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(54) PROCESS HEAT RECOVERY SYSTEM

(57) A process heat recovery system (1) wherein a heat exchanger (2) of shell- and-tube type works either as a boiler or as a boiler feedwater preheater, with boiler water or boiler feedwater circulating on shell-side, so as to cool a hot process fluid circulating on tube-side. The heat exchanger (2) is connected to a steam drum (3) by downcomer piping (12) and riser piping (14) for water circulation between the heat exchanger (2) and the steam drum (3). The heat exchanger (2) receives either the boiler water from the steam drum (3) by the downcomer piping (12), when the heat exchanger (2) works as a boiler, or the boiler feedwater by a boiler feedwater piping (27), when the heat exchanger (2) works as a boiler feedwater preheater. The heat exchanger (2) delivers by the riser piping (14) to the steam drum (3) either boiler water, when the heat exchanger (2) works as a boiler, or preheated boiler feedwater, when the heat exchanger (2) works as a boiler feedwater preheater. The heat exchanger (2) is provided with shell-side plates or baffles (29) for imparting prevailing flow directions to circulating water so that, when the heat exchanger (2) works as a boiler, the shell-side water flow, crosswise the tubes, has a prevailing vertical direction, whereas, when the heat exchanger (2) works as a boiler feedwater preheater, the shell-side water flow, crosswise the tubes, has a prevailing horizontal direction.

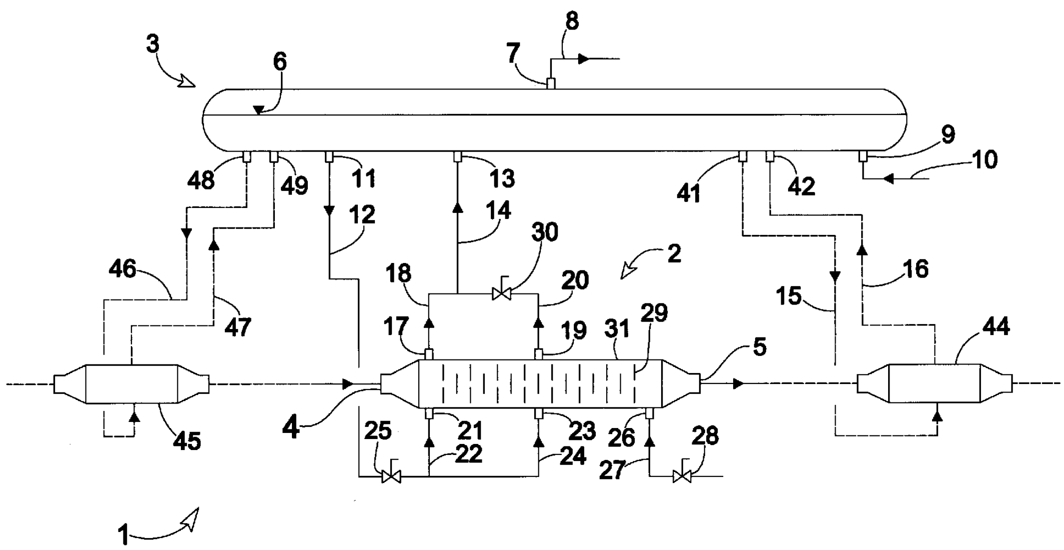

Fig.1

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Description

Field of the invention

[0001] The present invention refers in general to a process heat recovery system and, more specifically, to an innovative process heat recovery system comprising a horizontal, or slightly sloped, shell-and-tube heat exchanger, which cools a hot process fluid flowing on tube-side by means of either shell-side water vaporization or shell-side boiler feedwater preheating, and a steam drum for water-steam separation, which is connected to the heat exchanger by downcomer and riser piping. Such a heat recovery system can also comprise additional heat exchangers, like boilers, connected to the steam drum by additional downcomer and riser piping.

Background of the invention

[0002] It is common practice in process industry, when a chemical or petrochemical fluid at high temperature must be cooled, to implement a heat recovery system including a process boiler of shell-and-tube type connected to a steam drum by a piping assembly, wherein the hot process fluid is flowed in the boiler tubes, whereas the boiler water is flowed on the boiler shell-side crosswise the tubes. In the present specification, with the term "crosswise" it is meant that the water is moving across the tubes or is crossing the tubes bundle of the heat exchanger, wherein the expression "boiler water" means that said water can be water in liquid form and a mixture of water in liquid form and steam. The water-steam mixture produced in the boiler is delivered, by riser piping, to the steam drum which has a controlled water-level and separation devices for providing for water-steam separation. Fresh boiler water is delivered by the steam drum to the boiler by means of downcomer piping. The water therefore circulates in between the boiler and the steam drum as in a loop. The produced steam, after water-steam separation in the steam drum, is delivered to other power or process equipment. The amount of the leaving steam is reintegrated by an equivalent amount of boiler feedwater injected into the steam drum and mixed with the water inside the steam drum.

[0003] The boiler feedwater is normally preheated before injection into the steam drum. Consequently, the process heat recovery system can also include an additional shell-and-tube heat exchanger working as a boiler feedwater preheater. Such a preheater can preheat the boiler feedwater by cooling either the same process fluid flowing through the boiler or another hot fluid. When the boiler feedwater preheater cools the same hot process fluid flowing in the boiler tubes, the preheater is normally considered an integral part of the process heat recovery system, and therefore the system comprises two distinct shell-and-tube heat exchangers, that is, a boiler and a feedwater preheater.

[0004] Process intensifications of heat recovery systems comprising a boiler and a preheater both of shell-and-tube type are known in the state of the art.

[0005] For example, document US 4074660 A discloses a system comprising at least a steam drum and a shell-and-tube heat exchanger, connected together via piping, for cooling a hot fluid flowing on the heat exchanger tube-side by cold water flowing on the heat exchanger shell-side. The heat exchanger shell is split, by a partition wall, into two chambers that are not in direct fluid communication, so that two different streams of water can be flowed in the shell with no direct mixing. In the first shell-side chamber boiler water is flowed, and therefore the heat exchanger works as a boiler in said first shell-side chamber, whereas in the second shell-side chamber boiling or subcooled water is flowed, and therefore the heat exchanger works as a boiler or boiler feedwater preheater in said second shell-side chamber.

[0006] Document US 7784433 B2 discloses another system comprising a steam drum and a shell-and-tube heat exchanger, connected together via piping, for cooling a hot process gas flowing on the heat exchanger tube-side by cold water flowing on the heat exchanger shell-side. The heat exchanger shell is split, by a partition wall, into two chambers that are in direct fluid communication. The first shell-side chamber works as a boiler, whereas the second shell-side chamber works as a boiler feedwater preheater. Each chamber is provided with distinct inlet and outlet piping, and more specifically with distinct piping for connecting with the steam drum. The boiler chamber is connected to the steam drum by riser and downcomer piping. The preheater chamber is connected to the steam drum by a boiler feedwater piping.

