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(54) **Supercritical Downshot Boiler**

Abhitzekessel zur Erzeugung von überkritischem Dampf mit nach unten gerichteten Brennern

Chaudière supercritique équipée de brûleurs dirigés vers le bas

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- **FRANKE J ET AL: "BENSON-DAMPFERZEUGER MIT SENKRECHT BEROHRTER BRENNKAMMER PRAXISNAHER GROSSVERSUCH BELEGT AUSLEGUNGSSICHERHEIT" VGB KRAFTWERKSTECHNIK, VGB KRAFTWERKSTECHNIK GMBH. ESSEN, DE, vol. 75, no. 4, 1 April 1995 (1995-04-01), pages 353-359, XP000498642 ISSN: 0372-5715**
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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 kg/m^{2}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 kg/m^{2}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 kg/m^{2}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] Franke J et al: "Benson - Dampferzeuger mit Senkrecht Beroherter Brennkammer Praxisnaher Grossversuch Belegt Auslegungssicherheit", VGB Kraftwerkstechnik, VGB Kraftwerkstechnik GmbH Essen, describes a conventional once through supercritical steam generator. The steam generator is fired by conventional horizontal wall firing.

[0026] DE1551036 is an example of another system designed for supercritical operation. DE1551036 is fired by a burner arrangement that is inclined downwards from a wall portion that serves to give a venturi effect.

[0027] The book "Boilers and Burners" by P. Basu, C Kefa and L Jestin (Springer 2000) describes a down-shot flame combustion technique on pages 257-259.

[0028] According to a first aspect of the present invention, there is provided a boiler adapted to heat water to a supercritical condition in once-through operation comprising:

a first combustion chamber;
a plurality of tubes for transporting water, each tube including a vertical portion, each tube being at least partially located at the first combustion chamber; and heating means for heating the first combustion chamber;

characterised in that:

the internal bore of each tube is rifled or ribbed such as to be adapted to operate at a mass flow of less than 1300 kg/m^{2}s, and in that
the boiler is a downshot boiler, and
the heating means comprises one or more downshot burners mounted on arches of the boiler to direct heat down into the first combustion chamber.

[0029] Each tube includes a substantially linear portion. Each tube includes a substantially vertical portion.

[0030] The downshot boiler includes a plurality of tubes.

[0031] 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.

[0032] Preferably each tube has a single inlet and a single outlet.

[0033] According to a second aspect of the present invention, there is provided a method of heating water to a supercritical condition comprising:

transporting the water within a plurality of tubes to a first combustion chamber provided in a boiler, each tube including a vertical portion, each tube at least partially located at the first combustion chamber; and
heating the first combustion chamber such that the water within each tube is heated to a supercritical condition in a once-through operation,
characterised in that

the internal bore of each tube is rifled or ribbed to operate at a mass flow of less than 1300kg/m^{2}s, and in that

the first combustion chamber is provided in a downshot boiler, and the first combustion chamber is heated using one or more downshot burners mounted on arches of the boiler to direct heat down into the first combustion chamber.

[0034] 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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.

[0039] 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.

[0040] 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.

[0041] 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.

[0042] For smaller size units a half section of the 'W' shaped furnace may be used. This is called a 'U' fired shape.

[0043] 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.

[0044] 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.

[0045] 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.

[0046] 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.

[0047] 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.

[0048] 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.

[0049] Other advantages of a boiler according to the invention include that the boiler pressure loss is minimized and the pump power required is reduced.

[0050] The boiler heats the water to a supercritical condition. The steam generated is superheated in the upper portion 12 of the boiler any superheater sections, shown typically as a primary superheater 33, a platen superheater 30 and a final superheater 32 before being transported to the turbine.

[0051] 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.

[0052] 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.

Claims

1. A boiler adapted to heat water to a supercritical condition in once through operation comprising:

   a first combustion chamber (10);
   a plurality of tubes (110) for transporting water, each tube including a vertical portion, each tube at least partially located at the first combustion chamber (10); and
   heating means (20, 22) for heating the first combustion chamber;
   characterised in that:

   the internal bore of each tube is rifled or ribbed such as to be adapted to operate at a mass flow of less than 1300kg/m^{2}s, and **in that**
   the boiler is a downshot boiler, and
   the heating means comprises one or more downshot burners (22) mounted on arches of the boiler to direct heat down into the first combustion chamber (10).

