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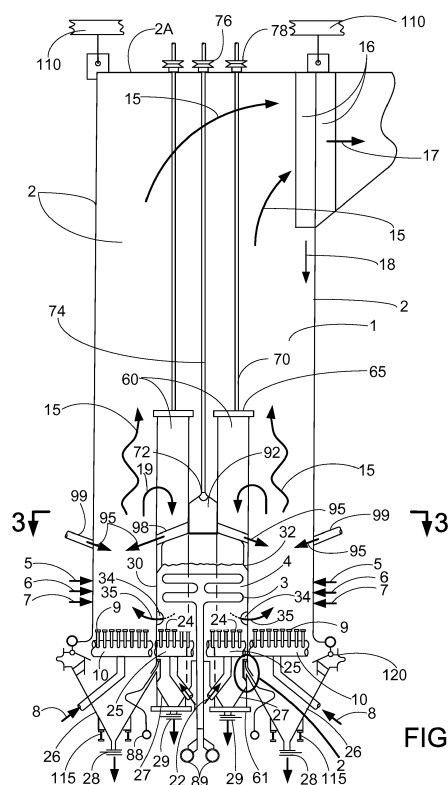
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(54) **CIRCULATING FLUIDIZED BED BOILER WITH BOTTOM-SUPPORTED IN-BED HEAT EXCHANGER**

(57) A circulating fluidized bed (CFB) boiler has one or more bubbling fluidized bed enclosures containing heating surfaces and located within a lower portion of the CFB boiler to provide an in-bed heat exchanger (IBHX). Solids in the bubbling fluidized bed are maintained in a slow bubbling fluidized bed state by separately controlled fluidization gas supplies. The beds feature open bottom distribution grids with hoppers disposed below to collect solids. The enclosure defining the IBHX is supported from structures below the grids and the enclosure can be supported from the hoppers.



**FIG. 1**

## Description

### RELATED APPLICATION DATA

[0001] This patent application claims priority to United States Provisional Patent Application No. 62/349,627 filed June 13, 2016 and titled "CIRCULATING FLUIDIZED BED BOILER WITH BOTTOM-SUPPORTED IN-BED HEAT EXCHANGER." The complete text of this patent application is hereby incorporated by reference as though fully set forth herein in its entirety.

### FIELD AND BACKGROUND OF THE INVENTION

#### 1. Technical Field

[0002] The present disclosure generally relates to the field of circulating fluidized bed (CFB) reactors or boilers such as those used in electric power generation facilities and, in particular, to a new and useful CFB reactor arrangement which permits temperature control within the CFB reaction chamber and/or of the effluent solids with an in-bed heat exchanger (IBHX). The CFB reactor arrangement provides a bottom-supported IBHX wherein the enclosure that defines the IBHX is supported from the dormant solids hoppers for the CFB and bubbling fluidized bed (BFB) of the IBHX.

#### 2. Background Information

[0003] Circulating fluidized bed (CFB) reactors or boilers are used in the production of steam for industrial processes and electric power generation; see, for example, U.S. Pat. Nos. 5,799,593, 4,992,085, 4,891,052, 5,343,830, 5,378,253, 5,435,820, and 5,809,940. For an overview of the design and operation of CFB boilers, see Steam/its generation and use, 42nd Edition, edited by G.L. Tomei, Copyright 2015, The Babcock & Wilcox Company, ISBN 978-0-9634570-2-8, the text of which is hereby incorporated by reference as though fully set forth herein.

[0004] In a CFB boiler, upward gas flow carries reacting and non-reacting solids to an outlet at the upper portion of the furnace where the solids are separated from the gas, often by a staggered array of impact-type particle separators. The solids are used within the combustion process to transfer heat from the chemical process to the boiler water-cooled enclosure walls and other heating surfaces. The solids thus help control the overall furnace temperature that results in reducing NO<sub>x</sub> and SO<sub>2</sub>. The bulk of the solids reaching the top of the furnace are collected and returned to the furnace bottom.

[0005] U.S. Patent 6,532,905 discloses a controllable solids heat exchanger called an in-bed heat exchanger (IBHX). The heat exchanger is immersed within a bubbling fluidized bed (BFB). Heat transfer in the heat exchanger is controlled by controlling the rate of solids discharge from the lower part of the BFB into the furnace.

The discharge control is accomplished using at least one non-mechanical valve being operated by controlling flow rate of fluidizing gas in the vicinity of the non-mechanical valve. Reducing or completely shutting off fluidizing gas flow to the controlling fluidizing device (typically, a plurality of bubble caps are used to distribute the fluidizing gas) hampers local fluidization and, correspondingly, slows down solids movement through the non-mechanical valve thus allowing the control of the solids discharge from the BFB to the CFB. U.S. Patent 8,434,430 discloses an example of a controllable non-mechanical valve for an IBHX in FIG. 3 of the patent.

[0006] An undesired drawback of reducing the flow rate of the fluidizing gas in the vicinity of the non-mechanical valve is bed material agglomeration. The decrease of the local fluidizing velocity and corresponding reduction of the bed mixing (while combustion takes place) can result in a local bed temperature rise sufficient for bed material agglomeration. Solids agglomeration may also happen elsewhere in the bed of the IBHX because generally lower fluidizing velocity in the BFB (compared to CFB) results in less vigorous mixing and thus higher potential for temperature and chemical nonuniformity leading to forming agglomerates. To be discharged from the IBHX through a dedicated drain opening, the agglomerates have to be moved towards this opening by the solids discharge flow. If the flow is not sufficient to move the agglomerates, they will eventually accumulate in the IBHX rendering its inoperable.