[0007] Document US 10744474 B2 discloses still another system comprising a steam drum and a shell-and-tube heat exchanger, connected together via piping, for cooling a hot process gas flowing on tube-side by cold water flowing on shell-side. The heat exchanger shell is not provided with partition walls and therefore the heat exchanger shell is not split into different chambers. The heat exchanger can work either as a boiler or as a boiler feedwater preheater or, in other words, either boiler water or boiler feedwater can be flowed through the heat exchanger shell. The system is provided with downcomer and riser piping for respectively delivering boiler water from the steam drum to the heat exchanger shell and for delivering boiler water from the heat exchanger shell to the steam drum, and with boiler feedwater inlet and outlet piping for respectively injecting boiler feedwater into the heat exchanger shell and for delivering preheated boiler feedwater from the heat exchanger shell to the steam drum. Consequently, the technology described in document US 10744474 B2 is characterized by two distinct piping circuits connecting the heat exchanger shell to the steam drum. More specifically, one piping circuit is designed for boiling operations and consists of downcomer and riser piping, whereas the other piping circuit is designed for preheating operations and consists of boiler feedwater outlet piping. Therefore, when the heat exchanger works as a boiler, the boiler water under boiling conditions is delivered from the heat exchanger to the steam drum via riser piping, whereas, when the heat exchanger works as a preheater, the preheated boiler feedwater under subcooled conditions is delivered from the heat exchanger to the steam drum via a boiler feedwater piping which is distinct from said riser piping. The downcomer, the riser and the boiler feedwater piping are all provided with intercepting valves so to intercept and switch-off one circuit, whereas the other circuit is open and switched-on.

[0008] The intensified process heat recovery systems described in the above documents are competitive, since instead of two independent heat exchangers, that is, a boiler and a preheater, there is one single heat exchanger capable of working as a boiler and/or a preheater. However, a drawback of the intensified process heat recovery systems disclosed in document US 7784433 B2 and especially in document US 10744474 B2 is due to a complex piping and valves configuration, because the heat exchangers that work as a boiler or preheater are respectively connected to the steam drum by two distinct piping circuits for each single heat exchanger.

Summary of the invention

[0009] One object of the present invention is therefore to provide a process heat recovery system which is capable of resolving the drawbacks of the prior art in a simple, inexpensive and particularly functional manner.

[0010] In detail, one object of the present invention is to provide a process heat recovery system which is capable of optimizing piping and valves that connect a heat exchanger, working as a boiler or as a boiler feedwater preheater, to a steam drum. Such a process heat recovery system is designed to have a piping and valves configuration which is less complex with respect to similar systems according to the prior art, resulting more practical and competitive from engineering, manufacturing, and operational standpoint.

[0011] Another object of the present invention is to provide a process heat recovery system comprising a shell-and-tube heat exchanger with a special configuration of shell-side baffles, so as to impart to the circulating water different prevailing flow directions depending on boiler or preheating operations. The hot process fluid flows through the shell-and-tube heat exchanger on tube-side, by one or more passageways. On the shell-side, either boiler water at, or near at, saturation conditions, or boiler feedwater in subcooled conditions, flows. In the first case, the heat exchanger works as a boiler and the boiler water has a significant vaporization inside the heat exchanger shell, whereas in the latter case the heat exchanger works as a boiler feedwater preheater and the boiler feedwater is preheated with no vaporization or with a negligible vaporization inside the heat exchanger shell. The heat exchanger shell is not provided with partition walls forming distinct shell-side chambers.

[0012] These objects are achieved according to the present invention by providing a process heat recovery system as set forth in the attached claims.

[0013] Further features of the invention are underlined by the dependent claims, which are an integral part of the present description.

[0014] The process heat recovery system according to the present invention is designed for cooling a hot process fluid by means of boiler water vaporization or boiler feedwater preheating. This process heat recovery system comprises at least one heat exchanger, designed for cooling the hot process fluid, at least one steam drum and at least one interconnecting piping assembly, which connects the heat exchanger and the steam drum.

[0015] The heat exchanger is of shell-and-tube type and is provided with a shell, with a plurality of tubes, with at least one hot process fluid inlet, for inletting said hot process fluid that flows on tube-side of the heat exchanger by one or more tube-side passageways, with at least one hot process fluid outlet, for outletting said hot process fluid from the tube-side of the heat exchanger, with at least one shell downcomer connection, through which the boiler water flowing through the shell enters said shell, and with at least one boiler feedwater connection, through which the boiler feedwater flowing through the shell enters said shell.

[0016] The steam drum is provided with at least one drum downcomer connection and at least one drum riser connection. The interconnecting piping assembly comprises at least one downcomer piping connected, at one end thereof, to the drum downcomer connection and, at the other end thereof, to the shell downcomer connection via at least one respective downcomer duct, so that the boiler water is delivered from the steam drum to the heat exchanger via the downcomer piping. The boiler feedwater connection is connected to at least one respective boiler feedwater piping, so that the boiler feedwater is delivered to the heat exchanger via the boiler feedwater piping.

[0017] At least one downcomer intercepting valve is provided on the downcomer piping, or on each downcomer duct, or on the downcomer piping and on at least one downcomer duct. The boiler feedwater piping is provided in turn with at least one boiler feedwater intercepting valve.

[0018] The shell is provided with at least two shell riser connections for outletting either the boiler water or the boiler feedwater, whereas the interconnecting piping assembly comprises a single riser piping connected, at one end thereof, to the drum riser connection of the steam drum and, at the other end thereof, to the at least two shell riser connections of the heat exchanger via a riser duct for each shell riser connection, so that either the boiler water or the boiler feedwater flowing through the shell is delivered from the heat exchanger to the steam drum via said single riser piping.

[0019] Preferably, at least one of the riser ducts is provided with a respective riser intercepting valve.

[0020] The process heat recovery system according to the present invention may comprise at least one additional upstream heat exchanger. Therefore, the hot process fluid inlet may be connected to the upstream heat exchanger, whereas the steam drum may be provided with at least one drum upstream inlet connection and with at least one drum upstream outlet connection, so that the upstream heat exchanger may be connected to the steam drum by means of at least one drum upstream riser piping, via said drum upstream inlet connection, and by means of at least one drum upstream downcomer piping, via said drum upstream outlet connection.

[0021] The process heat recovery system according to the present invention may also comprise at least one additional downstream heat exchanger. Therefore, the hot process fluid outlet may be connected to the downstream heat exchanger, whereas the steam drum may be provided with at least one drum downstream inlet connection and with at least one drum downstream outlet connection, so that the downstream heat exchanger may be connected to the steam drum by means of at least one drum downstream riser piping, via said drum downstream inlet connection, and by means of at least one drum downstream downcomer piping, via said drum downstream outlet connection.