2. A boiler as claimed in claim 1, wherein the diameter of each tube (110) is less than 38 mm.

3. A boiler as claimed in claim 2, wherein the diameter of each tube (110) is around 25 mm.

4. A boiler as claimed in any preceding claim, wherein the boiler includes a plurality of support members (40).

5. A boiler as claimed in any preceding claim, wherein each tube (110) has a single inlet and a single outlet.

6. A method of heating water to a supercritical condition comprising:

   transporting the water within a plurality of tubes to a first combustion chamber (10) provided in a boiler, each tube including a vertical portion, each tube at least partially located at the first combustion chamber; and
   heating the first combustion chamber (10) such that the water within each tube (110) is heated to a supercritical condition in a once-through operation;
   characterised in that
   the internal bore of each tube is rifled or ribbed to operate at a mass flow of less than 1300kg/m^{2}s, and **in that**
   the first combustion chamber (10) is provided in a downshot boiler, and the first combustion chamber (10) is heated using one or more downshot burners (22) mounted on arches of the boiler to direct heat down into the first combustion chamber (10).

Patentansprüche

1. Ein Kessel, der angepasst ist, um Wasser in einem Durchlaufsbetrieb auf einen überkritischen Zustand zu erhitzen, der Folgendes beinhaltet:

   eine erste Brennkammer (10);
   eine Vielzahl von Rohren (110) zum Transportieren von Wasser, wobei jedes Rohr einen vertikalen Abschnitt umfasst, wobei jedes Rohr mindestens teilweise bei der ersten Brennkammer (10) befindlich ist; und
   Heizmittel (20, 22) zum Erhitzen der ersten Brennkammer;
   dadurch gekennzeichnet, dass:

   die Innenbohrung jedes Rohrs geriffelt oder gerippt ist, so dass sie angepasst ist, um mit einem Massenstrom von weniger als 1300 kg/m^{2}s zu arbeiten, und **dadurch, dass**
   der Kessel ein Deckenfeuerkessel ist und
   das Heizmittel ein oder mehrere Deckenbrenner (22) beinhaltet, die an Gewölben des Kessels montiert sind, um Wärme nach unten in die erste Brennkammer (10) zu lenken.

2. Kessel gemäß Anspruch 1, wobei der Durchmesser jedes Rohrs (110) kleiner als 38 mm ist.

3. Kessel gemäß Anspruch 2, wobei der Durchmesser jedes Rohrs (110) etwa 25 mm beträgt.

4. Kessel gemäß einem der vorhergehenden Ansprüche, wobei der Kessel eine Vielzahl von Stützelementen (40) umfasst.

5. Kessel gemäß einem der vorhergehenden Ansprüche, wobei jedes Rohr (110) einen einzelnen Einlass und einen einzelnen Auslass aufweist.

6. Ein Verfahren zum Erhitzen von Wasser auf einen überkritischen Zustand, das Folgendes beinhaltet:

   Transportieren des Wassers innerhalb einer Vielzahl von Rohren zu einer ersten Brennkammer (10), die in einem Kessel bereitgestellt ist,

wobei jedes Rohr einen vertikalen Abschnitt umfasst, wobei jedes Rohr mindestens teilweise bei der ersten Brennkammer befindlich ist; und Erhitzen der ersten Brennkammer (10), so dass das Wasser innerhalb jedes Rohrs (110) in einem Durchlaufsbetrieb auf einen überkritischen Zustand erhitzt wird; **dadurch gekennzeichnet, dass**
die Innenbohrung jedes Rohrs geriffelt oder gerippt ist, um mit einem Massenstrom von weniger als 1300 kg/m^{2}s zu arbeiten, und **dadurch, dass** die erste Brennkammer (10) in einem Dekkenfeuerkessel bereitgestellt ist und die erste Brennkammer (10) unter Verwendung eines oder mehrerer Deckenbrenner (22), die an Gewölben des Kessels montiert sind, um Wärme nach unten in die erste Brennkammer (10) zu lenken, erhitzt wird.

