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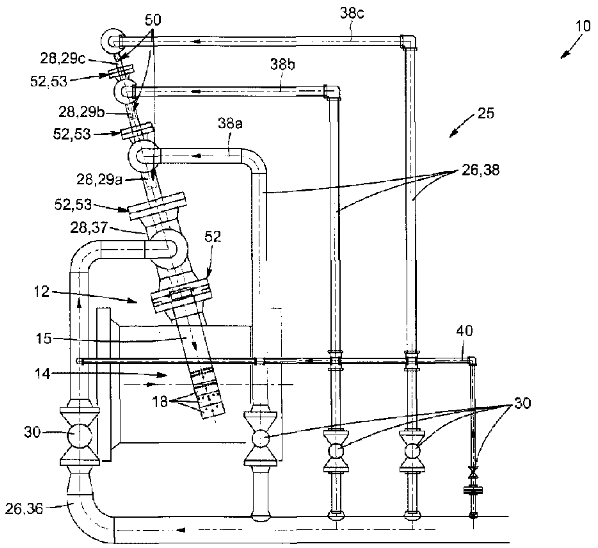

(57) **Abrégé/Abstract:**
Direct steam injection (DSI) heating techniques can use a heater to heat a process stream in bitumen froth treatment. The DSI heater includes a diffuser in fluid communication with a steam source and configured to receive steam therefrom. The diffuser includes an injection nozzle extending into the process stream. The injection nozzle has a plurality of injection caps connected thereto and having multiple outlets in fluid communication with the process stream for injecting steam therein. The DSI heater also includes a steam supply assembly to establish fluid communication between the steam source and the diffuser. The steam supply assembly includes steam inlet pipes adapted to provide steam to a corresponding one of the injection caps and are independently operable to control a steam injection rate of the DSI heater.

ABSTRACT

Direct steam injection (DSI) heating techniques can use a heater to heat a process stream in bitumen froth treatment. The DSI heater includes a diffuser in fluid communication with a steam source and configured to receive steam therefrom. The diffuser includes an injection nozzle extending into the process stream. The injection nozzle has a plurality of injection caps connected thereto and having multiple outlets in fluid communication with the process stream for injecting steam therein. The DSI heater also includes a steam supply assembly to establish fluid communication between the steam source and the diffuser. The steam supply assembly includes steam inlet pipes adapted to provide steam to a corresponding one of the injection caps and are independently operable to control a steam injection rate of the DSI heater.

STATIC DIRECT STEAM INJECTION (DSI) HEATER AND USE IN BITUMEN FROTH TREATMENT OPERATIONS

TECHNICAL FIELD

[001] The technical field generally relates to direct steam injection (DSI) heating of process streams in bitumen froth treatment operations, and the like, and more particularly to enhance designs and operations for DSI heating of streams with variable heating requirements.

BACKGROUND

[002] In bitumen froth treatment operations, various process streams require heating which can be achieved by directly injecting steam into the process stream. Direct steam injection (DSI) heaters can be used for this purpose where the DSI heaters include a diffuser that extends into the process stream and has outlets through which the steam is injected directly into the process stream.

[003] Heating requirements of the process streams can vary over time and thus the DSI heaters can be configured to provide variable steam injection rates. Some DSI heaters use a dynamic approach where a component can be displaced in order to alternately expose or block some of the outlets of the diffuser so that more or less steam can be injected into the process stream. However, using these types of dynamic DSI heaters can lead to risks of steam leakage via joints and interfaces of the components that move with respect to each other, which can in turn lead to increased cavitation and wear on the equipment and/or inefficient heating operations.

[004] There is indeed a need for technology that overcomes at least some of the drawbacks of existing DSI heating, particularly as used in bitumen froth treatment operations.

SUMMARY

[005] Various techniques are described herein for providing enhanced direct steam injection (DSI) heating of process streams in a bitumen froth treatment operation.

[006] According to a first aspect, a direct steam injection (DSI) heater for heating a process stream in a bitumen froth treatment operation is provided. The DSI heater comprises a diffuser in fluid communication with a steam source and is configured to receive steam therefrom. The diffuser includes an injection nozzle extending into the process stream, the injection nozzle having a proximal conduit and one or more injection caps connected to the proximal conduit. Each injection cap having multiple outlets in fluid communication with the process stream for injecting steam therein. The DSI heater further includes a steam supply assembly for establishing fluid communication between the diffuser and the steam source. The steam supply assembly includes steam inlet pipes adapted to provide steam to respective ones of the injection caps and being independently operable to control a steam injection rate of the DSI heater.

[007] According to a possible embodiment, the proximal conduit includes a plurality of outlets arranged about a distal end thereof, and the proximal conduit is in fluid communication with one of the steam inlet pipes.

[008] According to a possible embodiment, the steam inlet pipes include a main inlet pipe in fluid communication with the proximal conduit for providing steam thereto, and a plurality of auxiliary steam inlet pipes extending from the main inlet pipe and being in fluid communication with respective injection caps.

[009] According to a possible embodiment, each steam inlet pipe includes a flow valve adapted to control the flow of steam flowing therethrough.

[0010] According to a possible embodiment, the diffuser is substantially static, and the steam injection rate of the diffuser is controlled via adjustment of the flow valves.

[0011] According to a possible embodiment, the steam supply assembly further includes a plurality of steam conduits coupled between the injection nozzle and steam inlet pipes for providing steam to respective injection caps.

[0012] According to a possible embodiment, the steam conduits include a main steam conduit coupled between the proximal conduit and the main inlet pipe, and auxiliary steam conduits coupled between the auxiliary steam inlet pipes and respective injection caps.

[0013] According to a possible embodiment, the proximal conduit is removably connectable to the main steam conduit.

[0014] According to a possible embodiment, the steam conduits are concentrically disposed with respect to one another.

[0015] According to a possible embodiment, the auxiliary steam conduits concentrically extend within the proximal conduit.

[0016] According to a possible embodiment, each steam conduit comprises a coupling section for connecting with the corresponding steam inlet pipe.

[0017] According to a possible embodiment, each of the coupling sections comprises at least one coupling interface connectable to an adjacent coupling interface in order to position and secure steam conduits with respect to one another.

[0018] According to a possible embodiment, the injection nozzle is substantially cylindrical, and wherein the injection caps are connectable to one another in an end-to-end manner so as to extend along a common axis and into the process stream.

[0019] According to a possible embodiment, the injection caps comprise a proximal injection cap connected to the proximal conduit and a distal injection cap positioned at a distal end of the injection nozzle.

[0020] According to a possible embodiment, the injection caps further comprise at least one intermediate injection cap coupled between the proximal and distal injection caps.

[0021] According to a possible embodiment, each injection cap comprises a front section and a rear section, the rear section being shaped and sized to engage the proximal conduit or the front section of a preceding injection cap so as to be connected thereto.

[0022] According to a possible embodiment, each injection cap comprises a peripheral rabbet, and wherein the front section of a corresponding injection cap abuts the peripheral rabbet of the subsequent injection cap along the common axis.

[0023] According to a possible embodiment, the rear section defines an inner chamber within the preceding injection cap when connected thereto, and wherein the outlets of each injection cap are in fluid communication with corresponding inner chambers.

[0024] According to a possible embodiment, each injection cap comprises a rear opening defined in the rear section for receiving a corresponding auxiliary steam conduit therein and providing steam to the inner chamber.

[0025] According to a possible embodiment, the injection caps are interchangeable.

[0026] According to a possible embodiment, the injection caps are connected via a threaded connection.

[0027] According to a possible embodiment, the injection caps are connected via a press-fit connection.

[0028] According to a possible embodiment, the injection caps are connected via mechanical fasteners.

[0029] According to a possible embodiment, the outlets are arranged in multiple side-by-side rows on respective planes across the proximal conduit and injection caps, each plane being perpendicular to a longitudinal axis of the diffuser.

[0030] According to a possible embodiment, each injection cap comprises at least one row of outlets.

[0031] According to a possible embodiment, the proximal conduit comprises two rows of outlets and each injection cap comprises a single row of outlets.

[0032] According to a possible embodiment, the outlets are sized and configured for injecting the steam at sonic flow conditions.

[0033] According to a possible embodiment, the outlets are all of the same size.

[0034] According to a possible embodiment, at least some components of the DSI heater are composed of or coated with carbide tungsten.

[0035] According to a second aspect, a process for heating a process stream having variable heating requirements and flowing in a bitumen froth treatment operation it provided. The process includes injecting steam directly into the process stream via a direct steam injection (DSI) heater having a diffuser in fluid communication with a steam source and configured to receive steam therefrom. The diffuser has an injection nozzle extending into the process stream, the injection nozzle comprising a proximal conduit and one or more injection caps connected to the proximal conduit and each having multiple outlets in fluid communication with the process stream for injecting steam therein. The DSI further includes a steam supply assembly for establishing fluid communication between the diffuser and the steam source. The steam supply assembly includes steam inlet pipes adapted to provide steam to respective injection caps and being independently operable to control a steam injection rate of the DSI heater. The process further includes determining heating requirements of the process stream and operating one or more inlet pipe in response to the determined heating requirements to provide steam to the injection nozzle and/or injection caps in order to inject steam into the process stream.

[0036] According to a possible embodiment, the determining of the heating requirements of the process stream includes measuring a temperature of the process stream downstream of the DSI heater; comparing the measured temperature with a target temperature; and determining a corresponding increase or decrease in steam injection via the DSI heater to achieve the target temperature.

[0037] According to a possible embodiment, multiple DSI heaters are provided in series for heating the process stream; and the multiple DSI heaters are controlled to provide an overall steam injection.

[0038] According to a possible embodiment, multiple DSI heaters are provided in parallel.

[0039] According to a possible embodiment, the multiple DSI heaters are provided in at least two parallel heating trains, each train comprising at least two of the DSI heaters.

[0040] According to a possible embodiment, the parallel heating trains are operated alternately.

[0041] According to a possible embodiment, the process stream includes a slurry stream.

[0042] According to a possible embodiment, the process stream includes a bitumen froth stream.

[0043] According to a possible embodiment, the process stream includes a hydrocarbon stream.