[0022] According to a preferred aspect of the present invention, the shell of the heat exchanger may have a substantially horizontal longitudinal axis and may be internally provided with one or more shell-side plates or baffles, which are substantially perpendicular to the longitudinal axis of the shell and through which the tubes of the heat exchanger pass. The plates or baffles are provided with main cuts or openings designed to distribute either the boiler water or the boiler feedwater all along the direction of said longitudinal axis through shell-side predefined flow directions.

[0023] Preferably, at least part of the plates or baffles may be provided with one or more respective top cuts or openings designed to distribute at least part of either the boiler water or the boiler feedwater along substantially horizontal top-shell flow directions at a top portion of the shell. Always preferably, at least part of the plates or baffles may be provided with one or more respective bottom cuts or openings designed to distribute at least part of either the boiler water or the boiler feedwater along substantially horizontal bottom-shell flow directions at a bottom portion of the shell. The plates or baffles may be single-segmental plates or baffles, or double-segmental plates or baffles, or triple-segmental plates or baffles, or also disc-and-donut type plates or baffles.

[0024] According to a first preferred embodiment of the process heat recovery system, the plates or baffles, the shell downcomer connection and the shell riser connections are designed and positioned on the heat exchanger to impart a prevailing vertical flow, crosswise the tubes, to the boiler water when the heat exchanger works as a boiler. Preferably, the hot process fluid is a hot process gas discharged from a chemical reactor or furnace. The heat exchanger may thus be a process gas cooler working as a boiler, for boiling operations, therefore producing boiler water with a significant fraction of steam, or a water-steam mixture, delivered to the steam drum via the drum riser connection.

[0025] According to a second preferred embodiment of the process heat recovery system, the plates or baffles, the boiler feedwater connection and the shell riser connections are designed and positioned on the heat exchanger to impart a prevailing horizontal flow direction, with a tortuous path or chicanes crosswise the tubes, to the boiler feedwater when the heat exchanger works as a boiler feedwater preheater. Preferably, the hot process fluid is once again a hot process gas discharged from a chemical reactor or furnace, and the heat exchanger may be a process gas cooler working as a boiler feedwater preheater, therefore producing a preheated boiler feedwater, with no vaporization or with a negligible vaporization, delivered to the steam drum via the drum riser connection.

[0026] Preferably, the steam drum may be placed above said heat exchanger and may be provided with at least one outlet steam connection, connected to at least one corresponding outlet steam piping, at least one drum feedwater connection, connected to at least one corresponding drum feedwater piping, and preferably control means to control a water-level within the steam drum.

[0027] The process heat recovery system according to the present invention may thus implement a method for recovering process heat, wherein the heat exchanger may alternately work as a boiler, for boiling operations, and as a boiler feedwater preheater, for preheating operations. When the heat exchanger works as a boiler, the boiler feedwater intercepting valve is closed and the downcomer intercepting valve is open, so that the boiler water is delivered from the steam drum to the heat exchanger via the downcomer piping, said boiler water flows and vaporizes crosswise the tubes of the heat exchanger and then said boiler water is delivered from the heat exchanger to the steam drum via the single riser piping. When the heat exchanger works as a boiler feedwater preheater, the boiler feedwater intercepting valve is open and the downcomer intercepting valve is closed, so that the boiler feedwater is delivered to the heat exchanger via the boiler feedwater piping, said boiler feedwater flows and preheats crosswise the tubes of the heat exchanger and then said boiler feedwater is delivered from the heat exchanger to the steam drum via the single riser piping. Preferably, a respective riser intercepting valve, provided on at least one of the riser ducts, is open when the heat exchanger works as a boiler and is closed when the heat exchanger works as a boiler feedwater preheater.

[0028] Therefore, in the process heat recovery system according to the present invention the heat exchanger is connected to the steam drum by downcomer and riser piping only. There is no additional and distinct boiler feedwater piping connecting the heat exchanger to the steam drum as in the prior art documents cited above.

[0029] When the heat exchanger of the system according to the present invention works as a boiler, the shell-side boiler water at saturation conditions and with a significant fraction of steam, or the water-steam mixture, is delivered from the heat exchanger shell to the steam drum by means of riser piping, while fresh boiler water, at or near at saturation conditions and with no steam, is delivered from the steam drum to the heat exchanger shell by the downcomer piping.

[0030] When the heat exchanger of the system according to the present invention works as a boiler feedwater preheater, the preheated boiler feedwater, in subcooled conditions or with a negligible vaporization, is delivered from the heat exchanger shell to the steam drum by means of said riser piping and not by an additional, distinct boiler feedwater piping. Therefore, the riser piping is not necessarily provided with intercepting valve, since it works under both boiling and preheating operations.

[0031] In other words, the process heat recovery system according to the present invention is characterized by an innovative process intensification: instead of two distinct piping for respectively delivering boiler water and boiler feedwater from the heat exchanger shell to the steam drum, there is a common single piping. As a result, the piping and valves configuration of the process heat recovery system according to the present invention is simplified (intensified) regarding prior art technologies, both from manufacturing and operational standpoint.

Brief description of the drawings

[0032] The features and advantages of a process heat recovery system according to the present invention will be clearer from the following exemplifying and nonlimiting description, with reference to the enclosed schematic drawings, in which:

Figure 1 is a schematic view of a preferred embodiment of a process heat recovery system according to the present invention, wherein the side-view of the heat exchanger, the side-view of the steam drum, the interconnecting piping assembly between the heat exchanger and the steam drum, other piping connected to the heat exchanger and the steam drum, as well as piping flows directions, are shown;

Figure 2 is a schematic side-view of the heat exchanger of Figure 1, wherein said heat exchanger works as a boiler and wherein the respective shell-side inlet and outlet flow directions, as well as the prevailing flow directions inside the heat exchanger shell, are shown;

Figure 3 is another schematic side-view of the heat exchanger of Figure 1, wherein said heat exchanger works as a boiler feedwater preheater and wherein the respective shell-side inlet and outlet flow directions, as well as the prevailing flow directions inside the heat exchanger shell, are shown.

Detailed description of the invention

[0033] With specific reference to figure 1, a first preferred embodiment of a process heat recovery system according to the present invention is shown. The process heat recovery system is indicated as a whole with reference numeral 1 and is configured for cooling a hot process fluid by means of boiler water vaporization or boiler feedwater preheating. The process heat recovery system 1 comprises at least one heat exchanger 2, designed for cooling the hot process fluid, and a steam drum 3, preferably placed above the heat exchanger 2. At least one interconnecting piping assembly 12, 22, 24 and 14, 18, 20, as will be better explained below, connects the heat exchanger 2 and the steam drum 3. The heat exchanger 2 is of the shell-and-tube type and preferably has a horizontal or slightly sloped layout. In other words, the heat exchanger 2 is provided with a shell 31 preferably having a substantially horizontal, or slightly sloped, longitudinal axis.