[0007] Using an open bottom design (see Steam: Its Generation and Use, 41 st ed., page 17-3 (2005; The Babcock & Wilcox Company, Barberton, Ohio) allows draining agglomerates from any location of the IBHX thus greatly improving its operation reliability. Using an open bottom design with an IBHX, however, is associated with a substantial weight of bed material in the hopper(s) below the IBHX and corresponding load increase on the boiler support steel.

### SUMMARY OF THE INVENTION

[0008] The present disclosure improves reliability of the CFB boiler with IBHX while reducing its cost and widening the range of design options.

[0009] The disclosure provides a configuration wherein the enclosure of the IBHX is supported from the dormant solids hoppers for CFB and IBHX located under the distribution grids.

[0010] The disclosure provides a support configuration wherein the membranes between the tubes of the enclosure walls are removed to define loose tubes that extend through the hopper walls to accommodate thermal expansion.

[0011] The disclosure provides a support configuration wherein a skirt is disposed inside the IBHX hopper to prevent gas leakage from the IBHX hopper to the CFB hopper around the enclosure supports.

[0012] The disclosure provides a support configuration

wherein a secondary gas conduit is supported by the CFB hopper with a secondary gas duct carried by the IBHX enclosure with nozzles to provide secondary gas to the CFB.

**[0013]** One embodiment discloses a circulating fluidized bed (CFB) boiler comprising: a CFB reaction chamber having side walls and an open-bottom grid defining a floor at a lower end of the CFB reaction chamber for providing fluidizing gas into the CFB reaction chamber; at least one bubbling fluidized bed (BFB) located within a lower portion of the CFB reaction chamber and being bound by enclosure walls and the floor of the CFB reaction chamber, with the fluidizing gas feed to the BFB portion of the grid controlled separately from the fluidizing gas feed to the CFB portion of the grid; at least one controllable in-bed heat exchanger (IBHX), the IBHX occupying part of the CFB reaction chamber floor and being surrounded by the enclosure walls of the BFB; bottom-supported hoppers containing dormant solids disposed under the CFB and the BFB; the enclosure walls of the BFB being supported off the bottom-supported hoppers; the enclosure walls of the BFB are of cooled membrane gas-tight design around the perimeter of the BFB, including: at least one top opening for CFB solids influx into the BFB; at least one overflow port for setting the BFB height; at least one underflow port for BFB solids controlled recycle back into the CFB; the gas-tight BFB enclosure extending below the grid to the elevation sufficient for not exceeding a preset percentage of leakage of the fluidizing gas from the BFB into the CFB through the bed of the dormant solids between the aforementioned elevation and the grid; and the tubes of the BFB enclosure below that elevation becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hoppers as the tubes penetrate the walls of the hoppers.

**[0014]** Another embodiment discloses a circulating fluidized bed (CFB) boiler comprising: a CFB reaction chamber having walls and an open-bottom grid defining a floor at a lower end of the CFB reaction chamber for providing fluidizing gas into the CFB reaction chamber; at least one bubbling fluidized bed (BFB) located within a lower portion of the CFB reaction chamber and being bound by enclosure walls and the floor of the CFB reaction chamber, with the fluidizing gas feed to the BFB portion of the grid controlled separately from the fluidizing gas feed to the CFB portion of the grid; at least one controllable in-bed heat exchanger (IBHX), the IBHX occupying part of the CFB reaction chamber floor and being surrounded by the enclosure walls of the BFB; hoppers containing dormant solids disposed under the CFB and the BFB; and the enclosure walls of the BFB being supported off the bottom-supported hoppers.

**[0015]** Yet another embodiment discloses a circulating fluidized bed (CFB) boiler comprising: a CFB reaction chamber having walls and an open-bottom grid defining a floor at a lower end of the CFB reaction chamber for providing fluidizing gas into the CFB reaction chamber;

at least one bubbling fluidized bed (BFB) located within a lower portion of the CFB reaction chamber and being bound by enclosure walls and the floor of the CFB reaction chamber, with the fluidizing gas feed to the BFB portion of the grid controlled separately from the fluidizing gas feed to the CFB portion of the grid; the enclosure walls of the BFB are of cooled membrane gas-tight design; at least one controllable in-bed heat exchanger (IBHX), the IBHX occupying part of the CFB reaction chamber floor and being surrounded by the enclosure walls of the BFB; hoppers containing dormant solids disposed under the CFB and the BFB; and the enclosure walls of the BFB being connected to at least one of the bottom-supported hoppers with supports and becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hopper as the tubes penetrate the hopper wall.

**[0016]** The preceding non-limiting aspects, as well as others, are more particularly described below. A more complete understanding of the processes and equipment can be obtained by reference to the accompanying drawings, which are not intended to indicate relative size and dimensions of the assemblies or components thereof. In those drawings and the description below, like numeric designations refer to components of like function. Specific terms used in that description are intended to refer only to the particular structure of the embodiments selected for illustration in the drawings, and are not intended to define or limit the scope of the disclosure.

## BRIEF DESCRIPTION OF THE DRAWINGS

### **[0017]**

FIG. 1 is a sectional side elevation view of a CFB boiler depicting a first exemplary configuration of the disclosure, illustrating a bubbling fluidized bed (BFB) enclosure within the CFB boiler.

FIG. 2 is an enlarged view of a portion of the BFB enclosure disposed below the distribution grid of the CFB.

FIG. 2A is a view taken along line 2A-2A of FIG. 2.

FIG. 3 is a plan view looking down along line 3-3 of FIG. 1.

FIG. 4 is a section view taken along line 4-4 of FIG. 3.

