of the or each tube is sub-
stantially rifled. 15
7. A downshot boiler as claimed in any preceding claim,
wherein the boiler includes a plurality of support
members. 20
8. A downshot boiler as claimed in any preceding claim,
wherein the or each tube has a single inlet and a
single outlet. 25
9. A method of heating water comprising:
transporting the water within at least one tube 25
to a first combustion chamber provided in a
downshot boiler; and
heating the first combustion chamber using a
downshot burner such that the water within the
or each tube is heated to a supercritical condi- 30
tion.

35

40

45

50

55

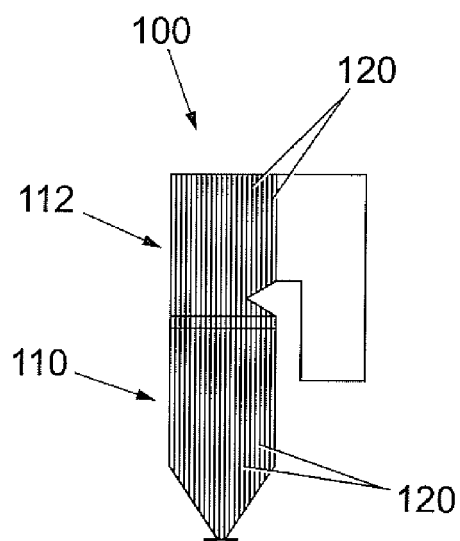


Fig. 1a

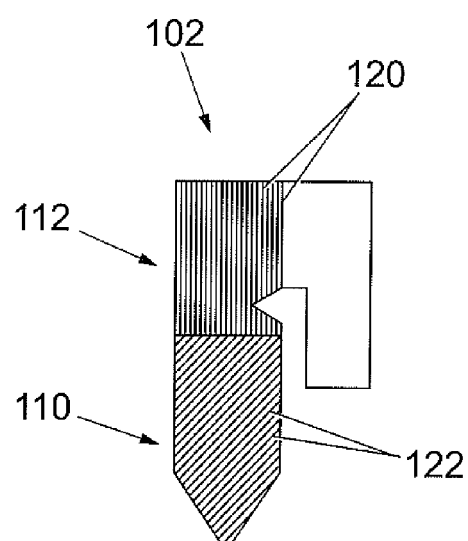


Fig. 1b

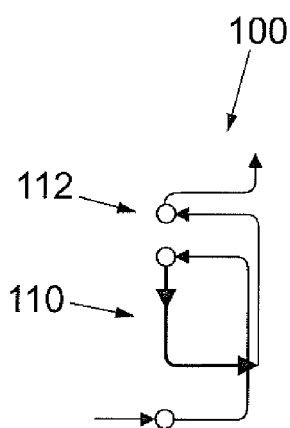


Fig. 2a

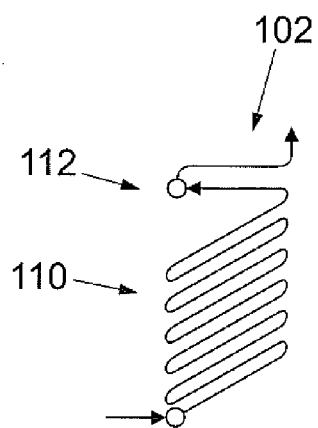


Fig. 2b

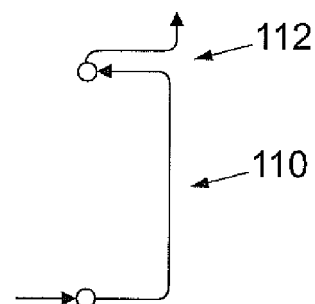


Fig. 2c

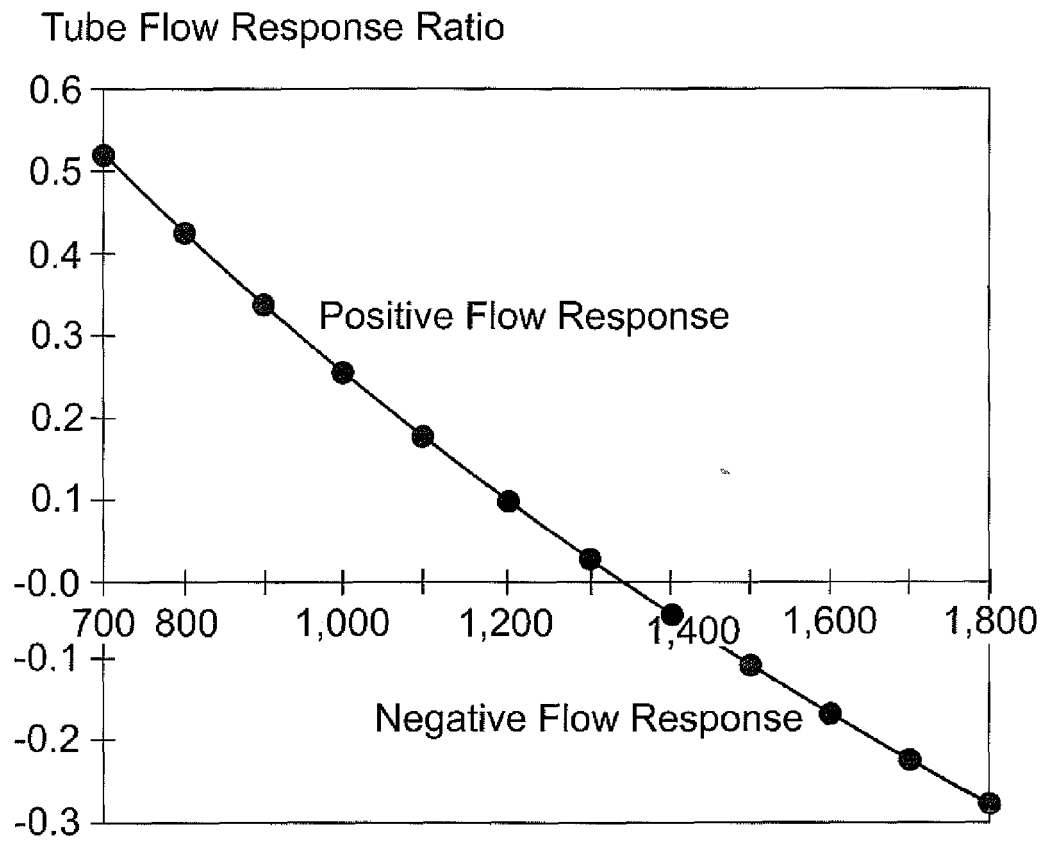


Fig. 3

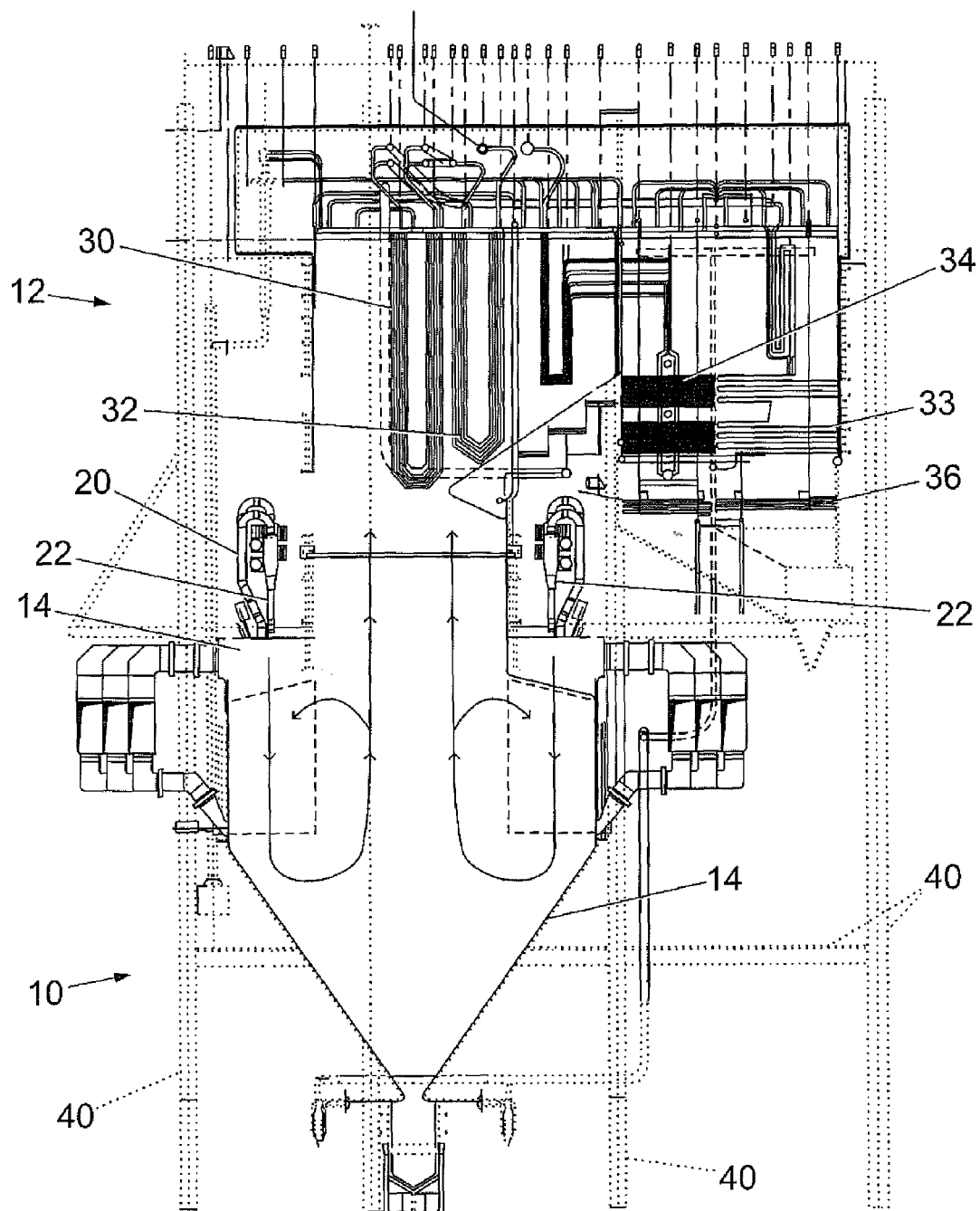


Fig. 4