[0044] According to a possible embodiment, the process stream includes a process water stream.

[0045] According to a possible embodiment, the process stream includes a tailings stream.

[0046] According to a possible embodiment, the bitumen froth treatment operation is a paraffinic froth treatment operation.

[0047] According to a possible embodiment, the sonic flow conditions of the steam are provided by substantially maintaining a constant steam velocity and providing the outlets with size and configuration for sonic flow.

[0048] According to a possible embodiment, the steam provided from the steam source to the diffuser has a steam temperature that is at least 10°C superheated.

[0049] According to a possible embodiment, the steam provided from the steam source to the diffuser has a steam temperature that between 10°C and 25°C superheated.

[0050] According to a possible embodiment, the steam provided from the steam source to the diffuser has a steam pressure of at least 2000 kPag.

[0051] According to a possible embodiment, the steam provided from the steam source to the diffuser has a steam pressure of at least 2200 kPag.

[0052] According to a possible embodiment, the steam provided from the steam source to the diffuser has a steam pressure of between 2100 and 2950 kPag.

[0053] According to a third aspect, a direct steam injection (DSI) heater for heating a process stream in a bitumen froth treatment operation is provided. The DSI heater includes a diffuser in fluid communication with a steam source and configured to receive steam therefrom. The diffuser includes multiple steam injection stages that are static and each has outlets for steam injection into the process stream. The DSI also includes a steam supply assembly coupled between the diffuser and the steam source to establish fluid communication therebetween, and configured to independently and selectively supply steam to each of the steam injection stages of the diffuser.

[0054] According to a possible embodiment, the steam injection stages comprise a proximal conduit and injection caps, and wherein the steam supply assembly comprises steam inlet pipes adapted to provide steam to respective injection caps and being independently operable to control a steam injection rate of the DSI heater.

[0055] According to still another aspect, a process for heating a process stream having variable heating requirements and flowing in a bitumen froth treatment operation is provided. The process includes providing a steam source, supplying steam from the steam source through a plurality of independently operable steam inlet pipes of a direct steam injection (DSI) heater having a diffuser with a plurality of injection stages in fluid communication with a corresponding one of the steam inlet pipes, injecting steam directly into the process stream via outlets of one or more stages of the diffuser and controlling the supply of steam flowing through the steam inlet pipes to vary the amount of steam being injected into the process stream.

[0056] According to yet another aspect, a process for heating a process stream flowing in a bitumen froth treatment operation is provided. The process includes the steps of providing a main steam flow, splitting the main steam flow into multiple steam flows, delivering the multiple steam flows to respective injection stages located together at a fixed location in the process stream for direct heating thereof and controlling the multiple steam flows independently to regulate steam injection into the process stream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0057] Figure 1 is an exploded perspective view of an example DSI heater showing multiple steam inlet pipes connected to a diffuser.

[0058] Figure 2 is a cut view of a section of the diffuser, showing multiple concentric steam conduits connected to a corresponding injection cap.

[0059] Figures 3a to 3c are cut views of injection cap implementations.

[0060] Figure 4 is a block diagram of an example DSI heating system with multiple parallel trains.

DETAILED DESCRIPTION

[0061] Various techniques are described herein for enhanced operation of direct steam injection (DSI) heating of process streams in bitumen froth treatment operations. For instance, DSI heaters with enhanced functionality particularly in terms of inhibiting steam leakage associated with equipment maintenance, among others, are described herein along with methods of implementing such heaters in bitumen froth treatment operations.

[0062] In some implementations, the DSI heating is performed using a DSI heater that includes a diffuser having an injection nozzle with a proximal conduit having outlets for injecting steam into the process stream, and thus into the process fluid. The outlets can be arranged in multiple rows that are perpendicular to a longitudinal axis of the diffuser. The injection nozzle can include injection caps coupled thereto and to one another in an end-to-end manner to extend into the process stream. In a similar fashion as the proximal conduit, each injection cap can include one or more rows of outlets for injecting steam into the process fluid. The injection caps are connected to one another and/or to the proximal conduit in a manner which prevents fluid communication therebetween, i.e., between the proximal conduit and the injection caps, and between two adjacent injection caps. Furthermore, the DSI heater includes a steam supply assembly for establishing fluid communication between the diffuser and a steam source. The steam supply assembly can include a plurality of steam inlet pipes in fluid communication with one of the injection caps or the proximal conduit in order to inject steam within the process stream via the outlets. Each steam inlet pipe can be independently operable to control the amount of steam flowing therethrough, thereby enabling control of steam injection rates in response to variable heating requirements of the process fluid. Various other structural features as well as methods of operation can also be used to enhance DSI heating.

[0063] Referring to Figure 1, an exemplary implementation of a DSI heater 10 is illustrated. The DSI heater 10 includes a diffuser 12 configured to inject steam into the process stream. Therefore, it should be understood that the diffuser 12 is configured to receive steam from a steam source (not shown), as will be described further below. In some implementations, the diffuser 12 includes an injection nozzle 14 configured to extend within the process stream so as to inject steam therein. The injection nozzle 14 can include a proximal conduit 15 having a substantially cylindrical shape and a plurality of steam outlets 16, best seen in Figure 2, configured to expel steam therefrom and into the process stream. In the context of this disclosure, the steam outlets 16 can also be referred to as holes or perforations. In some implementations, it is appreciated that the diffuser 12, or components thereof (e.g., the proximal conduit 15) extend along a longitudinal axis, with the outlets 16 being arranged about a distal end of the proximal conduit 15 to facilitate injection within the process stream, although other configurations are possible.

[0064] In some implementations, and as seen in exemplary implementations of Figures 1 and 2, the injection nozzle 14 can further include a plurality of injection caps 18 coupled to the proximal conduit 15. The injection caps 18 also have multiple steam outlets 16 arranged thereon for allowing injection of additional steam into the process stream. As illustrated, the injection caps 18 can be coupled to one another so as to extend into the process stream following the longitudinal axis of the proximal conduit 15. In the present implementation, the steam outlets 16 are arranged in a plurality of adjacent rows 20 where adjacent rows 20 are arranged across the multiple injection caps 18 and the proximal conduit 15. The diffuser 12 can also include at its distal end a diffuser end cap 24 (Figure 2) which can be coupled to the distal-most element of the diffuser 12. For example, the diffuser end cap 24 can be coupled to the distal-most injection cap 18, or directly to the proximal conduit 15 (e.g., when no injection caps 18 are connected). It is appreciated that the diffuser end cap 24 can include and cooperate with an end cap O-ring for example, positioned in between the end cap 24 and the distal-most element for sealing functionality.

[0065] Still referring to Figure 1, the DSI heater 10 further includes a steam supply assembly 25 configured for effectively supplying steam to the diffuser 12 so as to inject said steam into the process stream. In the present implementation, the steam supply assembly 25 includes a plurality of steam inlet pipes 26 in fluid communication with the steam source for supplying steam to the diffuser 12. More specifically, each steam inlet pipe 26 can be configured to be in fluid communication with one of the injection caps 18 or proximal conduit 15 so as to provide steam thereto for ultimately injecting said steam into the process stream. In other words, the proximal conduit 15 and injection caps 18 are respectively configured to be in fluid communication with a single steam inlet pipe 26, although it is appreciated that other configurations are possible. In the present implementation, the steam supply assembly 25 further includes steam conduits 28 coupled between respective inlet pipes 26 and corresponding injection cap 18 and/or proximal conduit 15 for establishing fluid communication therebetween, as will be described further below.

[0066] In Figure 1, steam flow direction is schematically illustrated using dotted arrows. In some implementations, the steam provided to the diffuser 12 is superheated and can have a steam temperature that is at least 10°C superheated, or between 10°C and 25°C superheated. The steam can have a steam pressure of at least 2000 kPag, at least 2200 kPag, or between 2100 and 2950 kPag, for example. The steam can have other properties and can be generated using various steam generation units and processes.

[0067] In some implementations, each steam inlet pipe 26 is independently operable to control the amount of steam flowing therethrough, thereby controlling which of the proximal conduit 15 and/or injection caps 18 is provided with steam. Therefore, it should be understood that the DSI heater 10 can be configured for enabling control of steam injection rates in response to variable heating requirements of the process fluid. Furthermore, the steam inlet pipes 26 can be provided with any known and/or suitable means adapted to control the flow of steam circulating therethrough. In some examples, the steam inlet pipes 26 are respectively provided with a steam flow valve 30 configured to control the amount of steam flowing through the corresponding steam inlet pipe 26. In some implementations, the steam flow valves 30 can be operable between an opened position, where steam is allowed to circulate along the corresponding steam inlet pipe 26 and towards the diffuser 12, and a closed position where steam is blocked from entering the corresponding steam inlet pipe 26. It should thus be readily understood that the diffuser 12 can be substantially static and that the steam injection rate is controlled via adjustments of the steam flow valves 30.

[0068] In some implementations, the steam flow valves 30 are operable between a fully opened position and a fully closed position (e.g., on/off valves). However, it is appreciated that the steam flow valves 30 can be alternatively adjustable in various positions between the fully opened and fully closed positions. As such, the amount of steam being allowed through each inlet pipe 26 can be further controlled, advantageously allowing additional control over the amount of steam being routed to the process stream. During operation of the DSI heater 10, it should be understood that, in order to have the highest injection rate from the DSI heater 10, each steam flow valve 30 is operated in the fully open position. It should be further understood that, in response to a reduction in heating requirements, the steam injection rate can be lowered by operating one or more steam flow valves in the closed position or any suitable position between the opened and closed positions. It is thus appreciated that the steam injection rate is controlled via adjustments of the valves 30, and without the use of moving parts in or around the diffuser 12.

[0069] In some implementations, each outlet row 20 can have the same number of outlets 16 with the same outlet size and spacing, for example. Alternatively, the spacing between the rows 20 can be different, the size of the outlets 16 can be different within each row and/or between rows, and the spacing between rows can also be different.