## DETAILED DESCRIPTION OF THE DISCLOSURE

**[0018]** As shown in Figures 1 - 4, a circulating fluidized bed (CFB) furnace 1 includes walls 2 (including roof 2a) and an in-bed heat exchanger (IBHX) 3 immersed in bubbling fluidized bed (BFB) 4. The circulating fluidized bed of furnace 1 predominantly includes solids made up of the ash of fuel 5, sulfated sorbent 6 and, in some cases, external inert material 7 fed through at least one of walls 2 and fluidized by fluidizing gas (typically, primary air) 8 supplied through a distribution grid 9 fed from pipes 10. Dormant solids below grid 9 effectively define a part of

the furnace floor. Some solids are entrained by gases resulting from the fuel combustion and move upward (arrows 15) eventually reaching a particle separator 16 at the furnace exit. While some of the solids (arrow 17) pass separator 16, the bulk of them (arrow 18) are captured and recycled back to the furnace. Those solids along with others (arrow 19), falling out of upflow solids stream 15, feed BFB 4 that is being fluidized by fluidizing gas (typically, air) 22 supplied through a BFB distribution grid 24 fed from pipes 25. Dormant solids below grid 24 effectively define another part of the furnace floor. The dormant solids under CFB and BFB are contained in hoppers (26 and 27, correspondingly) equipped with outlets for draining solids from CFB and BFB (28 and 29, correspondingly). Pipes 10 and 25 are supported off hoppers 26 and 27, correspondingly (supports are not shown).

**[0019]** BFB 4 is separated from the CFB by an enclosure 30 made of gas-tight cooled membrane panels. Enclosure 30 surrounds the perimeter of BFB 4 but is essentially open from the top allowing solids influx from CFB into BFB (arrow 19). Enclosure 30 includes overflow ports (that can be formed as vertical slots connected to top opening 31; see Figure 3) 32, which lowest elevation essentially defines the height of BFB 4. Enclosure 30 also includes underflow ports 34. Controlling rate of solids recycle 35 through underflow ports 34 allows controlling the heat duty of IBHX 3. The rate of solids recycle 35 is controlled by separately controlling (not shown) feed rate of fluidizing medium 22 to BFB plan areas adjacent to underflow ports 34.

**[0020]** The pressure within enclosure 30 equals the pressure outside of it at the elevation of the top of BFB 4. Due to higher bulk density of BFB compared to CFB, the pressure below that elevation is higher on the BFB side, i.e. within enclosure 30. The highest pressure differential is at the elevation of the distribution grids (9 and 24, located essentially at the same elevation). Cooled membrane panels 60 are used as stiffeners of enclosure walls 30 providing the rigidity necessary to withstand the pressure differential. The height of panels 60 depends on the amount of heat transfer surface required for the furnace heat duty. They can extend all the way through the furnace roof 2A or be cut shorter and topped with headers 65, from which pipes 70 continue up to roof 2A. The lower ends of panels 60 penetrate through hoppers 27 and terminate with headers 61.

**[0021]** Enclosure 30 is topped with a header 72 that is connected with the outside of the furnace through pipes 74. If temperature of the cooling medium in enclosure 30 and/or panels 60 differs from that of walls 2, corresponding penetrations through roof 2A are equipped with expansion joints 76 and 78. The lower part of enclosure 30 extends below grid 24. The weight of enclosure 30 is supported off hoppers 26 and 27. An exemplary configuration of a supports 79 and 80 for supporting enclosure 30 is depicted in FIGS. 2 and 2A. Support 79 is welded to the walls of the hoppers 26 and 27 while support 80 is welded to membranes 81. Horizontal pads 82 and 83

are welded to supports 79 and 80, respectively. The pads 82 and 83 can slide against each other that allows for independent thermal expansion of enclosure 30 and hoppers 26 and 27. FIGS. 2 and 2A depict one exemplary configuration but other support arrangements can be used to support enclosure 30 from one or both of hoppers 26 and 27. Below the support elevation, the membranes 81 in the panels forming enclosure 30 terminate, and the resulting configuration of loose tubes 84 provides flexibility to accommodate differences in thermal expansion of tubes 84 and hoppers 26 and 27 as tubes 84 penetrate the walls of hopper 26. Skirt 86 is attached to the inside of enclosure 30 above support 80 and extends into hopper 27. Positive pressure in hopper 27 (compared to hopper 26) pushes skirt 86 against the wall of hopper 27 creating a seal (along with the resistance of the layer of dormant solids below grid 24) that essentially eliminates fluidizing gas leakage between hoppers 26 and 27. Loose tubes 84 are connected to headers 88 outside hoppers 26 and 27.

**[0022]** IBHX 3 can be supported off platework between hoppers 27 or off enclosure 30 or some combination thereof. IBHX 3 terminates at headers 89.

**[0023]** Enclosure 30 also includes a duct 92 for supplying part of secondary gas (typically, secondary air) 95 through nozzles 98 into the CFB. Nozzles 98 can be formed of enclosure 30 tubes. Another part of secondary gas 95 is supplied through nozzles 99 on walls 2. The combination of nozzles 98 and 99 allows effective coverage of furnace 1 plan area by secondary gas 95. One type of nozzle that can be used is disclosed in U.S. Pat. No. 8,622,029, the text of which is hereby incorporated by reference as though fully set forth herein. At certain conditions, e.g. for smaller furnace sizes, it is possible to provide an acceptable secondary gas coverage by using only nozzles 99 on walls 2. In such a configuration, duct 92 is not required and can be removed.

**[0024]** Duct 92 is supplied with secondary gas 95 through a conduit 102 made of membrane panels 104. As shown in Figure 4, part of the panel 104 between duct 92 and conduit 102 turns into screen 105 to allow a passage for the secondary gas from conduit 102 into duct 92. Panels 104 at the upper end can terminate at header 72 and/or dedicated headers (not shown). Their lower ends extend downward to essentially the same elevation as where gas-tight BFB enclosure 30 turns into a loose-tube type design. At that elevation conduit 102 made of panels 104 is connected gas-tightly to plate-type conduit 106 that continues to the wall of hopper 26 and penetrates the wall. Conduit 106 is equipped with expansion joints 107 on its both ends for accommodating its thermal expansion versus conduit 102 and hopper 26. Upon the connection with conduit 106, membrane panels 104 turn into loose tubes 108, which configuration allows accommodation of the difference in thermal expansion between tubes 108 and hopper 26 as the tubes penetrate the hopper wall and terminate at header 109.