Revendications

1. Une chaudière adaptée pour chauffer de l'eau jusqu'à un état supercritique dans un fonctionnement à passage unique comprenant :

une première chambre de combustion (10) ;
une pluralité de tubes (110) destinés à transporter de l'eau, chaque tube incluant une portion verticale, chaque tube étant au moins en partie situé au niveau de la première chambre de combustion (10) ; et
un moyen de chauffage (20, 22) destiné à chauffer la première chambre de combustion ;
caractérisée en ce que :

l'alésage interne de chaque tube est rayé ou nervuré de telle sorte qu'il soit adapté pour fonctionner à un débit massique inférieur à 1 300 kg / m^{2}s, et **en ce que** la chaudière est une chaudière à inversion de flamme, et
le moyen de chauffage comprend un ou plusieurs brûleurs à inversion de flamme (22) montés sur des voûtes de la chaudière pour diriger la chaleur vers le bas dans la première chambre de combustion (10).

2. Une chaudière telle que revendiquée dans la revendication 1, où le diamètre de chaque tube (110) est inférieur à 38 mm.

3. Une chaudière telle que revendiquée dans la revendication 2, où le diamètre de chaque tube (110) est d'environ 25 mm.

4. Une chaudière telle que revendiquée dans n'importe quelle revendication précédente, où la chaudière inclut une pluralité d'éléments de support (40).

5. Une chaudière telle que revendiquée dans n'importe quelle revendication précédente, où chaque tube (110) présente une entrée unique et une sortie unique.

6. Une méthode pour chauffer de l'eau jusqu'à un état supercritique comprenant :

transporter l'eau au sein d'une pluralité de tubes vers une première chambre de combustion (10) fournie dans une chaudière, chaque tube incluant une portion verticale, chaque tube étant au moins en partie situé au niveau de la première chambre de combustion ; et
chauffer la première chambre de combustion (10) de telle sorte que l'eau au sein de chaque tube (110) soit chauffée jusqu'à un état supercritique selon un fonctionnement à passage unique ;
caractérisée en ce que
l'alésage interne de chaque tube est rayé ou nervuré pour fonctionner à un débit massique inférieur à 1 300 kg / m^{2}s, et **en ce que**
la première chambre de combustion (10) est fournie dans une chaudière à inversion de flamme, et la première chambre de combustion (10) est chauffée à l'aide d'un ou
plusieurs brûleurs à inversion de flamme (22) montés sur des voûtes de la chaudière afin de diriger la chaleur vers le bas dans la première chambre de combustion (10).