[0070] In some implementations, as shown in Figure 2 and as previously described, the injection caps 18 are coupled to the proximal conduit 15 so as to form an extension thereof. The injection caps 18 have a substantially circular cross-section for matching with the distal end of the proximal conduit 15. The injection caps 18 are connected to one another in an end-to-end manner following the longitudinal axis of the diffuser 12. In this example, the injection caps 18 include a proximal injection cap 32 configured to be connected to the distal end of the proximal conduit 15, at least one intermediate injection cap 33 connected to the proximal injection cap 32, and a distal injection cap 34 connected to the intermediate injection cap 33. It should be understood that the injection caps 18 can include any suitable number of intermediate injection caps 33, or no intermediate injection cap 33 at all, coupled between the proximal and distal injection caps 32, 34. In addition, the injection caps 18 can be configured to be readily replaced when required (e.g., when damaged or at the end of their service life), as will be described further.

[0071] As mentioned above, each injection cap 18 can be provided with at least one row 20 of steam outlets 16. In one implementation, the row(s) 20 of the distal injection cap 34 includes fewer outlets 16 than the other rows 20 to enable finer or very low steam injection rates (e.g., when the heating requirements are relatively low for a given process stream). Relatively low injection rates or fine adjustments in injection rates can be desirable, for example, when multiple DSI heaters are used to heat a process stream and one DSI heater is used for finer adjustment of the heat input, or during turndown operations when a previously heated stream is recirculated and thus has only small heating requirements to maintain its temperature. In the illustrated implementations of Figures 3a to 3c, the row 20 of the distal injection cap 34 has fewer outlets 16 than the row 20 of the intermediate injection cap 33, which in turn has fewer outlets 16 than the rows 20 of the proximal injection cap 32 and/or the rows 20 of the proximal conduit 15. In other words, each subsequent injection cap 18 has fewer outlets 16 than the preceding injection cap 18 (i.e., the injection cap 18 it is connected to), however, it is appreciated that other configurations are possible.

[0072] In this example, each row 20 of each injection cap 18 has the same size of holes 16, with the holes 16 of the proximal conduit 15, proximal injection cap 32 and intermediate injection cap 33 being longitudinally aligned to define columns of holes 16. In other words, the holes 15 of the distal injection cap 34 are offset from the holes 16 of the other rows 20 and/or caps 18. However, the outlets 16 are preferably dimensioned to ensure sonic flow of the steam through the outlets 16, and thus it can be preferred for design and operation purposes to provide all outlets 16 having the same dimensions to ensure sonic flow conditions.

[0073] In bitumen froth treatment operations, heating requirements can vary for various different process streams and for example during different stages of operations (e.g., start-up, ramp-up, turndown, normal operation). It can thus be relatively advantageous to have the ability to provide higher steam injection rates (e.g., when each steam flow valve is in the fully open position) and relatively low or trim heating injection rates (e.g., when one or more steam flow valves 30 are closed).

[0074] It should also be noted that when multiple DSI heaters are used to heat a given process stream, the DSI heaters can be the same or different in terms of construction. For example, a first DSI heater can be designed for higher steam injection rates and can thus have the size and number of outlets 16 to achieve high heating rates. A second DSI heater can be designed for trim or fine heat adjustments and can thus have fewer outlets 16 per row 20 to enable finer adjustments in injection rates. A plurality of DSI heaters can be provided in this manner where some or all of the DSI heaters have different number and/or size of outlets 16 per row 20 to provide different degrees of precision in terms of adjusting steam injection rates. The DSI heaters can be operated together using a central controller to adjust the DSI heaters in response to variations in the heating requirements.

[0075] In some implementations, multiple DSI heaters 10 can be provided in series or in parallel. Multiple DSI heaters can provide further heating patterns or variations for variable heating requirements of the process fluid, where at least one of the DSI heaters could be fully closed and thus injecting no steam while at least one other DSI heater is at least partially open to provide steam heating of the process fluid. A number of different permutations of steam flow valves configurations in the respective DSI heaters can be provided to enable relatively precise heating of the process fluid.

[0076] Referring back to Figure 1, the steam inlet pipes 26 can include a main inlet pipe 36 coupled between the steam source and the injection nozzle 14. In the present implementation, the main inlet pipe 36 is configured to provide steam to the proximal conduit 15 which injects the steam into the process stream via the outlets 16. The steam inlet pipes 26 can further include auxiliary inlet pipes 38 extending from the main inlet pipe 36 and fluidly connecting said main inlet pipe 36 with a corresponding steam conduit 28. As described above, it is appreciated that each of the main inlet pipe 36 and auxiliary pipes 38 is provided with a steam flow valve 30 to control the amount of steam circulating therethrough.

[0077] In some implementations, the steam inlet pipes 26 can include a bypass pipe 40 configured to effectively bypass the flow valve 30 of the main inlet pipe 36. More specifically, the bypass pipe 40 extends from the main inlet pipe 36 in the section upstream of the flow valve 30, and connects again to the main inlet pipe 36 downstream of the flow valve 30. As such, if pressure builds up in the downstream section due to steam accumulation caused by a valve malfunction for example, small amounts of steam can circumvent the valve 30 and access the diffuser 12. It is appreciated that the DSI heater can be provided with any suitable number of bypass pipes 40 and that the bypass pipes 40 can be further connected to one or more of the auxiliary inlet pipes 38 for added security. In the present implementation, the bypass pipe 40 is also provided with a steam flow valve 30 to control the amount of steam circulating therethrough. In some embodiments, the bypass pipe 40 can be configured to allow steam to access the diffuser 12 in order to prevent or at least limit fluid ingress within the various caps 18 and pipes 36, 38. It is appreciated that the bypass pipe 40 can be shaped and sized according to the design of the caps 18 (e.g. size and/or number of steam outlets 16) in order to provide steam to the diffuser in order to maintain a pressure therein for preventing fluid ingress.

[0078] In this example, the main inlet pipe 36 has a diameter which is greater than that of the auxiliary inlet pipes 38. For example, the diameter of the main inlet pipe 36 can be between 1.5 to 3 times greater than that of the auxiliary inlet pipes 38. In the present implementation, the auxiliary inlet pipes 38 include a first auxiliary pipe 38a, a second auxiliary pipe 38b and a third auxiliary pipe 38c. It is appreciated that each auxiliary pipe

38 can have the same diameter, but can alternatively have different diameters compared to one another, or along a length thereof. For example, the first auxiliary pipe 38a has a greater diameter than the second inlet pipe 38b, which in turn has a greater diameter than the third inlet pipe 38c. However, it is appreciated that other configurations are possible.

[0079] In some implementation, and in a similar fashion as the inlet pipes 26, the steam conduits 28 can include a main steam conduit 37 coupled between the proximal conduit 15 and the main inlet pipe 36. In addition, it should be understood that each auxiliary inlet pipe 38 is adapted to be in fluid communication with one of the injection caps 18 via respective steam conduits 28, as described above. More specifically, in this implementation, the steam conduits 28 further include auxiliary steam conduits 29 coupled between the auxiliary inlet pipes 38 and the injection caps 18. For example, the first auxiliary pipe 38a is in fluid communication with the proximal injection cap 32 via a first auxiliary steam conduit 29a, the second auxiliary pipe 38b is in fluid communication with the intermediate injection cap 33 via a second auxiliary steam conduit 29b, and the third auxiliary pipe 38c is in fluid communication with the distal injection cap 34 via a third auxiliary steam conduit 29c. It is appreciated that the inlet pipes having larger diameters (e.g., the main inlet pipe 36 and first auxiliary inlet pipe 38a) can be configured to provide steam to the components with the most steam outlets 16, for example.

[0080] Now referring to Figures 1 and 2, the steam conduits 28 are adapted to extend along the longitudinal axis of the diffuser 12, with the auxiliary steam conduits 29 extending through the proximal conduit 15 and connecting to respective injection caps 18. In the present implementation, each steam conduit 28 can have a diameter substantially matching that of the steam inlet pipe 26 it is connected to. In other words, the first auxiliary steam conduit 29a has a greater diameter than the second auxiliary steam conduit 29b which in turn has a greater diameter than the third auxiliary steam conduit 29c. In a similar fashion, the proximal conduit 15 and main steam conduit 37 can have a diameter substantially matching that of the main inlet pipe 36, although other configurations are possible. As best seen in Figure 2, the auxiliary steam conduits 29 are sized and configured to extend through the main steam conduit 37, and within the proximal conduit 15. The steam conduits 28 can be further configured to extend within one another (e.g., concentrically) along the diffuser 12. More specifically, in this example, the third auxiliary steam conduit 29c extends within the second auxiliary steam conduit 29b, which extends within the first auxiliary steam conduit 29a, and the first auxiliary steam conduit 29a extends within the main steam conduit 37 which connects to the proximal conduit 15. In the present implementations, the steam conduits 28 concentrically extend along the longitudinal axis of the injection nozzle 14, however, it is appreciated that other configurations are possible.

[0081] Now referring to Figures 3a to 3c, in addition to Figure 2, implementations of the injection caps 18 are illustrated. More particularly, Figure 3a is an example of the proximal injection cap 32, Figure 3b is an example of the intermediate injection cap 33 and Figure 3c is an example of the distal injection cap 34. Each injection cap 18 has a rear section 42 and a front section 44, with the front section 44 having an opening 45 configured to receive the rear section 42 of a subsequent injection cap 18 and allow connection of two adjacent injection caps 18, as illustrated in Figure 2. It should be understood that the distal end of the proximal conduit 15 also has an opening configured for receiving the rear section 42 of the proximal injection cap 32. In some implementations, the injection caps 18 have a respective peripheral rabbet 46 defined between the rear and front sections 42, 44. More specifically, the injection caps 18 have an illustratively smaller rear section 42 compared to the front section 44, effectively defining the rabbet 46 therebetween. Therefore, it is appreciated that the front end of the front section 44 of a given injection cap 18 is adapted to abut the rabbet 46 of a subsequent injection cap 18, as best seen in Figure 2, to facilitate positioning the injection caps 18 with respect to one another.