**[0025]** Furnace walls 2 are supported off top steel 110

and expand downwards. Hoppers 26 and 27 have bottom supports 115 and expand upwards. A pressure seal allowing both expansions is provided by expansion joint 120 around the perimeter of furnace 1. At certain conditions, e.g. lower furnace height due to high fuel reactivity and/or relaxed combustion efficiency requirements and/or relaxed emissions requirements, etc., the entire boiler can be bottom-supported. This would eliminate the need in expansion joint 120.

**[0026]** The foregoing description has been made with reference to exemplary embodiments. Modifications and alterations of those embodiments will be apparent to one who reads and understands this general description. The present disclosure should be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or equivalents thereof.

**[0027]** The relevant portion(s) of any specifically referenced patent and/or published patent application is/are incorporated herein by reference.

**[0028]** Various further aspects and features are defined in the following numbered clauses:

1. A circulating fluidized bed (CFB) boiler comprising:

a CFB reaction chamber having side walls and an open-bottom grid defining a floor at a lower end of the CFB reaction chamber for providing fluidizing gas into the CFB reaction chamber; at least one bubbling fluidized bed (BFB) located within a lower portion of the CFB reaction chamber and being bound by enclosure walls and the floor of the CFB reaction chamber, with the fluidizing gas feed to the BFB portion of the grid controlled separately from the fluidizing gas feed to the CFB portion of the grid; at least one controllable in-bed heat exchanger (IBHX), the IBHX occupying part of the CFB reaction chamber floor and being surrounded by the enclosure walls of the BFB; bottom-supported hoppers containing dormant solids disposed under the CFB and the BFB; the enclosure walls of the BFB being supported off the bottom-supported hoppers; the enclosure walls of the BFB are of cooled membrane gas-tight design around the perimeter of the BFB, including:

at least one top opening for CFB solids influx into the BFB;

at least one overflow port for setting the BFB height;

at least one underflow port for BFB solids controlled recycle back into the CFB;

the gas-tight BFB enclosure extending below the grid to the elevation sufficient for not exceeding a preset percentage of leakage of the fluidizing gas from the BFB into the

CFB through the bed of the dormant solids between the aforementioned elevation and the grid; and

the tubes of the BFB enclosure below that elevation becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hoppers as the tubes penetrate the walls of the hoppers.

2. The CFB boiler according to clause 1, wherein the walls of the CFB reaction chamber are top supported and an expansion joint is installed around the perimeter of the reaction chamber between its walls and the hoppers for providing a pressure seal while allowing the downward expansion of the walls and the upward expansion of the hoppers.

3. The CFB boiler according to clause 1, wherein the BFB enclosure includes a secondary gas duct.

4. The CFB boiler according to clause 3, wherein the secondary gas duct is made of tubes of the BFB enclosure.

5. The CFB boiler according to clause 3, wherein the secondary gas duct is supplied with the secondary gas through at least one conduit made of membrane panels extending downward to essentially the same elevation as where the gas-tight BFB enclosure terminates and turns into a loose-tube design.

6. The CFB boiler according to clause 5, wherein the at least one secondary gas conduit upon termination of the membrane-panel design:

continues as a plate-type design gas-tightly connected to the membrane-panel part of the conduit, the connection design allowing an independent thermal expansion of either part, the plate-type part further penetrating through the hopper wall, the penetration design accommodating independent thermal expansions of the conduit and the hopper, and the tubes forming the membrane-type part becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hopper as the tubes penetrate the hopper wall.

7. The CFB boiler according to clause 1, wherein the walls of the CFB reaction chamber are bottom supported.

8. A circulating fluidized bed (CFB) boiler comprising:

a CFB reaction chamber having walls and an open-bottom grid defining a floor at a lower end

of the CFB reaction chamber for providing fluidizing gas into the CFB reaction chamber;  
 at least one bubbling fluidized bed (BFB) located within a lower portion of the CFB reaction chamber and being bound by enclosure walls and the floor of the CFB reaction chamber, with the fluidizing gas feed to the BFB portion of the grid controlled separately from the fluidizing gas feed to the CFB portion of the grid;  
 at least one controllable in-bed heat exchanger (IBHX), the IBHX occupying part of the CFB reaction chamber floor and being surrounded by the enclosure walls of the BFB;  
 hoppers containing dormant solids disposed under the CFB and the BFB; and  
 the enclosure walls of the BFB being supported off the bottom-supported hoppers.

9. The CFB boiler of clause 8, wherein the hoppers include an inner hopper for the BFB and an outer hopper for the CFB; a skirt connected to a portion of the enclosure walls and extending into the inner hopper to form a seal.

10. The CFB boiler of clause 8, further comprising thermal expansion accommodating support plates supporting the enclosure walls from the bottom-supported hoppers.

11. The CFB boiler of clause 10, wherein the enclosure walls include membranes; the support plates being connected to the membranes.

12. The CFB boiler of clause 11, wherein the membranes terminate below the connection of the support plates and the membranes.

13. The CFB boiler of clause 8, wherein the walls of the CFB reaction chamber are top supported and an expansion joint is disposed around the perimeter of the CFB reaction chamber between its walls and the hoppers for providing a pressure seal while allowing the downward expansion of the walls and the upward expansion of the hoppers.