[0034] The heat exchanger 2 has at least one hot process fluid inlet 4 and at least one hot process fluid outlet 5 on tube-side. The hot process fluid to be cooled therefore flows through the plurality of tubes of the heat exchanger 2, by one or more tube-side passageways. On shell-side, the heat exchanger 2 is provided with plates or baffles 29 installed inside the shell 31 for imparting to shell-side fluid preferred and prevailing flow directions, as one can see in figures 2 and 3. The plates or baffles 29 do not form any distinct chamber inside the shell 31 of the heat exchanger 2.

[0035] The shell 31 of the heat exchanger 2 is provided with at least one shell downcomer connection 21, 23, connected to respective downcomer ducts 22, 24 of the interconnecting piping assembly, for inletting the boiler water into the shell 31 of the heat exchanger 2. The shell 31 of the heat exchanger 2 is also provided with at least two shell riser connections 17, 19, connected to respective riser ducts 18, 20 of the interconnecting piping assembly, for outletting either the produced water-steam mixture or the preheated boiler feedwater from the shell 31. The shell 31 of the heat exchanger 2 is furthermore provided with at least one boiler feedwater connection 26, connected to at least one respective boiler feedwater piping 27, for inletting the boiler feedwater into the shell 31. The two riser ducts 18, 20 are collected, preferably nearby the heat exchanger 2, into a single riser piping 14 connected to the steam drum 3 via at least one drum riser connection 13, preferably a single drum riser connection 13. Similarly, the two downcomer ducts 22, 24 are collected, preferably nearby the heat exchanger 2, into at least one downcomer piping 12 connected to the drum 3 via at least one drum downcomer connection 11. Preferably, a single downcomer piping 12 and a single drum downcomer connection 11 are provided.

[0036] In the preferred embodiment of the process heat recovery system 1 shown in figure 1, at least one of the riser ducts 20 is provided with a respective riser intercepting valve 30. In another possible configuration of the process heat recovery system, different than that of figure 1 and not shown in the drawings, the riser ducts are not provided with intercepting valves.

[0037] In the preferred embodiment of the process heat recovery system 1 shown in figure 1, the single riser piping 14 is not provided with intercepting valve. The downcomer piping 12 is preferably provided with a single downcomer intercepting valve 25, whereas downcomer ducts 22, 24 are not provided with intercepting valves. In another possible configuration of the process heat recovery system, different than that of figure 1 and not shown in the drawings, the downcomer piping is not provided with intercepting valves, whereas the downcomer ducts are provided with respective downcomer intercepting valves (not shown). In a further, possible configuration of the process heat recovery system, different than that of figure 1 and not shown in the drawings, the downcomer piping is provided with a single intercepting valve and at least one of the downcomer ducts is provided with a respective downcomer intercepting valve.

[0038] In the preferred embodiment of the process heat recovery system 1 shown in figure 1, the boiler feedwater piping 27 is provided with a boiler feedwater intercepting valve 28.

[0039] The steam drum 3 has also an outlet steam connection 7, connected to a corresponding outlet steam piping 8, for outletting the steam produced in the heat exchanger 2 and then separated in the steam drum 3, and a drum feedwater connection 9, connected to a corresponding drum feedwater piping 10. The steam drum 3 can also be provided with at least one additional drum downstream/upstream inlet connection 42, 49 and at least one additional drum downstream/upstream outlet connection 41, 48 for respective additional drum downstream/upstream riser piping 16, 47 and drum downstream/upstream downcomer piping 15, 46, connecting the steam drum 3 to other boilers or exchangers, like for example one or more additional downstream heat exchangers 44, connected to the steam drum 3 via a drum downstream downcomer piping 15 and a drum downstream riser piping 16, and/or one or more additional upstream heat exchangers 45, connected to the steam drum 3 via a drum upstream downcomer piping 46 and a drum upstream riser piping 47. The steam drum 3 is also usually provided with other well-known connections (not shown) for drains, blowdowns, instruments, etc. The steam drum 3 preferably comprises control means to control a water-level 6 within the steam drum 3.

[0040] The heat exchanger 2 of the process heat recovery system 1 according to the present invention can work either as a boiler (for boiling operations) or as a boiler feedwater preheater (for preheating operations).

[0041] Under boiling operations, the single downcomer intercepting valve 25, or the multiple downcomer intercepting valves (not shown), if present, are open so that the boiler water, at saturation conditions or near saturation conditions, flows from the steam drum 3 to the shell 31 of the heat exchanger 2 via the downcomer piping 12 and the downcomer ducts 22, 24. The riser intercepting valve 30 is preferably open. The water-steam mixture produced in the heat exchanger 2 flows from the shell 31 to the steam drum 3 via the riser ducts 18, 20 and the single riser piping 14. The boiler feedwater intercepting valve 28 is closed, so that no flow circulates in boiler feedwater piping 27. The boiler water coming from the downcomer ducts 22, 24 is injected into the shell 31 via the shell downcomer connections 21, 23, flows on the heat exchanger shell-side crosswise the tubes, partially vaporizes, and then exits from the shell 31 through the shell riser connections 17, 19. The water-steam mixture produced in the heat exchanger 2 is discharged into the steam drum 3 through the drum riser connection 13. In the steam drum 3, the water is separated from the steam by means of separating devices (not shown), the separated water is recirculated to the heat exchanger 2 via the drum downcomer connection 11, and the separated steam leaves the steam drum 3 through the outlet steam connection 7. During the water vaporization, the hot process fluid flowing on the heat exchanger tube-side is cooled down by means of the indirect heat exchange with the boiler water.

[0042] Under preheating operations, the single downcomer intercepting valve 25, or the multiple downcomer intercepting valves (not shown), if present, are closed so that there is no boiler water flow from the steam drum 3 to the shell 31 of the heat exchanger 2. The boiler feedwater intercepting valve 28 is open, so that the boiler feedwater flows in the boiler feedwater piping 27 and is injected into the shell 31 of the heat exchanger 2 through the boiler feedwater connection 26. The riser intercepting valve 30 is preferably closed, so that the boiler feedwater flows from the shell 31 of the heat exchanger 2 to the steam drum 3 via only one of the riser ducts 18 and via the single riser piping 14. The boiler feedwater injected into the shell 31 via the boiler feedwater connection 26 is in subcooled conditions. The preheated boiler feedwater leaving the shell 31 has no vaporization or a negligible vaporization. During preheating, the hot process fluid flowing on the heat exchanger tube-side is cooled down by means of the indirect heat exchange with the boiler feedwater.

[0043] Figure 2 shows the heat exchanger 2 working as a boiler (for boiling operations) according to a preferred embodiment of the present invention. In particular, possible prevailing flow directions 32, 33, 34 of the boiler water circulating on shell-side are shown. The plates or baffles 29 are vertical plates or baffles or, in other words, plates or baffles installed in a substantially perpendicular position with respect to the shell longitudinal axis. The heat exchanger tubes pass through said plates or baffles 29. The plates or baffles 29 can be of single-segmental or, preferably, of double-segmental or of triple-segmental or of disc-and-donut type. Number, position, and layout of the plates or baffles 29 are shown with explanatory but not limiting purposes in figure 2 and can be different than those of figure 2.