[0082] In some implementations, the injection caps 18 can be connected to one another (or to the proximal conduit 15) using various fastening means and/or methods, such as by a screw inserted through an aperture 47 provided in the wall of the injection cap 18 or proximal conduit 15 and into the subsequent injection cap 18. It is appreciated that the diffuser end cap 24 can be connected to the distal injection cap 34 in a similar manner for blocking the front opening 45 thereof. It should thus be understood that the injection caps 18 are removably connected to one another, therefore facilitating replacement and maintenance thereof. In alternative implementations, it is appreciated that the injection caps 18 can be connected to one another using various methods, such as press-fit connections, threaded connections or any other suitable connection method.

[0083] In the present implementation, engaging the rear section 42 of a given injection cap 18 in the front section 44 of the corresponding preceding injection cap 18 defines an inner chamber 48 in said preceding injection cap 18. As illustrated in Figure 2, it is appreciated that the diffuser end cap 24 also defines an inner chamber 48 within the distal injection cap 34. Each inner chamber 48 can have substantially the same size, or varying sizes for each injection cap 18. For example, the inner chamber 18 of the proximal injection cap 32 is illustratively smaller than the inner chamber 48 of the intermediate and/or distal injection caps 33, 34. In this example, the outlets 16 are arranged about the injection caps 18 so as to be in fluid communication with the corresponding inner chambers 48 of the injection caps 18.

[0084] Referring to Figures 2 to 3c, each injection cap 18 can further include a rear opening 49 configured to allow the corresponding steam conduits 28 to extend therein and provide steam to the inner chambers 48. As previously mentioned, the injection caps 18 are coupled to one another in a manner preventing fluid communication therebetween. Therefore, steam being provided to one injection cap 18 can only exit through the outlets 16 of said injection cap 18. In some implementations, the steam conduits 28 are connected to the injection caps 18 via a press-fit connection so as to substantially seal the rear opening 49 thereof. However, it is appreciated that other connection means/methods are possible for connecting the steam conduits 28 to the injection caps 18 and/or for sealing the rear opening 49. In addition, the inner chamber 48 of each injection cap 18 is also substantially sealed due to the presence of the subsequent injection cap 18 (or diffuser end cap 24) and corresponding steam conduit 28 sealing the rear opening 49 thereof. It is appreciated that sealing the front and rear openings 45, 49 effectively reduces loss of steam through potential interstices between components of the diffuser 12 (e.g., between two injection caps 18).

[0085] Referring more specifically to Figure 1, the steam conduits 28 can be further connected to the injection nozzle 14 and/or to one another via various connection means. For example, each steam conduit 28 can include a coupling section 50 having at least one coupling interface 52 configured to connect to an adjacent coupling interface 52 for connecting adjacent coupling sections 50 together. In the present implementation, the coupling interface 52 can include a circular platform 53 extending radially and outwardly from the corresponding steam conduits 28. The circular platform 53 can be sized and configured to engage the circular platform 53 of an adjacent coupling section 50. Therefore, the circular platforms 53 can then be connected to one another using any suitable fastening means such as screws for example. As illustrated in Figure 1, the auxiliary inlet pipes 38 can be connected to the coupling section 50 of the corresponding auxiliary steam conduits 29, although it is appreciated that other configurations are possible.

[0086] In some implementations, one or more of the steam conduits 28 can be provided with a pair of coupling interfaces so as to be connected to two separate coupling sections 50 on either side thereof. For example, the main steam conduit 37 can be provided with a first coupling interface 52 so as to allow the coupling section 50 of one of the auxiliary steam conduits 29 to be connected thereto. In addition, the main steam conduit 37 includes a second coupling interface 52 for connection with the proximal conduit 15. Similarly, some auxiliary steam conduits 29 can also be provided with a pair of coupling interfaces 52 so as to be connected to two separate coupling sections 50 on either side thereof for example. It should thus be understood that the coupling sections 50 are arranged in an end-to-end manner and extend along the longitudinal axis of the diffuser 12. For example, the coupling section 50 of the first auxiliary steam conduit 29a includes two coupling interfaces 52 for connecting to the main steam conduit 37 on a first side thereof, and to the coupling section 50 of the second auxliary steam conduit 29b of a second side.

[0087] In this example, in order to assemble the diffuser 12, the proximal conduit 15 of the injection nozzle 14 is initially coupled to the main steam conduit 37 via engagement of the coupling interfaces 52. Then, the first auxliary steam conduit 29a can be inserted through the main steam conduit 37 and proximal conduit 15 until the coupling interfaces 52 of the first auxliary steam conduit 29a and main steam conduit 37 engage one another. As seen in Figure 2, once the first auxliary steam conduit 29a is inserted through the proximal conduit 15, the proximal injection cap 32 can be connected to the distal end of the first auxliary steam conduit 29a, and secured thereto by inserting a fastener (e.g., a screw), through the aperture 47 located on the proximal conduit 15. Then, the subsequent steam conduits 28 can be inserted in a similar manner as previously described. In this example, the second auxliary steam conduit 29b can be inserted through the first auxliary steam conduit 29a until the coupling interfaces 52 engage one another, effectively connecting the coupling sections 50 together. Once inserted, the intermediate injection cap 33 can be connected to the distal end of the second auxliary steam conduit 29b and secured thereto by inserting a screw through the aperture 47 located on the proximal injection cap 32. It is appreciated that each subsequent steam conduit 28 has a length which is longer than a previous steam conduit 28 since it must go through the injection cap(s) 18 already connected.

[0088] It should also be noted that various components of the DSI heater 10, including the conduits and pipes of the steam supply assembly 25, proximal conduit 15 and injection caps 18, among others, can be composed of certain materials to further minimize wear and breakdown. For example, the aforementioned components can be made from tungsten carbide to increase service life. However, it is appreciated that other materials (e.g., steel) and/or combination thereof are possible. Furthermore, the materials used can be treated, for example via nitriding, in order to increase hardness thereof.

[0089] The DSI heater 10 can be coupled to a measurement or monitoring device that acquires information regarding the process stream. In some implementations, the monitoring device obtains a measurement, such as the temperature of the process stream, and provides this information to the controller which, in turn, implements a control strategy which can be based on a predetermined algorithm. The control setup can be based on a feed-back or feed-forward control paradigm.

[0090] Referring to Figure 4, the DSI heating of a process stream can be controlled according to various DSI arrangements. In Figure 4, the DSI heating system includes two parallel trains 88a, 88b of multiple DSI heaters 10. The trains 88a, 88b can be identical to each other in terms of the piping, number of DSI heaters 10, and other features, or they can be different. In an example operating setup, the process stream 90 is supplied from a main line and is fed into one of the trains, while the other train is on standby. Of course, multiple parallel trains could also be operated simultaneously, if desired. Primary inlet valves 92a, 92b are used to control which train is active. A steam source 94 is provided for supplying steam 96 to the DSI heaters 10.

[0091] Each DSI heater 10 is mounted to the process line to extend into a heating conduit 98 through which the process stream flows. Steam valve assemblies 100 are controlled to supply steam to each of the operating DSI heaters 10 of a given train. It should be understood that the steam valve assemblies 100 include the multiple steam flow valves 30 coupled to the inlet pipes 26, as illustrated in Figure 1 and as previously described. Each train can include multiple DSI heaters 10, e.g., two, three, four, or five heaters. In the illustrated implementation, three DSI heaters 10 are provided in series for each train. Not all DSI heaters 10 of a given train are necessarily operated at any given time (e.g., two DSI heaters can be on while one is off). The two parallel trains 88a, 88b can be fully redundant so that only one is operating at a time. Trains 88a, 88b can be switched when maintenance or heater replacement is needed on one or more DSI heaters 10 or other equipment.

[0092] For the operating train, the upstream DSI heater (e.g., A1) can be used to provide the bulk of the heating and may often be fully open during normal operations, while downstream DSI heaters (e.g., A2, A3) are partially closed to provide partial or trim heating. During certain operating times, such as turndown, the first DSI heater 10 can also be partially closed.

[0093] By way of example, referring to Figure 4, during normal operations A1 can be fully open while A2 is partially open and A3 is fully closed. Temperature measurements can be taken upstream (for feedforward control) or downstream (for feedback control) or both. If a slight increase in heating requirements is determined, then A3 can be opened to expose only one end row of outlets, particularly if A2 is already operating in the normal row range. In some implementations, DSI heaters 10 are provided such that the typical heating requirements of the process stream are such that at least one of the DSI heaters 10 can operate mainly with slight adjustments around the distal end rows, which can facilitate precision heating.

[0094] Still referring to Figure 4, there may be one or more temperature measurement devices 102 provided within the overall DSI heating system, some of which are illustrated. A controller 104 can also be provided and configured to receive input variables (e.g., temperature measurements) and can control various aspects of the heating (e.g., steam valves, input valves, piston plug location for each DSI heater, etc.). As shown in Figure 4, the DSI heating system produces a heated process stream 106 exiting the operating train, which in this figure is train A (88a) as corresponding valves for train B (88b) are closed.

[0095] As noted throughout the present description, the DSI heater 10 can be implemented in a bitumen froth treatment operation for heating various process streams during various phases of the process. In a bitumen froth treatment operation, there are various stages of the process that may require or benefit from different DSI heating strategies. For example, during start-up operations, the process fluids may be relatively cold and therefore need to be supplied with higher thermal energy and thus during start-up periods all DSI heaters 10 may be turned to the fully open positions to provide the maximum steam injection. During normal operation, certain process streams may have variable heating requirements due to varying compositions (e.g., bitumen froth) or upstream variations, and thus slight adjustments to the steam injection rates can be done by opening one or more inlet pipes 26 of the DSI heaters 10 to respond to the variable heating demands. During turn-down operations where hot fluids may be recirculated for a period of time, heating requirements may be minimal and thus during this phase of process operations one or more inlet pipes 26 can be operated in a more closed position, e.g., where some steam flow valves 30 are fully closed while others are mostly closed with only a low amount of heating being provided to the process fluid to keep it at a relatively constant temperature until normal operations are resumed.