14. The CFB boiler of clause 8, wherein the enclosure walls of the BFB are of cooled membrane gas-tight design.

15. The CFB boiler of clause 14, wherein the BFB enclosure includes a secondary gas duct.

16. The CFB boiler of clause 15, wherein the secondary gas duct is made of portions of the BFB enclosure walls.

17. The CFB boiler of clause 15, wherein the secondary gas duct is supplied with the secondary gas

through at least one conduit made of membrane panels extending downward to about the same elevation as where the BFB enclosure is supported by the hoppers.

18. The CFB boiler of clause 17, wherein the at least one secondary gas conduit, below the same elevation:

continues as a plate-type design gas-tightly connected to the membrane-panel part of the conduit, the connection design allowing an independent thermal expansion of either part; the plate-type part further penetrating through the hopper wall, the penetration design accommodating independent thermal expansions of the conduit and the hopper; and the tubes forming the membrane-type part becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hopper as the tubes penetrate the hopper wall.

19. A circulating fluidized bed (CFB) boiler comprising:

a CFB reaction chamber having walls and an open-bottom grid defining a floor at a lower end of the CFB reaction chamber for providing fluidizing gas into the CFB reaction chamber;  
 at least one bubbling fluidized bed (BFB) located within a lower portion of the CFB reaction chamber and being bound by enclosure walls and the floor of the CFB reaction chamber, with the fluidizing gas feed to the BFB portion of the grid controlled separately from the fluidizing gas feed to the CFB portion of the grid;  
 the enclosure walls of the BFB are of cooled membrane gas-tight design;  
 at least one controllable in-bed heat exchanger (IBHX), the IBHX occupying part of the CFB reaction chamber floor and being surrounded by the enclosure walls of the BFB;  
 hoppers containing dormant solids disposed under the CFB and the BFB; and  
 the enclosure walls of the BFB being connected to at least one of the bottom-supported hoppers with supports and becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hopper as the tubes penetrate the hopper wall.

## Claims

1. A circulating fluidized bed (CFB) boiler comprising:

- a CFB reaction chamber having side walls and an open-bottom grid defining a floor at a lower end of the CFB reaction chamber for providing fluidizing gas into the CFB reaction chamber; at least one bubbling fluidized bed (BFB) located within a lower portion of the CFB reaction chamber and being bound by enclosure walls and the floor of the CFB reaction chamber, with the fluidizing gas feed to the BFB portion of the grid controlled separately from the fluidizing gas feed to the CFB portion of the grid; at least one controllable in-bed heat exchanger (IBHX), the IBHX occupying part of the CFB reaction chamber floor and being surrounded by the enclosure walls of the BFB; bottom-supported hoppers containing dormant solids disposed under the CFB and the BFB; the enclosure walls of the BFB being supported off the bottom-supported hoppers; the enclosure walls of the BFB are of cooled membrane gas-tight design around the perimeter of the BFB, including:
- at least one top opening for CFB solids influx into the BFB;
  - at least one overflow port for setting the BFB height;
  - at least one underflow port for BFB solids controlled recycle back into the CFB;
  - the gas-tight BFB enclosure extending below the grid to the elevation sufficient for not exceeding a preset percentage of leakage of the fluidizing gas from the BFB into the CFB through the bed of the dormant solids between the aforementioned elevation and the grid; and
  - the tubes of the BFB enclosure below that elevation becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hoppers as the tubes penetrate the walls of the hoppers.
2. The CFB boiler according to claim 1, wherein the walls of the CFB reaction chamber are top supported and an expansion joint is installed around the perimeter of the reaction chamber between its walls and the hoppers for providing a pressure seal while allowing the downward expansion of the walls and the upward expansion of the hoppers.
  3. The CFB boiler according to claim 1 or claim 2, wherein the BFB enclosure includes a secondary gas duct and optionally wherein the secondary gas duct is made of tubes of the BFB enclosure.
  4. The CFB boiler according to claim 3, wherein the secondary gas duct is supplied with the secondary gas through at least one conduit made of membrane panels extending downward to essentially the same elevation as where the gas-tight BFB enclosure terminates and turns into a loose-tube design.
  5. The CFB boiler according to claim 4, wherein the at least one secondary gas conduit upon termination of the membrane-panel design:
    - continues as a plate-type design gas-tightly connected to the membrane-panel part of the conduit, the connection design allowing an independent thermal expansion of either part, the plate-type part further penetrating through the hopper wall, the penetration design accommodating independent thermal expansions of the conduit and the hopper, and
    - the tubes forming the membrane-type part becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hopper as the tubes penetrate the hopper wall.
  6. The CFB boiler according to claim 1, wherein the walls of the CFB reaction chamber are bottom supported.
  7. A circulating fluidized bed (CFB) boiler comprising:
    - a CFB reaction chamber having walls and an open-bottom grid defining a floor at a lower end of the CFB reaction chamber for providing fluidizing gas into the CFB reaction chamber;
    - at least one bubbling fluidized bed (BFB) located within a lower portion of the CFB reaction chamber and being bound by enclosure walls and the floor of the CFB reaction chamber, with the fluidizing gas feed to the BFB portion of the grid controlled separately from the fluidizing gas feed to the CFB portion of the grid;
    - at least one controllable in-bed heat exchanger (IBHX), the IBHX occupying part of the CFB reaction chamber floor and being surrounded by the enclosure walls of the BFB;
    - hoppers containing dormant solids disposed under the CFB and the BFB; and
    - the enclosure walls of the BFB being supported off the bottom-supported hoppers.
  8. The CFB boiler of claim 7, wherein the hoppers include an inner hopper for the BFB and an outer hopper for the CFB; a skirt connected to a portion of the enclosure walls and extending into the inner hopper to form a seal.
  9. The CFB boiler of claim 7 or claim 8, further comprising thermal expansion accommodating support plates supporting the enclosure walls from the bot-

tom-supported hoppers.