[0044] The plates or baffles 29 are conveniently provided with main cuts or openings 43 for distributing the water all along the shell 31 of the heat exchanger 2. The plates or baffles 29, or at least a part of them, are also provided with respective top cuts or openings 35. Optionally, the plates or baffles 29, or at least a part of them, can be provided with respective bottom cuts or openings 38. The boiler water, at saturation conditions or near saturation conditions, enters the shell 31 of the heat exchanger 2 via the shell downcomer connections 21, 23 and distributes along the shell longitudinal axis by means of the main cuts or openings 43 of the plates or baffles 29 and, optionally, by means of the bottom cuts or openings 38 of said plates or baffles 29 according to prevailing horizontal bottom-shell flow directions 33. Then, the boiler water moves and vaporizes crosswise the tubes of the heat exchanger 2 by a prevailing vertical flow direction 32 all along the shell longitudinal axis. The produced water-steam mixture collects at shell riser connections 17, 19 by means of the main cuts or openings 43 of the plates or baffles 29 and by means of the top cuts or openings 35 of said plates or baffles 29 according to prevailing horizontal top-shell flow directions 34.

[0045] The boiler water mostly exchanges heat with the hot process fluid and then vaporizes by means of the prevailing vertical flow direction 32. Such prevailing horizontal bottom-shell flow direction 33, vertical flow direction 32 and horizontal top-shell flow direction 34 are imparted to boiler water by means of the shell-side plates or baffles 29 and by means of specific positions of the shell downcomer connections 21, 23 and the shell riser connections 17, 19. The main cuts or openings 43 of the plates or baffles 29 assure a uniform and efficient flooding of the shell 31 of the heat exchanger 2. The optional bottom cuts or openings 38 of the plates or baffles 29 can improve the prevailing horizontal bottom-shell flow direction 33 and therefore the shell-side flooding. The top cuts or openings 35 of the plates or baffles 29 can improve the prevailing horizontal top-shell flow direction 34 and therefore assure an efficient and unrestrained collection of the steam-water mixture.

[0046] Figure 3 shows the heat exchanger 2 working as a boiler feedwater preheater (for preheating operations) according to a preferred embodiment of the present invention. In particular, figure 3 shows possible prevailing flow directions 36 of the boiler feedwater moving crosswise the tubes of the heat exchanger 2. The plates or baffles 29 configurations are the same described for figure 2. The boiler feedwater, in subcooled conditions, enters the shell 31 of the heat exchanger 2 via the boiler feedwater connection 26. Then, the boiler feedwater moves crosswise the tubes of the heat exchanger 2 towards the shell riser connection 17 according to a prevailing horizontal flow direction 36 characterized anyway by a tortuous path or chicanes 40 due to the action performed by the main cuts or openings 43 of the plates or baffles 29. The prevailing horizontal flow direction 36 includes possible horizontal bottom-shell flow direction 33 and horizontal top-shell flow direction 34. The boiler feedwater mostly exchanges heat with the hot process fluid and then heats-up through the prevailing horizontal flow direction 36. The preheated boiler feedwater, with no vaporization or with a negligible vaporization, exits the shell 31 of the heat exchanger 2 via the shell riser connection 17. Once again, number, position, and layout of the plates or baffles 29 are shown with explanatory but not limiting purposes in figure 3 and can be different than those of figure 3.

[0047] From the preferred embodiments of the process heat recovery system 1 described above and shown in figures 2 and 3, it is therefore apparent to anyone skilled in the art that, for efficient boiling or preheating operations:

- shell downcomer connections 21, 23 are preferably installed at shell bottom 39 at a predefined distance each other, so as to efficiently distribute the boiler water along the longitudinal axis of the shell 31, whereas shell riser connections 17, 19 are preferably installed at shell top 37, in-line or off-set regarding the shell downcomer connections 21, 23 and at a predefined distance each other, so as to efficiently collect the water-steam mixture, and finally so as to install a prevailing vertical flow direction all along the longitudinal axis of the shell 31;
- at least one of the shell downcomer connections 21 and at least one of the shell riser connections 17 are preferably installed at, or near at, the hot process fluid inlet 4, so as to guarantee an efficient water flooding and steam collection in the hottest portion of the shell 31 of the heat exchanger 2;
- the boiler feedwater connection 26 and at least one of the shell riser connections 17 outletting the boiler feedwater are preferably installed at, or near at, opposed ends of the shell 31, so as to install a prevailing horizontal flow direction;
- the boiler feedwater connection 26 is preferably installed at, or near at, the hot process fluid outlet 5, so as to install a prevailing horizontal flow direction in counter-current with the hot process fluid in case of a single tube-side passageway.

[0048] Moreover, from the preferred embodiments of the process heat recovery system 1 described above and shown in figures 2 and 3, it is therefore apparent to anyone skilled in the art that:

- the process heat recovery system 1 according to the present invention, comprising a heat exchanger 2 working either as boiler or as boiler feedwater preheater, has an optimized configuration for piping and valves, since the water-steam mixture produced in the heat exchanger 2 (for boiling operations) and the boiler feedwater preheated in the heat exchanger 2 (for preheating operations) are both delivered to the steam drum 3 by a common, single riser piping 14, and said single riser piping 14 has no intercepting valve;

- the heat exchanger 2 of heat recovery system 1 according to the present invention, working both under boiling and preheating operations, has optimized configurations for its shell-side plates or baffles 29.

[0049] Finally, regardless boiling or preheating operations, the hot process fluid inlet 4 and/or outlet 5 for the hot process fluid entering/exiting the heat exchanger 2 can be respectively connected to possible additional upstream heat exchangers 45 and/or additional downstream heat exchangers 44, in turn respectively connected to the steam drum 3 via additional drum downstream/upstream riser piping 16, 47 and/or drum downstream/upstream downcomer piping 15, 46. In this case, the additional upstream/downstream heat exchangers are usually boilers that cool the same hot process fluid by means of vaporizing water circulating in between the steam drum 3 and said upstream/downstream boiler. Thus, such upstream/downstream boiler can be part of the process heat recovery system 1.

[0050] It is thus seen that the process heat recovery system according to the present invention achieve the previously outlined objects. The process heat recovery system according to the present invention is substantially different than corresponding process heat recovery systems according to the prior art, with specific reference to the system of document US 10744474 B2, since the heat exchanger of the process heat recovery system according to the present invention, working as a boiler or a preheater:

- has no shell-side partition plates forming distinct shell-side chambers;
- delivers both boiler water and boiler feedwater from the exchanger shell to the steam drum by means of a common single piping, instead of plural distinct piping;
- said common single piping is not necessarily provided with an intercepting valve.