[0096] In addition, various process streams in a bitumen froth treatment operation can be heated using the DSI techniques disclosed herein. For example, water, oil and slurry type streams can be heated using DSI heaters 10. Example streams include bitumen froth, process water, diluted bitumen, and diluted tailings streams. Furthermore, the DSI heaters 10 can be implemented in various bitumen froth treatment processes, such as paraffinic froth treatment and naphthenic froth treatment. The DSI heaters 10 can also be implemented in the context of other hydrocarbon extraction or recovery processes where direct steam heating can be used for heating slurry streams, hydrocarbon streams, water streams, and other process streams.

[0097] Several alternative embodiments and examples have been described and illustrated herein. However, it is appreciated that the embodiments described above are intended to be exemplary only. A person of ordinary skill in the art would appreciate the features of the individual embodiments, and the possible combinations and variations of the components. A person of ordinary skill in the art would further appreciate that any of the embodiments could be provided in any combination with the other embodiments disclosed herein. The present examples and embodiments, therefore, are to be considered in all respects as illustrative and not restrictive, and not to be limited to the details given herein.

CLAIMS

1. A direct steam injection (DSI) heater for heating a process stream in a bitumen froth treatment operation, the DSI heater comprising:

   a diffuser in fluid communication with a steam source and configured to receive steam therefrom, the diffuser comprising an injection nozzle extending into the process stream, the injection nozzle comprising a proximal conduit in fluid communication with the steam source and one or more injection caps connected to the proximal conduit and each having multiple outlets in fluid communication with the process stream for injecting steam therein; and

   a steam supply assembly for establishing fluid communication between the diffuser and the steam source, the steam supply assembly comprising steam inlet pipes adapted to provide the steam to respective ones of the injection caps and being independently operable to control a steam injection rate of the DSI heater.

2. The DSI heater according to claim 1, wherein the proximal conduit comprises a plurality of outlets arranged about a distal end thereof, and wherein the proximal conduit is in fluid communication with one of the steam inlet pipes.

3. The DSI heater according to claim 2, wherein the steam inlet pipes comprise a main inlet pipe in fluid communication with the proximal conduit for providing the steam thereto, and a plurality of auxiliary steam inlet pipes extending from the main inlet pipe and being in fluid communication with respective injection caps.

4. The DSI heater according to any one of claims 1 to 3, wherein each steam inlet pipe comprises a flow valve adapted to control the flow of steam flowing therethrough.

5. The DSI heater according to claim 4, wherein the diffuser is static, and wherein the steam injection rate of the diffuser is controlled via adjustment of the flow valves.

6. The DSI heater according to any one of claims 1 to 5, wherein the steam supply assembly further comprises a plurality of steam conduits coupled between the

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injection nozzle and the steam inlet pipes for providing the steam to the respective injection caps.

7. The DSI heater according to claim 6, wherein the steam conduits comprise a main steam conduit coupled between the proximal conduit and the main inlet pipe, and auxiliary steam conduits coupled between the auxiliary steam inlet pipes and respective injection caps.

8. The DSI heater according to claim 7, wherein the proximal conduit is removably connectable to the main steam conduit.

9. The DSI heater according to any one of claims 6 to 8, wherein the steam conduits are concentrically disposed with respect to one another.

10. The DSI heater according to any one of claims 6 to 9, wherein the auxiliary steam conduits concentrically extend within the proximal conduit.

11. The DSI heater according to any one of claims 6 to 10, wherein each steam conduit comprises a coupling section for connecting with the corresponding steam inlet pipe.

12. The DSI heater according to claim 11, wherein each of the coupling sections comprises at least one coupling interface connectable to an adjacent coupling interface in order to position and secure steam conduits with respect to one another.

13. The DSI heater according to any one of claims 1 to 12, wherein the injection nozzle is cylindrical, and wherein the injection caps are connectable to one another in an end-to-end manner so as to extend along a common axis and into the process stream.

14. The DSI heater according to claim 13, wherein the injection caps comprise a proximal injection cap connected to the proximal conduit and a distal injection cap positioned at a distal end of the injection nozzle.

15. The DSI heater according to claim 14, wherein the injection caps further comprise at least one intermediate injection cap coupled between the proximal and distal injection caps.

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16. The DSI heater according to any one of claims 13 to 15, wherein each injection cap comprises a front section and a rear section, the rear section being shaped and sized to engage the proximal conduit or the front section of a preceding injection cap so as to be connected thereto.

17. The DSI heater according to claim 16, wherein each injection cap comprises a peripheral rabbet, and wherein the front section of a corresponding injection cap abuts the peripheral rabbet of a subsequent injection cap along the common axis.

18. The DSI heater according to claim 16 or 17, wherein the rear section defines an inner chamber within the preceding injection cap when connected thereto, and wherein the outlets of each injection cap are in fluid communication with corresponding inner chambers.

19. The DSI heater according to claim 18, wherein each injection cap comprises a rear opening defined in the rear section for receiving a corresponding auxiliary steam conduit therein and providing the steam to the inner chamber.

20. The DSI heater according to any one of claims 1 to 19, wherein the injection caps are interchangeable.

21. The DSI heater according to any one of claims 13 to 20, wherein the injection caps are connected via a threaded connection.

22. The DSI heater according to any one of claims 13 to 20, wherein the injection caps are connected via a press-fit connection.

23. The DSI heater according to any one of claims 13 to 20, wherein the injection caps are connected via mechanical fasteners.

24. The DSI heater according to any one of claims 1 to 23, wherein the outlets are arranged in multiple side-by-side rows on respective planes across the proximal conduit and injection caps, each plane being perpendicular to a longitudinal axis of the diffuser.

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25. The DSI heater according to claim 24, wherein each injection cap comprises at least one row of outlets.

26. The DSI heater according to claim 24 or 25, wherein the proximal conduit comprises two rows of outlets and each injection cap comprises a single row of outlets.

27. The DSI heater according to any one of claims 1 to 26, wherein the outlets are sized and configured for injecting the steam at sonic flow conditions.

28. The DSI heater according to any one of claims 1 to 27, wherein the outlets are all of the same size.

29. The DSI heater according to any one of claims 1 to 28, wherein at least some components of the DSI heater are composed of or coated with carbide tungsten.

30. A process for heating a process stream having variable heating requirements and flowing in a bitumen froth treatment operation, the process comprising:

providing a steam source;

supplying steam from the steam source through a plurality of independently operable steam inlet pipes of a direct steam injection (DSI) heater having a diffuser with a plurality of injection stages in fluid communication with a corresponding one of the steam inlet pipes;

injecting steam directly into the process stream via outlets of one or more stages of the diffuser; and

controlling the supply of steam flowing through the steam inlet pipes to vary the amount of steam being injected into the process stream.

31. The process according to claim 30, further comprising a step of determining the heating requirements of the process stream prior to controlling the supply of steam flowing though the steam inlet pipes.

32. The process according to claim 31, wherein the step of determining the heating requirements of the process stream comprises the steps of:

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measuring a temperature of the process stream downstream of the DSI heater;

comparing the measured temperature with a target temperature; and

determining a corresponding increase or decrease in steam injection via the diffuser to achieve the target temperature.

33. The process according to any one of claims 30 to 32, wherein the DSI heater is one of a plurality of DSI heaters provided for heating the process stream; the plurality of the DSI heaters being controlled to provide an overall steam injection, and wherein at least a pair of DSI heaters of the plurality of DSI heaters are provided in series.

34. The process according to claim 33, wherein at least two DSI heaters of the plurality of DSI heaters are provided in parallel.

35. The process according to claim 34, wherein the plurality of DSI heaters are provided in at least two parallel heating trains, each heating train comprising two or more DSI heaters of the plurality of DSI heaters.

36. The process according to claim 35, wherein the parallel heating trains are operated alternately.

37. The process according to any one of claims 30 to 36, wherein the process stream comprises a slurry stream.

38. The process according to any one of claims 30 to 36, wherein the process stream comprises a bitumen froth stream.

39. The process according to any one of claims 30 to 36, wherein the process stream comprises a hydrocarbon stream.

40. The process according to any one of claims 30 to 36, wherein the process stream comprises a process water stream.

41. The process according to any one of claims 30 to 36, wherein the process stream comprises a tailings stream.

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42. The process according to any one of claims 30 to 41, wherein the bitumen froth treatment operation is a paraffinic froth treatment operation.

43. The process according to any one of claims 30 to 42, wherein the outlets are sized and configured for injecting the steam at sonic flow conditions, and wherein the sonic flow conditions of the steam are provided by maintaining a constant steam velocity.

44. The process according to any one of claims 30 to 43, wherein the steam provided from the steam source to the diffuser has a steam temperature that is at least 10°C superheated.

45. The process according to claim 44, wherein the steam provided from the steam source to the diffuser has a steam temperature that is between 10°C and 25°C superheated.

46. The process according to any one of claims 30 to 45, wherein the steam provided from the steam source to the diffuser has a steam pressure of at least 2000 kPag.

47. The process according to claim 46, wherein the steam provided from the steam source to the diffuser has a steam pressure of at least 2200 kPag.

48. The process according to claim 46, wherein the steam provided from the steam source to the diffuser has a steam pressure of between 2100 and 2950 kPag.

49. The process according to any one of claims 30 to 48, wherein the injection stages of the DSI heater comprise a proximal conduit and one or more injection caps connected to the proximal conduit, the proximal conduit and the one or more injection caps comprising the outlets for injecting steam into the process stream.

50. The process according to claim 49, wherein the steam inlet pipes comprise a main inlet pipe in fluid communication with the proximal conduit for providing the steam thereto, and a plurality of auxiliary steam inlet pipes extending from the main inlet pipe and being in fluid communication with respective injection caps.

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51. The process according to any one of claims 30 to 50, wherein each steam inlet pipe comprises a flow valve adapted to control the flow of steam flowing therethrough.

52. The process according to claim 51, wherein the diffuser is static, and wherein the steam injection rate of the diffuser is controlled via adjustment of the flow valves.

53. The process according to any one of claims 49 to 52, wherein the DSI heater further comprises a plurality of steam conduits coupled between the diffuser and the corresponding steam inlet pipe for providing the steam to the respective injection caps.

54. The process according to claim 53, wherein the steam conduits comprise a main steam conduit coupled between the proximal conduit and the main inlet pipe, and auxiliary steam conduits coupled between the auxiliary steam inlet pipes and the respective injection caps.