10. The CFB boiler of claim 9, wherein the enclosure walls include membranes; the support plates being connected to the membranes and optionally wherein the membranes terminate below the connection of the support plates and the membranes. 5
11. The CFB boiler of any of claims 7 to 10, wherein the walls of the CFB reaction chamber are top supported and an expansion joint is disposed around the perimeter of the CFB reaction chamber between its walls and the hoppers for providing a pressure seal while allowing the downward expansion of the walls and the upward expansion of the hoppers. 10 15
12. The CFB boiler of any of claims 7 to 11, wherein the enclosure walls of the BFB are of cooled membrane gas-tight design. 20
13. The CFB boiler of claim 12, wherein the BFB enclosure includes a secondary gas duct and optionally wherein the secondary gas duct is made of portions of the BFB enclosure walls. 25
14. The CFB boiler of claim 13, wherein the secondary gas duct is supplied with the secondary gas through at least one conduit made of membrane panels extending downward to about the same elevation as where the BFB enclosure is supported by the hoppers. 30
15. The CFB boiler of claim 14, wherein the at least one secondary gas conduit, below the same elevation: 35  
continues as a plate-type design gas-tightly connected to the membrane-panel part of the conduit, the connection design allowing an independent thermal expansion of either part; the plate-type part further penetrating through the hopper wall, the penetration design accommodating independent thermal expansions of the conduit and the hopper; and the tubes forming the membrane-type part becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hopper as the tubes penetrate the hopper wall. 40 45
16. A circulating fluidized bed (CFB) boiler comprising: 50  
a CFB reaction chamber having walls and an open-bottom grid defining a floor at a lower end of the CFB reaction chamber for providing fluidizing gas into the CFB reaction chamber; 55  
at least one bubbling fluidized bed (BFB) located within a lower portion of the CFB reaction chamber and being bound by enclosure walls and the

floor of the CFB reaction chamber, with the fluidizing gas feed to the BFB portion of the grid controlled separately from the fluidizing gas feed to the CFB portion of the grid;  
the enclosure walls of the BFB are of cooled membrane gas-tight design;  
at least one controllable in-bed heat exchanger (IBHX), the IBHX occupying part of the CFB reaction chamber floor and being surrounded by the enclosure walls of the BFB;  
hoppers containing dormant solids disposed under the CFB and the BFB; and  
the enclosure walls of the BFB being connected to at least one of the bottom-supported hoppers with supports and becoming of a loose design with sufficient flexibility for accommodating differences in thermal expansion of the tubes and the hopper as the tubes penetrate the hopper wall.