[0051] The process heat recovery system of the present invention thus conceived is susceptible in any case of numerous modifications and variants, all falling within the same inventive concept; in addition, all the details can be substituted by technically equivalent elements. In practice, the materials used, as well as the shapes and size, can be of any type according to the technical requirements.

[0052] The scope of protection of the invention is therefore defined by the enclosed claims.

<u>**List of references**</u>

[0053]

1: process heat recovery system;
2: heat exchanger;
3: steam drum;
4: hot process fluid inlet;
5: hot process fluid outlet;
6: controlled water-level;
7: outlet steam connection;
8: outlet steam piping;
9: drum feedwater connection;
10: drum feedwater piping;
11: drum downcomer connection;
12: downcomer piping;
13: drum riser connection;
14: single riser piping;
15: drum downstream downcomer piping;
16: drum downstream riser piping;
17: shell riser connection;
18: riser duct;
19: shell riser connection;
20: riser duct;
21: shell downcomer connection;
22: downcomer duct;
23: shell downcomer connection;
24: downcomer duct;
25: downcomer intercepting valve;
26: boiler feedwater connection;
27: boiler feedwater piping;
28: boiler feedwater intercepting valve;
29: plates or baffles;
30: riser intercepting valve;
31: shell;
32: vertical flow direction;
33: horizontal bottom-shell flow direction;
34: horizontal top-shell flow direction;
35: top cuts or openings;
36: prevailing horizontal flow direction;
37: shell top;
38: bottom cuts or openings;
39: shell bottom;
40: tortuous path or chicanes;
41: drum downstream outlet connection;
42: drum downstream inlet connection;
43: main cuts or openings;
44: downstream heat exchanger;
45: upstream heat exchanger;
46: drum upstream downcomer piping;
47: drum upstream riser piping;
48: drum upstream outlet connection;
49: drum upstream inlet connection.

Claims

1. A process heat recovery system (1) for cooling a hot process fluid by means of boiler water vaporization or boiler feedwater preheating, said process heat recovery system (1) comprising:

- at least one heat exchanger (2), designed for cooling said hot process fluid,
- at least one steam drum (3), and
- at least one interconnecting piping assembly (12, 22, 24; 14, 18, 20), which connects said heat exchanger (2) and said steam drum (3),

wherein said heat exchanger (2) is of shell-and-tube type and is provided with:

- a shell (31),
- a plurality of tubes,
- at least one hot process fluid inlet (4), for inletting said hot process fluid that flows on tube-side of said heat exchanger (2) by one or more tube-side passageways,
- at least one hot process fluid outlet (5), for outletting said hot process fluid from tube-side of said heat exchanger (2),
- at least one shell downcomer connection (21, 23), through which said boiler water flowing through said shell (31) enters said shell (31), and
- at least one boiler feedwater connection (26), through which said boiler feedwater flowing through said shell (31) enters said shell (31),

wherein said steam drum (3) is provided with at least one drum downcomer connection (11) and at least one drum riser connection (13),
wherein said interconnecting piping assembly (12, 22, 24; 14, 18, 20) comprises at least one downcomer piping (12) connected, at one end thereof, to said at least one drum downcomer connection (11) and, at the other end thereof, to said at least one shell downcomer connection (21, 23) via at least one respective downcomer duct (22, 24), so that said boiler water is delivered from said steam drum (3) to said heat exchanger (2) via said at least one downcomer piping (12), wherein said boiler feedwater connection (26) is connected to at least one respective boiler feedwater piping (27), so that said boiler feedwater is delivered to said heat exchanger (2) via said at least one boiler feedwater piping (27),
wherein at least one downcomer intercepting valve (25) is provided on said downcomer piping (12), or on each downcomer duct (22, 24), or on said downcomer piping (12) and on at least one downcomer duct (22, 24), and wherein said boiler feedwater piping (27) is provided with at least one boiler feedwater intercepting valve (28),
said process heat recovery system (1) being **characterized in that:**

- said shell (31) is provided with at least two shell riser connections (17, 19) for outletting either said boiler water or said boiler feedwater, and
- said interconnecting piping assembly (12, 22, 24; 14, 18, 20) comprises a single riser piping (14) connected, at one end thereof, to said drum riser connection (13) and, at the other end thereof, to said at least two shell riser connections (17, 19) via a riser duct (18, 20) for each of said at least two shell riser connections (17, 19), so that either said boiler water or said boiler feedwater flowing through said shell (31) is delivered from said heat exchanger (2) to said steam drum (3) via said single riser piping (14).

2. The process heat recovery system (1) according to claim 1, **characterized in that** at least one of said riser ducts (18, 20) is provided with a respective riser intercepting valve (30).

3. The process heat recovery system (1) according to claim 1 or 2, comprising at least one additional upstream heat exchanger (45), wherein said hot process fluid inlet (4) is connected to said upstream heat exchanger (45) and wherein said steam drum (3) is provided with at least one drum upstream inlet connection (49) and with at least one drum upstream outlet connection (48), so that said upstream heat exchanger (45) is connected to said steam drum (3) by means of at least one drum upstream riser piping (47), via said drum upstream inlet connection (49), and by means of at least one drum upstream downcomer piping (46), via said drum upstream outlet connection (48).

4. The process heat recovery system (1) according to anyone of claims 1 to 3, comprising at least one additional downstream heat exchanger (44), wherein said hot process fluid outlet (5) is connected to said downstream heat exchanger (44) and wherein said steam drum (3) is provided with at least one drum downstream inlet connection (42) and with at least one drum downstream outlet connection (41), so that said downstream heat exchanger (44) is connected to said steam drum (3) by means of at least one drum downstream riser piping (16), via said drum downstream inlet connection (42), and by means of at least one drum downstream downcomer piping (15), via said drum downstream outlet connection (41).

5. The process heat recovery system (1) according to anyone of claims 1 to 4, **characterized in that** said shell (31) has a substantially horizontal longitudinal axis and is internally provided with one or more shell-side plates or baffles (29), which are substantially perpendicular to said longitudinal axis and through which the tubes of said heat exchanger (2) pass, wherein said plates or baffles (29) are provided with main cuts or openings (43) designed to distribute either said boiler water or said boiler feedwater all along the direction of said longitudinal axis through shell-side predefined flow directions (32, 33, 34, 36).

6. The process heat recovery system (1) according to claim 5, **characterized in that** at least part of said plates or baffles (29) is provided with one or more respective top cuts or openings (35) designed to distribute at least part of either said boiler water or said boiler feedwater along substantially horizontal top-shell flow directions (34) at a top portion (37) of said shell (31).

7. The process heat recovery system (1) according to claim 5 or 6, **characterized in that** at least part of said plates or baffles (29) is provided with one or more respective bottom cuts or openings (38) designed to distribute at least part of either said boiler water or said boiler feedwater along substantially horizontal bottom-shell flow directions (33) at a bottom portion (39) of said shell (31).