55. The process according to claim 54, wherein the proximal conduit is removably connectable to the main steam conduit.

56. The process according to any one of claims 53 to 55, wherein the steam conduits are concentrically disposed with respect to one another.

57. The process according to any one of claims 54 to 56, wherein the auxiliary steam conduits concentrically extend within the proximal conduit.

58. The process according to any one of claims 53 to 57, wherein each steam conduit comprises a coupling section for connecting with the corresponding steam inlet pipe.

59. The process according to claim 58, wherein each of the coupling sections comprises at least one coupling interface connectable to an adjacent coupling interface in order to position and secure the steam conduits with respect to one another.

60. The process according to any one of claims 49 to 59, wherein the proximal conduit is cylindrical, and wherein the injection caps are connectable to one another in an end-to-end manner so as to extend along a common axis and into the process stream.

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61. The process according to claim 60, wherein the injection caps comprise a proximal injection cap connected to the proximal conduit and a distal injection cap.

62. The process according to claim 61, wherein the injection caps further comprise at least one intermediate injection cap coupled between the proximal and distal injection caps.

63. The process according to any one of claims 60 to 62, wherein each injection cap comprises a front section and a rear section, the rear section being shaped and sized to engage the proximal conduit or the front section of a preceding injection cap so as to be connected thereto.

64. The process according to claim 63, wherein each injection cap comprises a peripheral rabbet, and wherein the front section of a corresponding injection cap abuts the peripheral rabbet of a subsequent injection cap along the common axis.

65. The process according to claim 63 or 64, wherein the rear section defines an inner chamber within the preceding injection cap when connected thereto, and wherein the outlets of each injection cap are in fluid communication with corresponding inner chambers.

66. The process according to claim 65, wherein each injection cap comprises a rear opening defined in the rear section for receiving a corresponding auxiliary steam conduit therein and providing the steam to the inner chamber.

67. The process according to any one of claims 60 to 66, wherein the injection caps are interchangeable.

68. The process according to any one of claims 60 to 67, wherein the injection caps are connected via a threaded connection.

69. The process according to any one of claims 60 to 67, wherein the injection caps are connected via a press-fit connection.

70. The process according to any one of claims 60 to 67, wherein the injection caps are connected via mechanical fasteners.

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71. The process according to any one of claims 49 to 70, wherein the outlets are arranged in multiple side-by-side rows on respective planes across the proximal conduit and the injection caps, each plane being perpendicular to a longitudinal axis of the diffuser.

72. The process according to claim 71, wherein each injection cap comprises at least one row of outlets.

73. The process according to claim 71 or 72, wherein the proximal conduit comprises two rows of outlets and each injection cap comprises a single row of outlets.

74. The process according to any one of claims 30 to 73, wherein the outlets are all of the same size.

75. The process according to any one of claims 30 to 74, wherein at least some components of the DSI heater are composed of or coated with carbide tungsten.

76. A direct steam injection (DSI) heater for heating a process stream in a bitumen froth treatment operation, the DSI heater comprising:

    a diffuser in fluid communication with a steam source and configured to receive steam therefrom, the diffuser comprising multiple steam injection stages that are static and each comprise outlets for steam injection into the process stream;

    steam supply assembly coupled between the diffuser and the steam source to establish fluid communication therebetween, and configured to independently and selectively supply steam to each of the steam injection stages of the diffuser.

77. The DSI heater according to claim 76, wherein the steam injection stages comprise a proximal conduit and injection caps, and wherein the steam supply assembly comprises steam inlet pipes adapted to provide steam to respective injection caps and being independently operable to control a steam injection rate of the DSI heater.

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78. The DSI heater according to claim 77, wherein the proximal conduit comprises a plurality of outlets arranged about a distal end thereof, and wherein the proximal conduit is in fluid communication with one of the steam inlet pipes.

79. The DSI heater according to claim 78, wherein the steam inlet pipes comprise a main inlet pipe in fluid communication with the proximal conduit for providing steam thereto, and a plurality of auxiliary steam inlet pipes extending from the main inlet pipe and being in fluid communication with the respective injection caps.

80. The DSI heater according to any one of claims 77 to 79, wherein each steam inlet pipe comprises a flow valve adapted to control the flow of steam flowing therethrough.

81. The DSI heater according to claim 80, wherein the diffuser is static, and wherein the steam injection rate of the diffuser is controlled via adjustment of the flow valves.

82. The DSI heater according to any one of claims 77 to 81, wherein the steam supply assembly further comprises a plurality of steam conduits coupled between the injection nozzle and steam inlet pipes for providing the steam to the respective injection caps.

83. The DSI heater according to claim 82, wherein the steam conduits comprise a main steam conduit coupled between the proximal conduit and the main inlet pipe, and auxiliary steam conduits coupled between the auxiliary steam inlet pipes and the respective injection caps.

84. The DSI heater according to claim 83, wherein the proximal conduit is removably connectable to the main steam conduit.

85. The DSI heater according to any one of claims 82 to 84, wherein the steam conduits are concentrically disposed with respect to one another.

86. The DSI heater according to any one of claims 82 to 85, wherein the auxiliary steam conduits concentrically extend within the proximal conduit.

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87. The DSI heater according to any one of claims 82 to 86, wherein each steam conduit comprises a coupling section for connecting with the corresponding steam inlet pipe.

88. The DSI heater according to claim 87, wherein each of the coupling sections comprises at least one coupling interface connectable to an adjacent coupling interface in order to position and secure the steam conduits with respect to one another.

89. The DSI heater according to any one of claims 77 to 88, wherein the injection nozzle is cylindrical, and wherein the injection caps are connectable to one another in an end-to-end manner so as to extend along a common axis and into the process stream.

90. The DSI heater according to claim 89, wherein the injection caps comprise a proximal injection cap connected to the proximal conduit and a distal injection cap positioned at a distal end of the injection nozzle.

91. The DSI heater according to claim 90, wherein the injection caps further comprise at least one intermediate injection cap coupled between the proximal and distal injection caps.

92. The DSI heater according to any one of claims 89 to 91, wherein each injection cap comprises a front section and a rear section, the rear section being shaped and sized to engage the proximal conduit or the front section of a preceding injection cap so as to be connected thereto.

93. The DSI heater according to claim 92, wherein each injection cap comprises a peripheral rabbet, and wherein the front section of a corresponding injection cap abuts the peripheral rabbet of a subsequent injection cap along the common axis.

94. The DSI heater according to claim 92 or 93, wherein the rear section defines an inner chamber within the preceding injection cap when connected thereto, and wherein the outlets of each injection cap are in fluid communication with corresponding inner chambers.

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95. The DSI heater according to claim 94, wherein each injection cap comprises a rear opening defined in the rear section for receiving a corresponding auxiliary steam conduit therein and providing the steam to the inner chamber.

96. The DSI heater according to any one of claims 77 to 95, wherein the injection caps are interchangeable.

97. The DSI heater according to any one of claims 89 to 96, wherein the injection caps are connected via a threaded connection.

98. The DSI heater according to any one of claims 89 to 96, wherein the injection caps are connected via a press-fit connection.

99. The DSI heater according to any one of claims 89 to 96, wherein the injection caps are connected via mechanical fasteners.

100. The DSI heater according to any one of claims 77 to 99, wherein the outlets are arranged in multiple side-by-side rows on respective planes across the proximal conduit and injection caps, each plane being perpendicular to a longitudinal axis of the diffuser.

101. The DSI heater according to claim 100, wherein each injection cap comprises at least one row of outlets.

102. The DSI heater according to claim 100 or 101, wherein the proximal conduit comprises two rows of outlets and each injection cap comprises a single row of outlets.

103. The DSI heater according to any one of claims 76 to 102, wherein the outlets are sized and configured for injecting the steam at sonic flow conditions.

104. The DSI heater according to any one of claims 76 to 103, wherein the outlets are all of the same size.

105. The DSI heater according to any one of claims 76 to 104, wherein at least some components of the DSI heater are composed of or coated with carbide tungsten.

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106. A process for heating a process stream flowing in a bitumen froth treatment operation, the process comprising:

providing a main steam flow;

splitting the main steam flow into multiple steam flows;

delivering the multiple steam flows to respective injection stages located together at a fixed location in the process stream for direct heating thereof; and

controlling the multiple steam flows independently to regulate steam injection into the process stream.

107. The process according to claim 106, further comprising a step of determining heating requirements of the process stream prior to the step of controlling the multiple steam flows.

108. The process of claim 107, wherein the step of determining the heating requirements of the process stream comprises the steps of:

measuring a temperature of the process stream downstream of the fixed location;

comparing the measured temperature with a target temperature; and

determining a corresponding increase or decrease in steam injection via the multiple steam flows to achieve the target temperature.

109. The process according to any one of claims 106 to 108, wherein the process stream comprises a slurry stream.

110. The process according to any one of claims 106 to 108, wherein the process stream comprises a bitumen froth stream.

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111. The process according to any one of claims 106 to 108, wherein the process stream comprises a hydrocarbon stream.

112. The process according to any one of claims 106 to 108, wherein the process stream comprises a process water stream.

113. The process according to any one of claims 106 to 108, wherein the process stream comprises a tailings stream.

114. The process according to any one of claims 106 to 113, wherein the bitumen froth treatment operation is a paraffinic froth treatment operation.

115. The process according to any one of claims 106 to 114, wherein the step of delivering the multiple steam flows for direct heating of the process stream is done at sonic flow conditions, and wherein the sonic flow conditions of the steam are provided by maintaining a constant steam velocity.

116. The process according to any one of claims 106 to 115, wherein the steam provided to the process stream has a steam temperature being at least 10°C superheated.

117. The process according to claim 116, wherein the steam provided to the process stream has a steam temperature being between 10°C and 25°C superheated.

118. The process according to any one of claims 106 to 117, wherein the steam provided to the process stream has a steam pressure of at least 2000 kPag.

119. The process according to claim 118, wherein the steam provided to the process stream has a steam pressure of at least 2200 kPag.