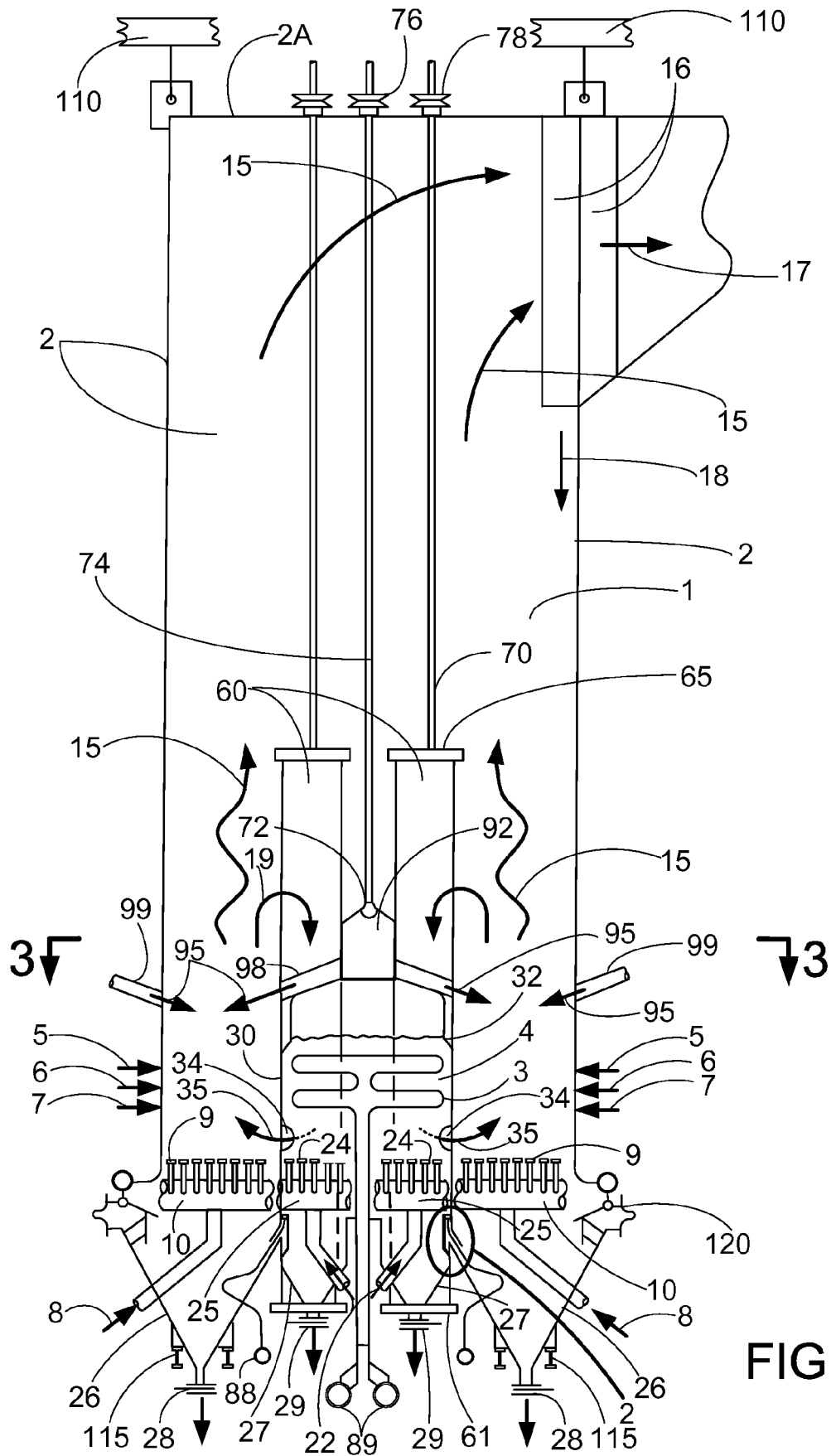
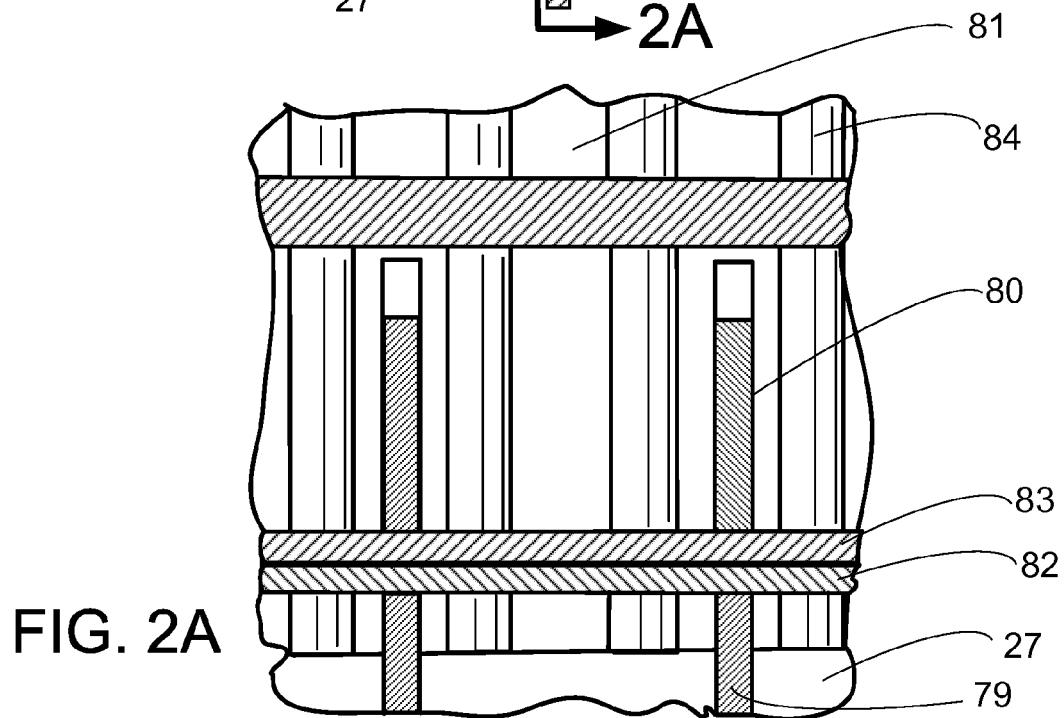
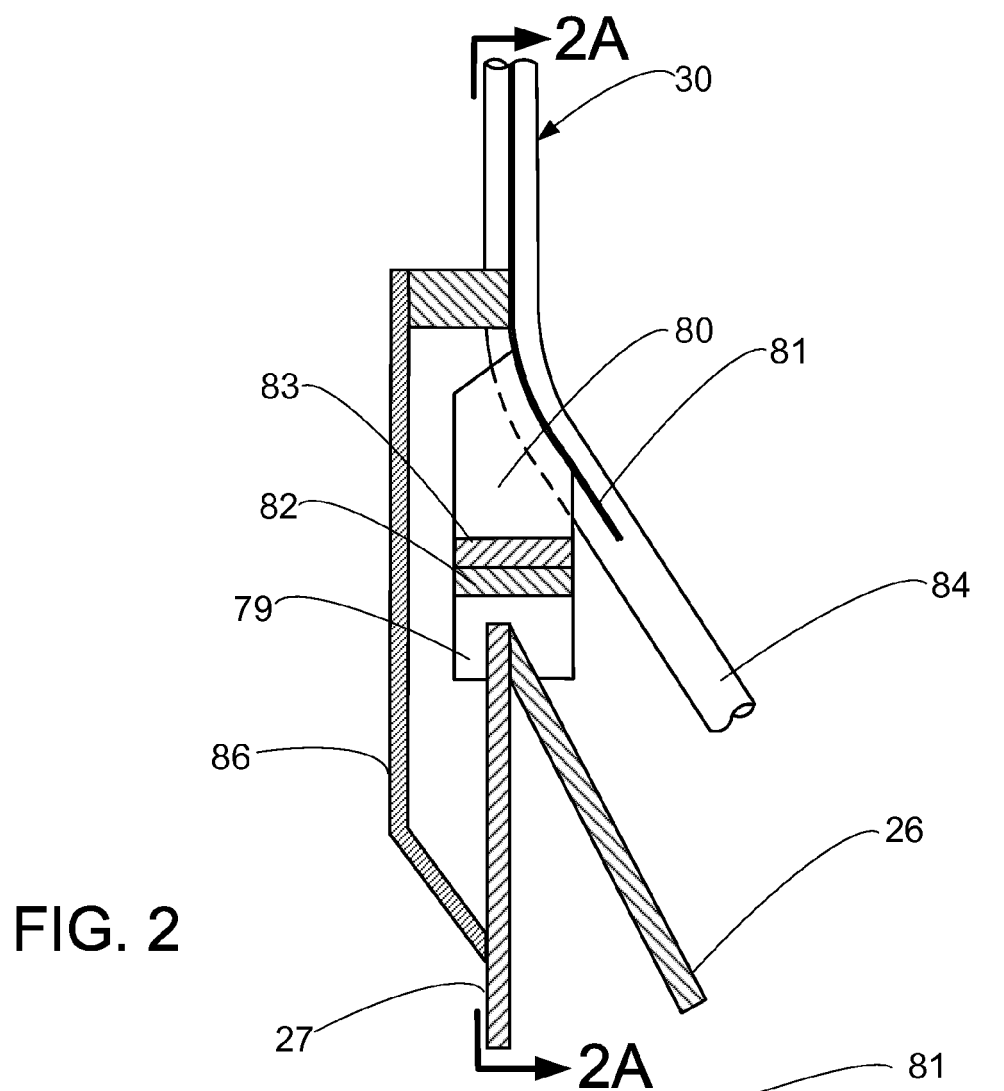