8. The process heat recovery system (1) according to anyone of claims 5 to 7, **characterized in that** said plates or baffles (29) are chosen from the group consisting of:

- single-segmental plates or baffles (29),
- double-segmental plates or baffles (29),
- triple-segmental plates or baffles (29),
- disc-and-donut type plates or baffles (29).

9. The process heat recovery system (1) according to anyone of claims 5 to 8, **characterized in that** said plates or baffles (29), said shell downcomer connection (21, 23) and said shell riser connections (17, 19) are designed and positioned on said heat exchanger (2) to impart a prevailing vertical flow direction (32), crosswise the tubes, to said boiler water when said heat exchanger (2) works as a boiler.

10. The process heat recovery system (1) according to claim 9, **characterized in that** said hot process fluid is a hot process gas discharged from a chemical reactor or furnace, and said heat exchanger (2) is a process gas cooler working as a boiler, for boiling operations, therefore producing boiler water with a significant fraction of steam, or a water-steam mixture, delivered to said steam drum (3) via said drum riser connection (13).

11. The process heat recovery system (1) according to anyone of claims 5 to 8, **characterized in that** said plates or baffles (29), said boiler feedwater connection (26) and said shell riser connections (17, 19) are designed and positioned on said heat exchanger (2) to impart a prevailing horizontal flow direction (36), with a tortuous path or chicanes (40) crosswise the tubes, to said boiler feedwater when said heat exchanger (2) works as a boiler feedwater preheater.

12. The process heat recovery system (1) according to claim 11, **characterized in that** said hot process fluid is a hot process gas discharged from a chemical reactor or furnace, and said heat exchanger (2) is a process gas cooler working as a boiler feedwater preheater, therefore producing a preheated boiler feedwater, with no vaporization or with a negligible vaporization, delivered to said steam drum (3) via said drum riser connection (13).

13. The process heat recovery system (1) according to anyone of claims 1 to 12, **characterized in that** said steam drum (3) is placed above said heat exchanger (2) and is provided with at least one outlet steam connection (7), connected to at least one corresponding outlet steam piping (8), at least one drum feedwater connection (9), connected to at least one corresponding drum feedwater piping (10), and preferably control means to control a water-level (6) within the steam drum (3).

14. A method for recovering process heat using at least one process heat recovery system (1) according to anyone of the preceding claims, wherein said heat exchanger (2) alternately works as a boiler, for boiling operations, and as a boiler feedwater preheater, for preheating operations, and wherein:

- when said heat exchanger (2) works as a boiler, said boiler feedwater intercepting valve (28) is closed and said downcomer intercepting valve (25) is open, so that said boiler water is delivered from said steam drum (3) to said heat exchanger (2) via said downcomer piping (12), said boiler water flows and vaporizes crosswise the tubes of said heat exchanger (2) and then said boiler water is delivered from said heat exchanger (2) to said steam drum (3) via said single riser piping (14), and
- when said heat exchanger (2) works as a boiler feedwater preheater, said boiler feedwater intercepting valve (28) is open and said downcomer intercepting valve (25) is closed, so that said boiler feedwater is delivered to said heat exchanger (2) via said boiler feedwater piping (27), said boiler feedwater flows and preheats crosswise the tubes of said heat exchanger (2) and then said boiler feedwater is delivered from said heat exchanger (2) to said steam drum (3) via said single riser piping (14).

15. The method according to claim 14, wherein a respective riser intercepting valve (30) provided on at least one of the riser ducts (18, 20) is open when said heat exchanger (2) works as a boiler and is closed when said heat exchanger (2) works as a boiler feedwater preheater.

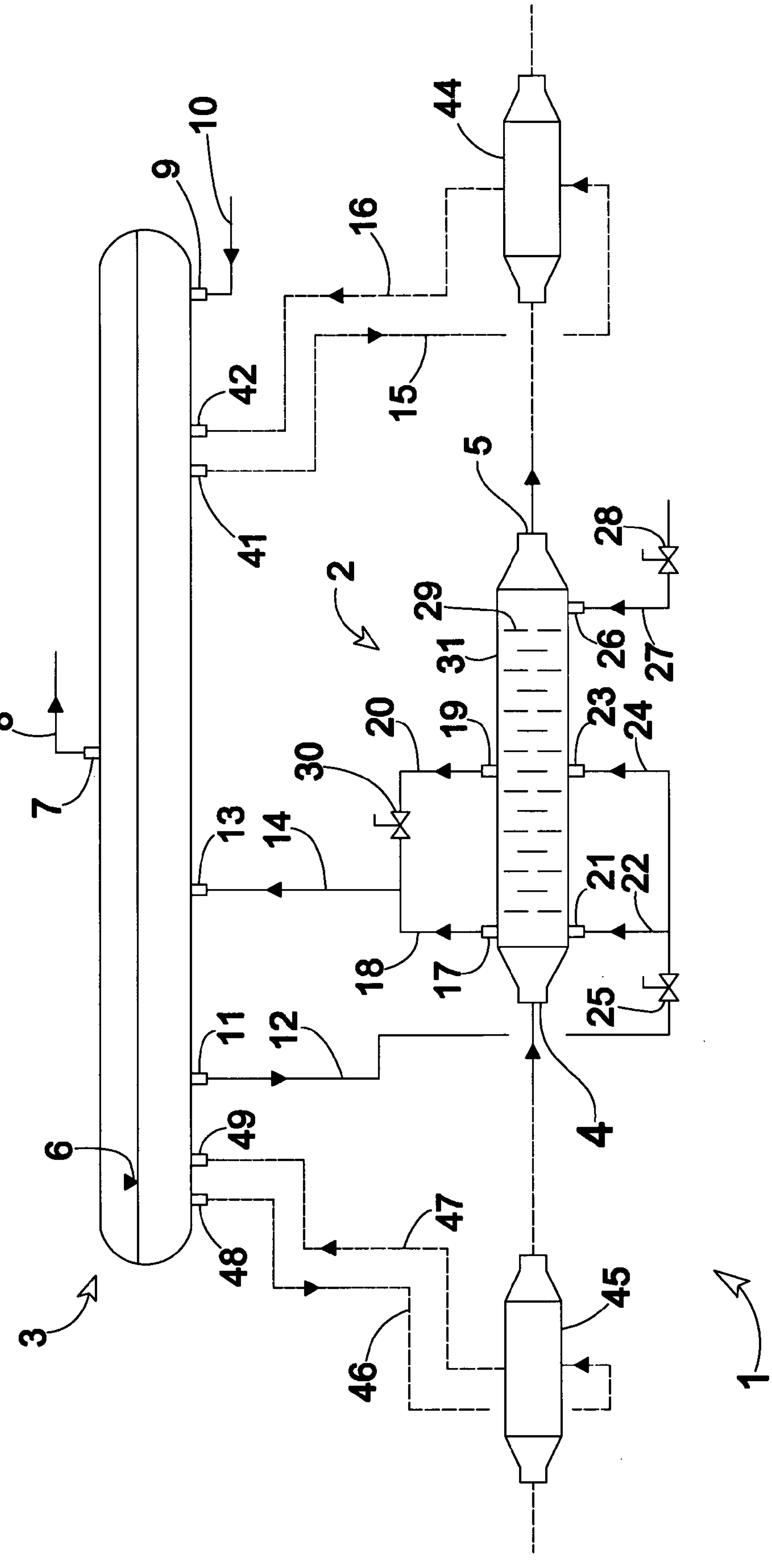
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Fig.1