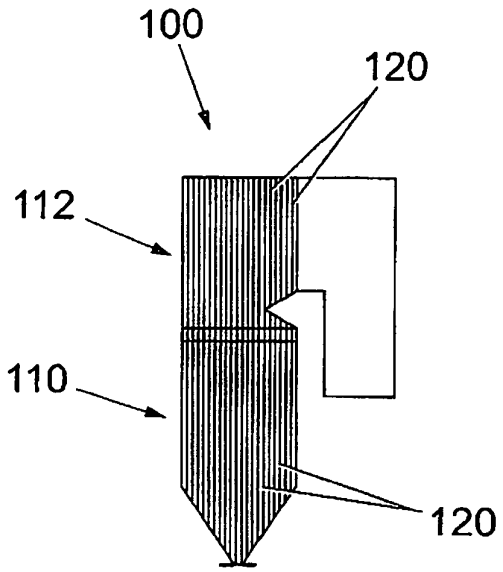


Fig. 1a

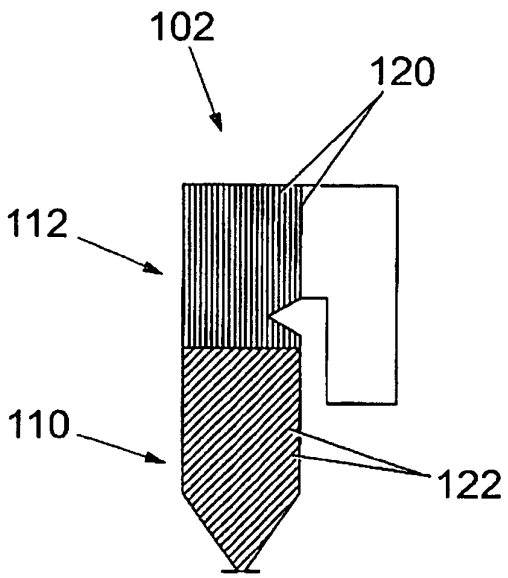


Fig. 1b

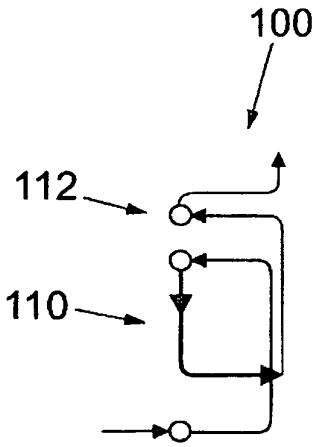


Fig. 2a

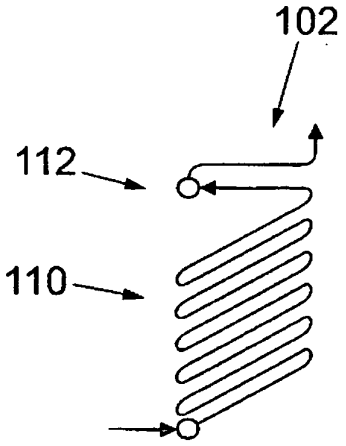


Fig. 2b

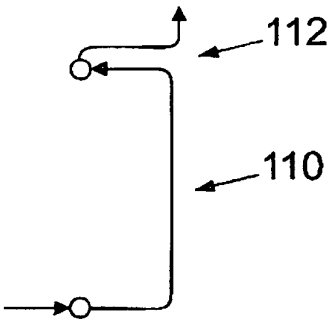


Fig. 2c

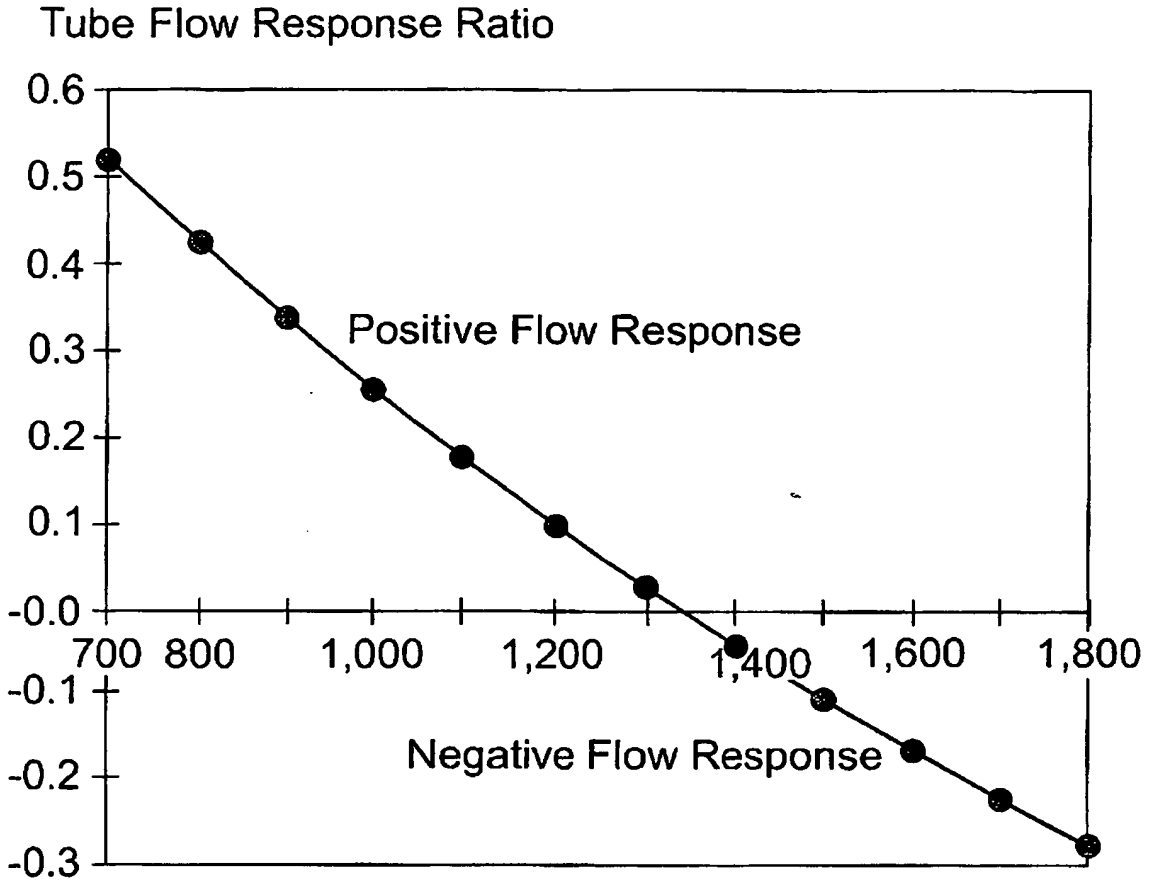

Tube Flow Response Ratio
0.6
0.5
0.4
0.3
0.2
0.1
-0.0
-0.1
-0.2
-0.3
700
800
1,000
1,200
1,400
1,600
1,800
Positive Flow Response
Negative Flow Response