FIG. 1



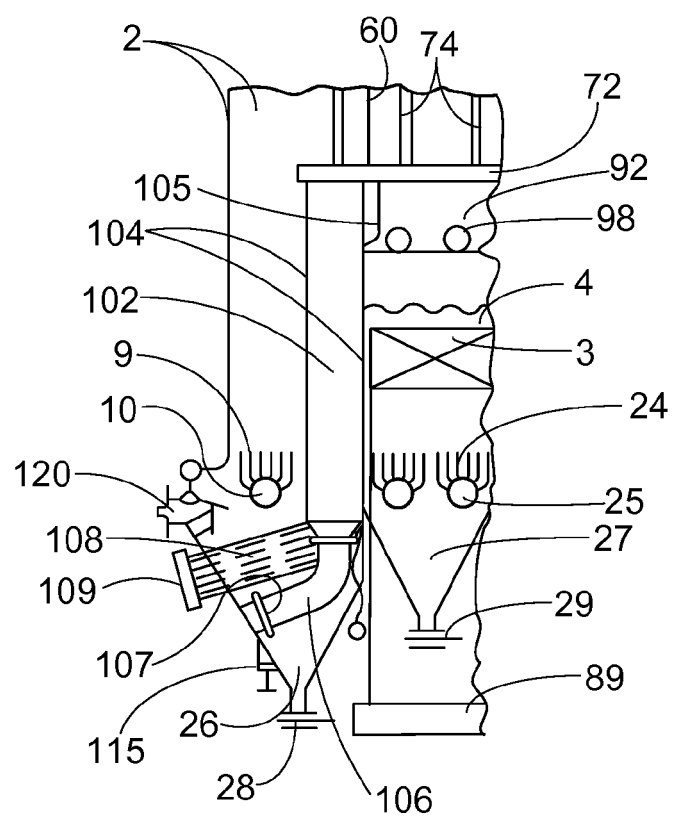
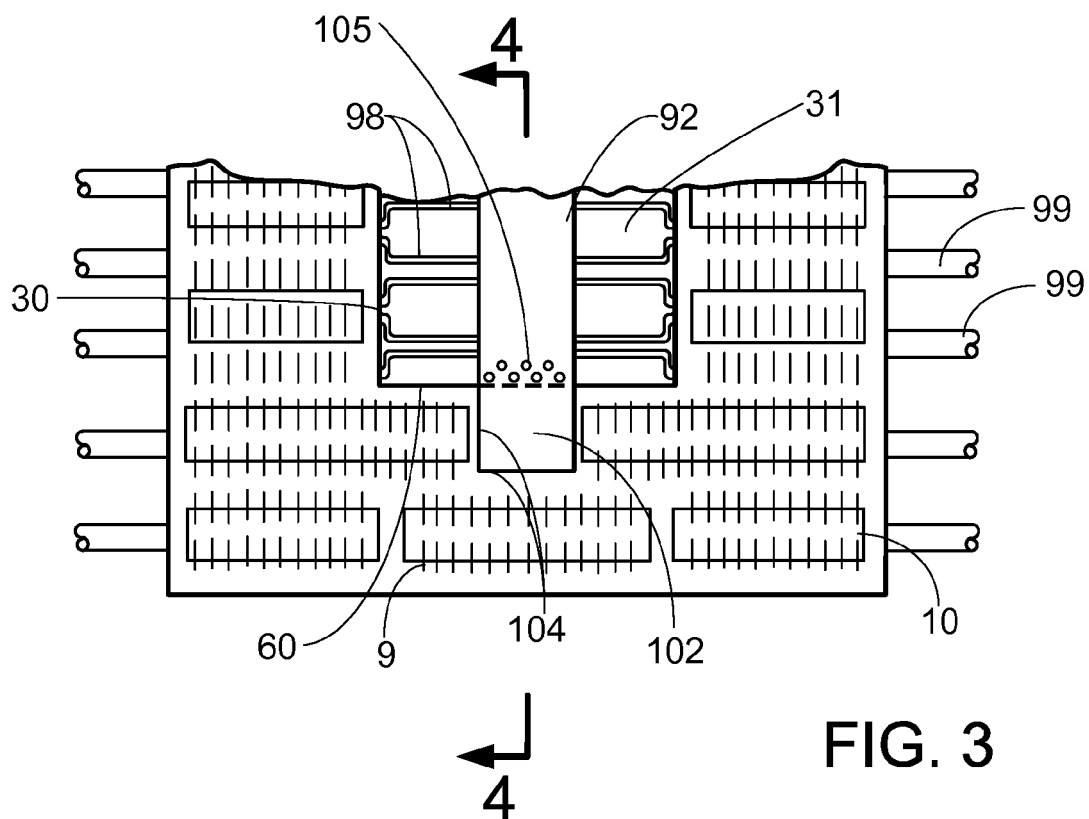


FIG. 4



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