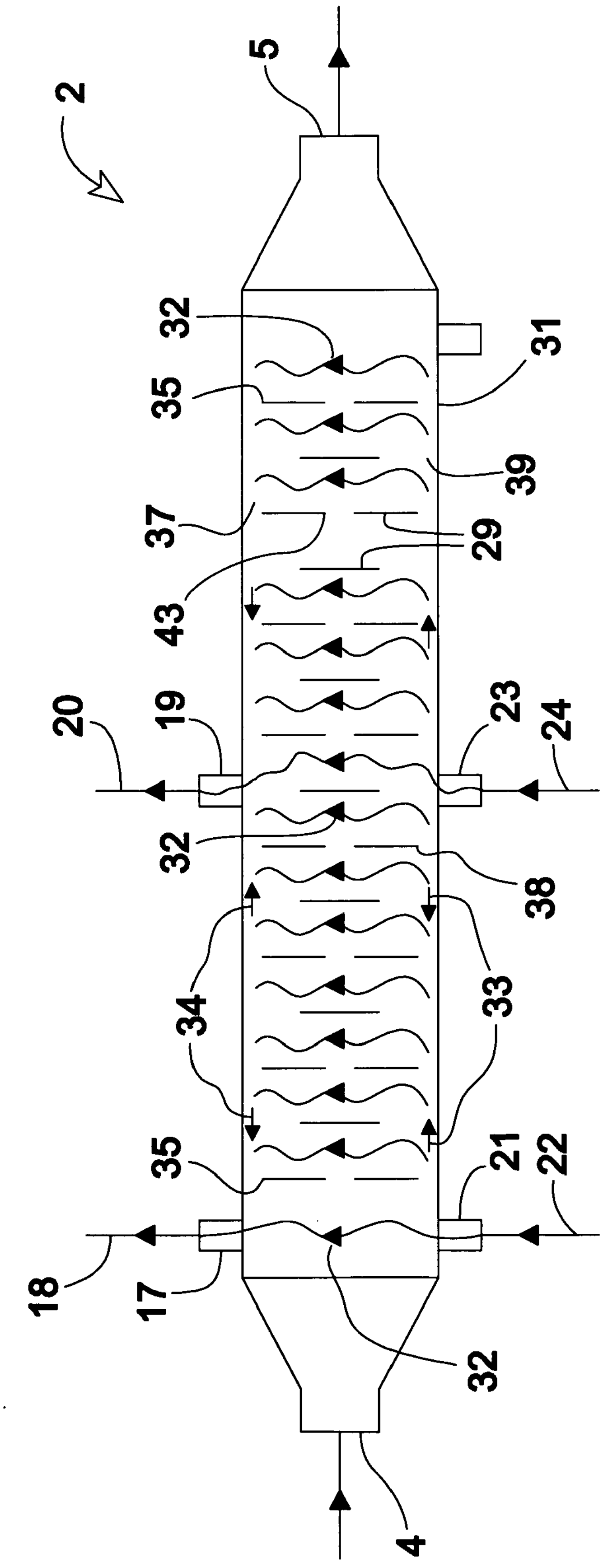

Fig.2

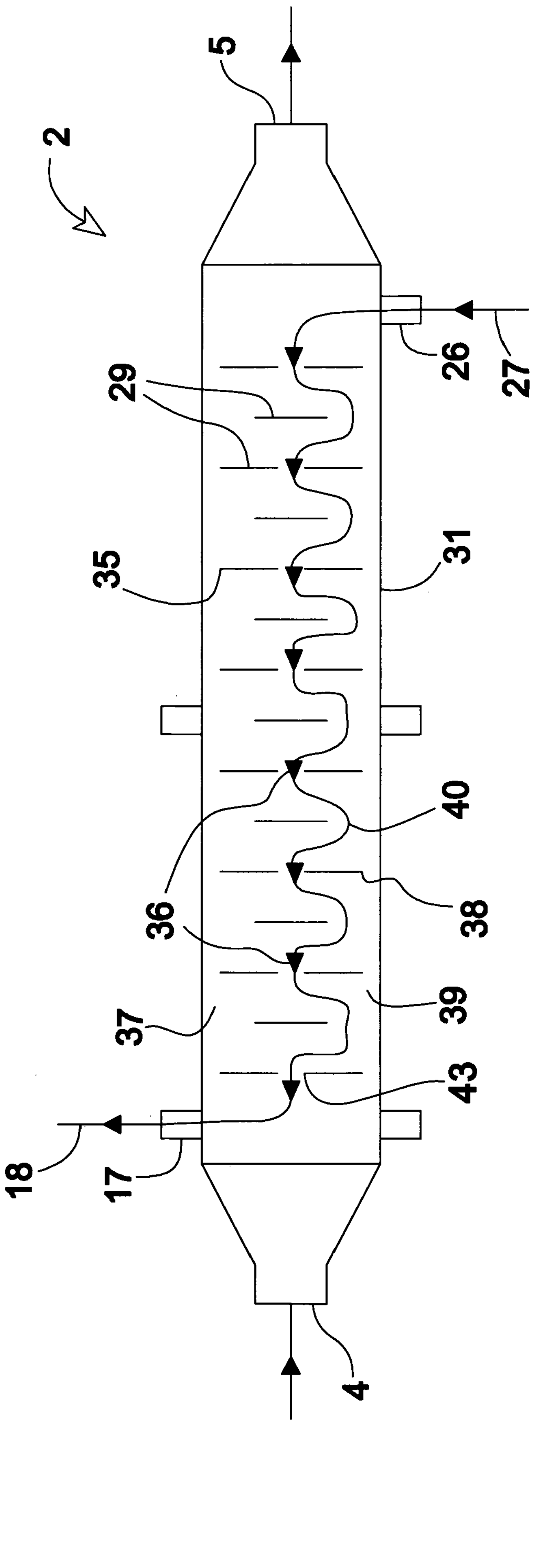

Fig.3

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EUROPEAN SEARCH REPORT

Application Number
EP 21 42 5009

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2019/275488 A1 (DRUS SEBASTIAN [DE] ET AL) 12 September 2019 (2019-09-12) * abstract; figures 1,2 * * paragraphs [0002] - [0028], [0033] - [0054] *	1-15	INV. F22B37/10 F22D1/00
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F22B
F22D

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	30 July 2021	Varelas, Dimitrios

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