120. The process according to claim 118, wherein the steam provided to the process stream has a steam pressure of between 2100 and 2950 kPag.

121. The process according to any one of claims 106 to 120, wherein the step of delivering the multiple steam flows to the respective injection stages is done using multiple steam inlet pipes, each steam inlet pipe being connected to a respective one of the injection stages.

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122. The process according to claim 121, wherein the steam inlet pipes comprise a main inlet pipe for providing the main steam flow, and a plurality of auxiliary steam inlet pipes extending from the main inlet pipe for splitting the main steam flow into multiple steam flows.

123. The process according to claim 121 or 122, wherein each steam inlet pipe comprises a flow valve adapted to control the flow of steam flowing therethrough.

124. The process according to claim 123, wherein the steam injection is controlled via adjustment of the flow valves.

125. The process according to any one of claims 121 to 124, wherein the injection stages are part of a direct steam injection (DSI) heater in fluid communication with a steam source.

126. The process according to claim 125, wherein the DSI heater is one of a plurality of DSI heaters provided for heating the process stream; the plurality of the DSI heaters being controlled to provide an overall steam injection, and wherein at least a pair of DSI heaters of the plurality of DSI heaters are provided in series.

127. The process according to claim 126, wherein at least two DSI heaters of the plurality of DSI heaters are provided in parallel.

128. The process according to claim 126 or 127, wherein the plurality of DSI heaters are provided in at least two parallel heating trains, each heating train comprising two or more DSI heaters of the plurality of DSI heaters.

129. The process according to claim 128, wherein the parallel heating trains are operated alternately.

130. The process according to any one of claims 125 to 129, wherein the DSI heater comprises a plurality of steam conduits coupled between the injection stages and the corresponding steam inlet pipe for providing the steam to the respective injection stages.

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131. The process according to claim 130, wherein the steam conduits comprise a main steam conduit coupled between the proximal conduit and the main inlet pipe, and auxiliary steam conduits coupled between the auxiliary steam inlet pipes and respective injection caps.

132. The process according to claim 131, wherein the proximal conduit is removably connectable to the main steam conduit.

133. The process according to any one of claims 130 to 132, wherein the steam conduits are concentrically disposed with respect to one another.

134. The process according to any one of claims 131 to 133, wherein the auxiliary steam conduits concentrically extend within the proximal conduit.

135. The process according to any one of claims 130 to 134, wherein each steam conduit comprises a coupling section for connecting with the corresponding steam inlet pipe.

136. The process according to claim 135, wherein each of the coupling sections comprises at least one coupling interface connectable to an adjacent coupling interface in order to position and secure the steam conduits with respect to one another.

137. The process according to any one of claims 125 to 136, wherein the injection stages comprise a proximal conduit and one or more injection caps connected to the proximal conduit, the proximal conduit and the injection caps comprising outlets for injecting steam into the process stream at the fixed location.

138. The process according to claim 137, wherein the proximal conduit is cylindrical, and wherein the injection caps are connectable to one another in an end-to-end manner so as to extend along a common axis and into the process stream.

139. The process according to claim 138, wherein the injection caps comprise a proximal injection cap connected to the proximal conduit and a distal injection cap.

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140. The process according to claim 139, wherein the injection caps further comprise at least one intermediate injection cap coupled between the proximal and distal injection caps.

141. The process according to any one of claims 138 to 140, wherein each injection cap comprises a front section and a rear section, the rear section being shaped and sized to engage the proximal conduit or the front section of a preceding injection cap so as to be connected thereto.

142. The process according to claim 141, wherein each injection cap comprises a peripheral rabbet, and wherein the front section of a corresponding injection cap abuts the peripheral rabbet of a subsequent injection cap along the common axis.

143. The process according to claim 141 or 142, wherein the rear section defines an inner chamber within the preceding injection cap when connected thereto, and wherein the outlets of each injection cap are in fluid communication with corresponding inner chambers.

144. The process according to claim 143, wherein each injection cap comprises a rear opening defined in the rear section for receiving a corresponding one of the auxiliary steam conduits therein and providing the steam to the inner chamber.

145. The process according to any one of claims 137 to 144, wherein the injection caps are interchangeable.

146. The process according to any one of claims 137 to 145, wherein the injection caps are connected via a threaded connection.

147. The process according to any one of claims 137 to 145, wherein the injection caps are connected via a press-fit connection.

148. The process according to any one of claims 137 to 145, wherein the injection caps are connected via mechanical fasteners.

149. The process according to any one of claims 137 to 148, wherein the outlets are arranged in multiple side-by-side rows on respective planes across the proximal

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conduit and the injection caps, each plane being perpendicular to a longitudinal axis of the diffuser.

150. The process according to claim 149, wherein each injection cap comprises at least one row of outlets.

151. The process according to claim 149 or 150, wherein the proximal conduit comprises two rows of outlets and each injection cap comprises a single row of outlets.

152. The process according to any one of claims 137 to 151, wherein the outlets are all of the same size.

153. The process according to any one of claims 125 to 152, wherein at least some components of the DSI heater are composed of or coated with carbide tungsten.

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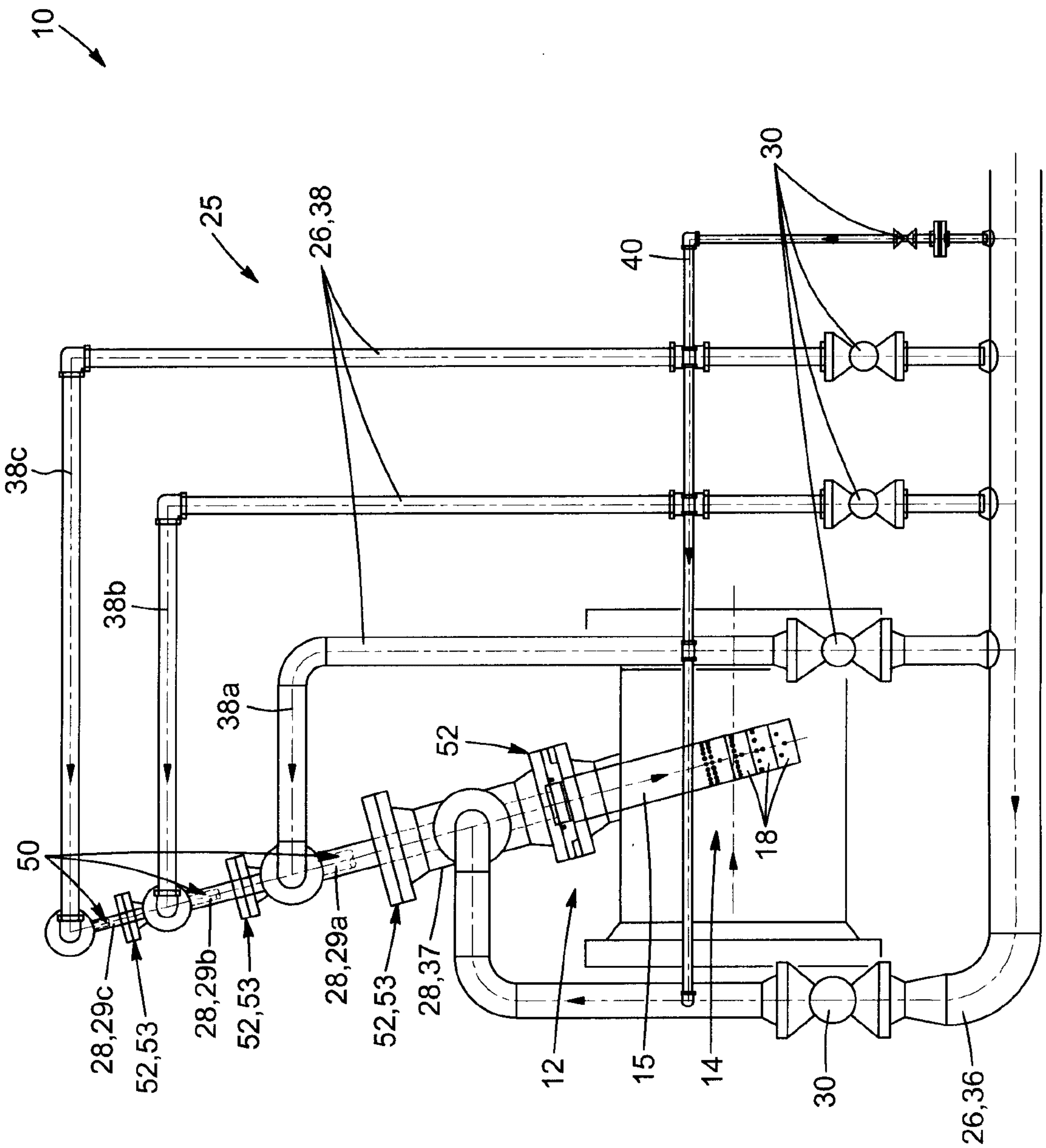
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FIG. 1