Fig. 3

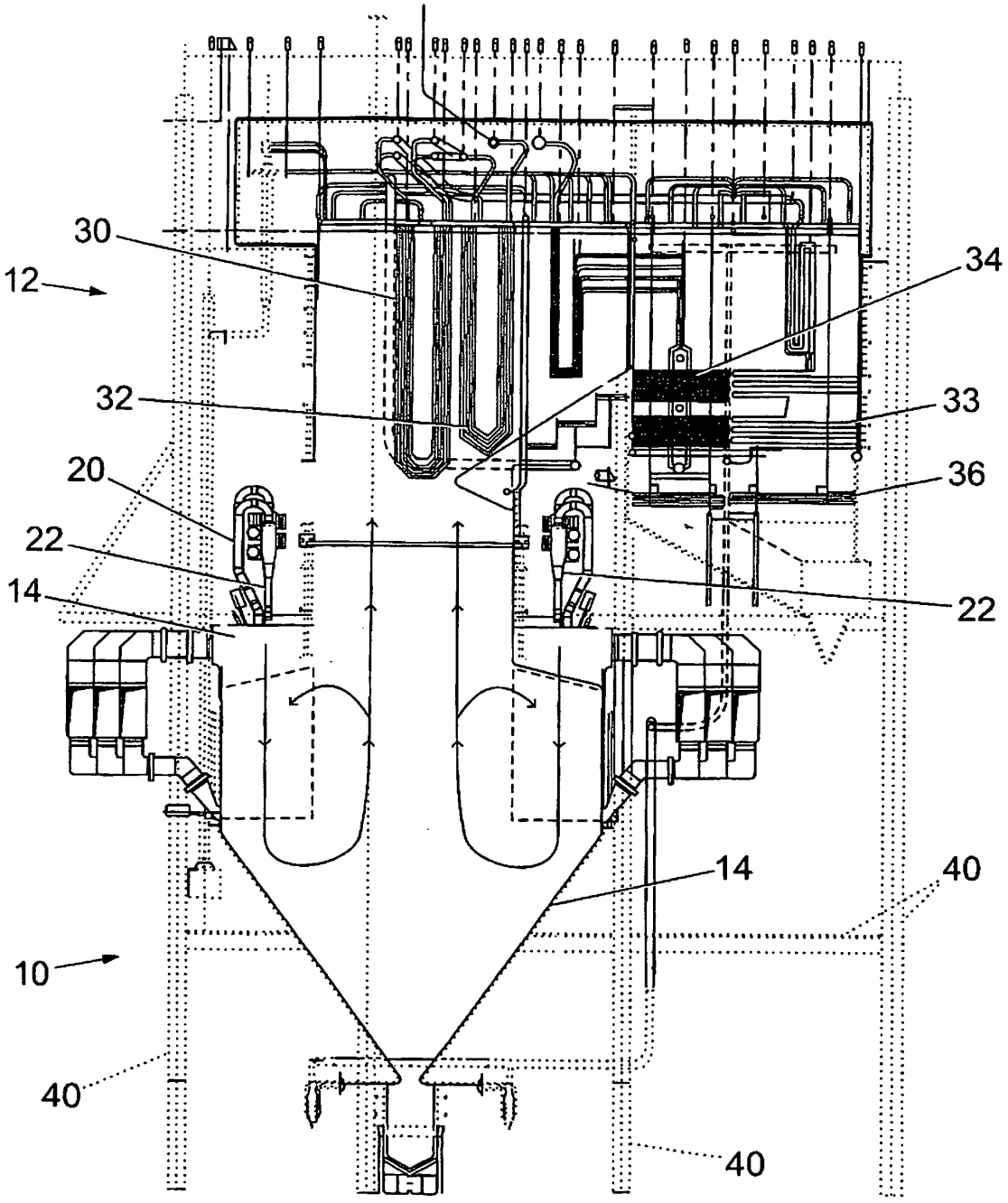


Fig. 4

REFERENCES CITED IN THE DESCRIPTION

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