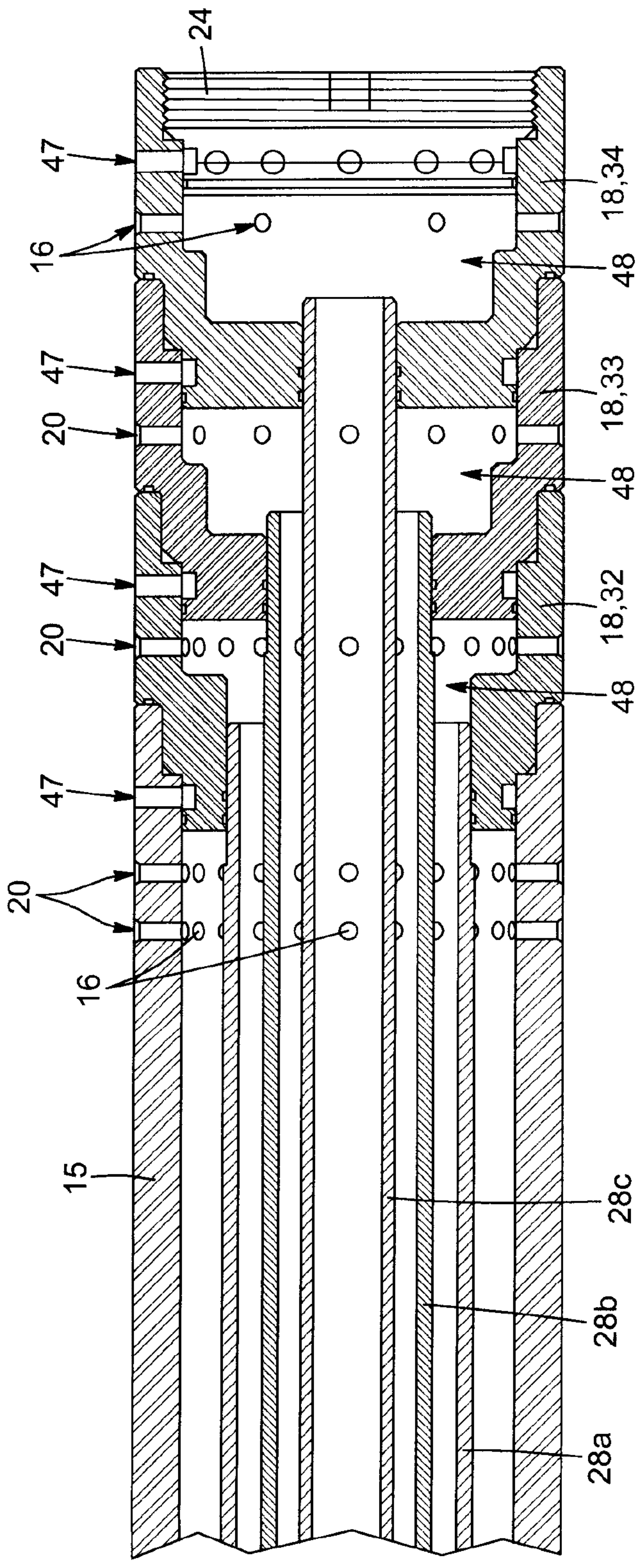

FIG. 2

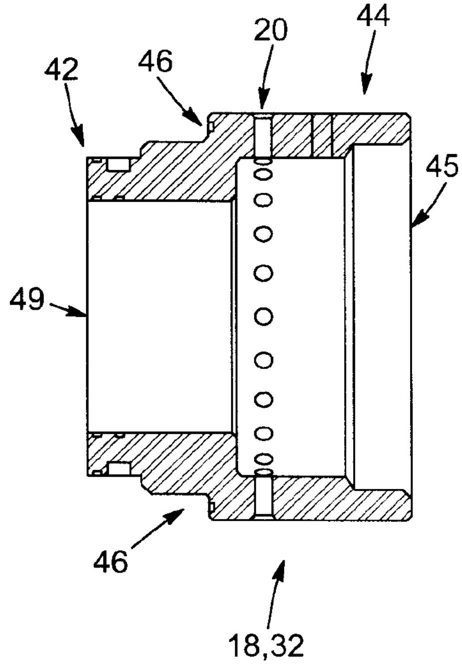

FIG. 3a

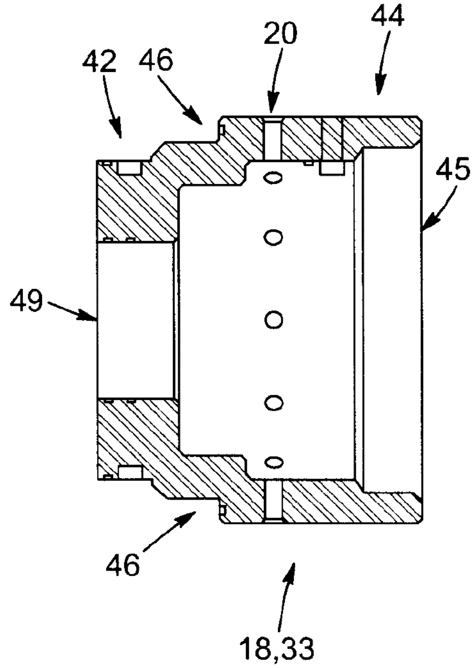

FIG. 3b

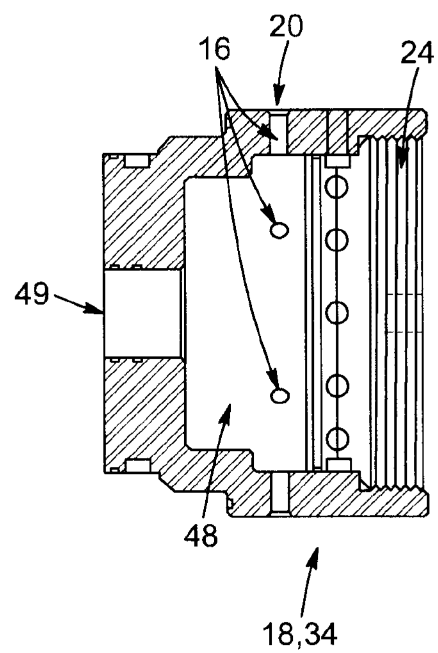

FIG. 3c

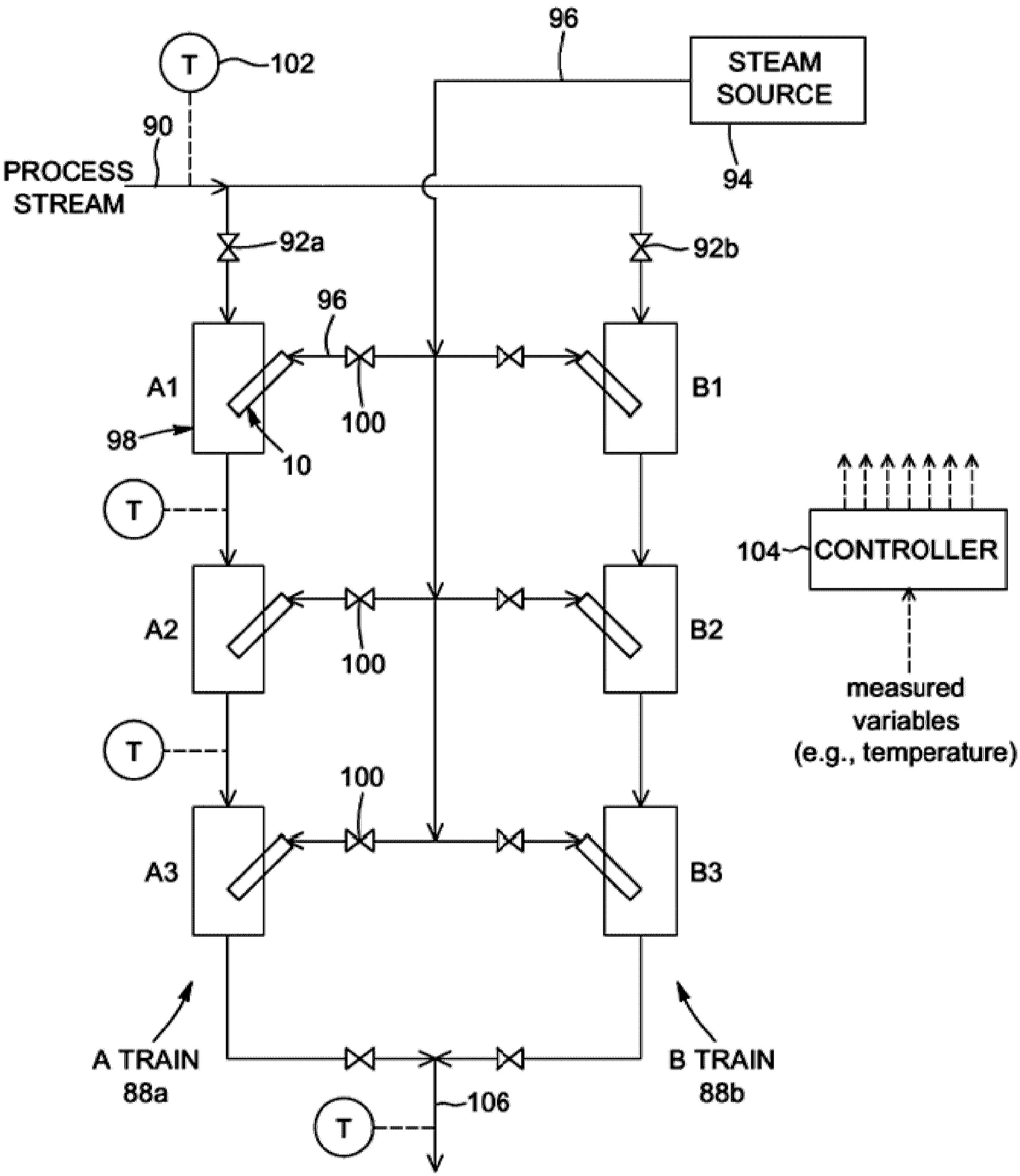

FIGURE 4

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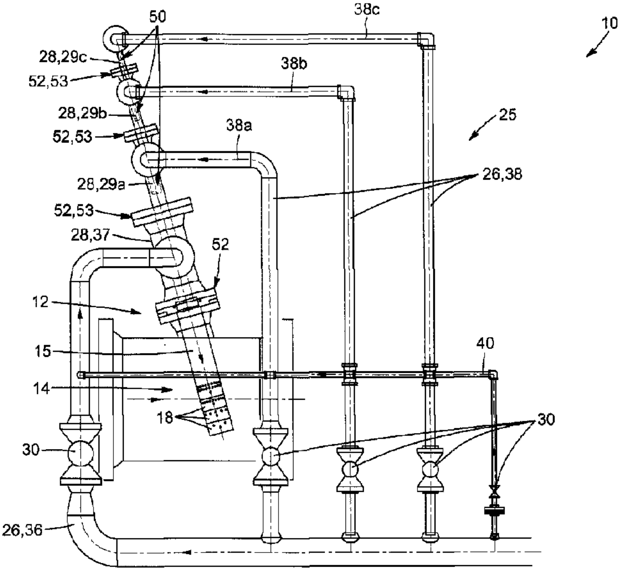
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