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(71) **Applicant: POLITECNICO DI MILANO** [IT/IT]; Piazza Leonardo da Vinci 32, 20133 Milano MI (IT).

(72) **Inventor; and**
(71) **Applicant: MANENTI, Giovanni** [IT/IT]; Via Beato Luigi Palazzolo 11/B, 24064 Grumello del Monte BG (IT).

(72) **Inventor: MANENTI, Flavio**; Via Decò e Canetta 55/A, 24068 Seriate BG (IT).

(74) **Agent: CERVINO, Stefano Matteo** et al.; c/o Perani & Partners S.p.A., Piazza Armando Diaz 7, 20123 Milan (IT).

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(54) **Title:** DOUBLE-ZONE SHELL AND TUBE EQUIPMENT, RELATED PLANT CONTAINING SAID EQUIPMENT AND PROCESS FOR PRODUCING A CHEMICAL IN SAID PLANT

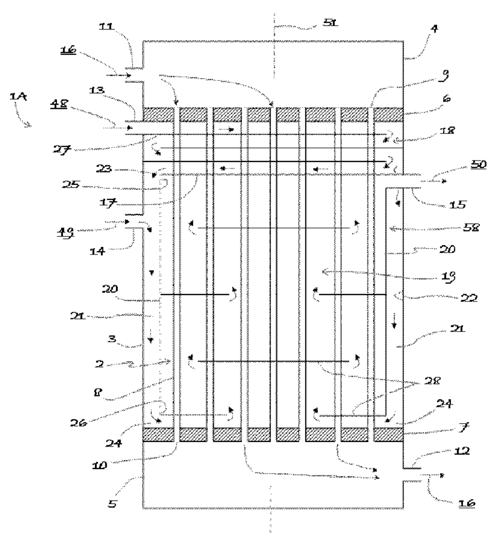

Fig. 1

(57) **Abstract:** Equipment (1A) comprising: a first and a second tube plate (6, 7), a tube bundle (2) comprising exchanger tubes (8) a shell (3) provided with at least a first, at least a second and at least a third shell-side connection (13, 14, 15) for feeding and removing said shell-side fluid, a first distributor (4) connected to said first tube plate (6), a second distributor (5) connected to said second tube plate (7), a partition wall (58) on the shell side configured to divide said shell (2) into a first and a second zone (18, 19), said partition wall (58) defining a perimeter duct (21) having a first and a second opening (23, 24), configured to put in fluid communication said first and said second zone (18, 19) through said perimeter duct (21); first and second diaphragms (27, 28) installed in said first and second zones (18, 19), respectively, adapted to support said heat exchanger tubes (8) and/or to perform deviations of the flow of said shell-side fluid in order to increase the heat exchange, said perimeter duct (21), essentially annular in shape, surrounding the portion of said tube bundle passing through said second zone (19), so that said first (13) and third shell-side connections (15) are respectively directly connected to the first zone (18) and to the second zone (19), and said second shell-side connection (14) is directly connected to the perimeter duct (21).

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"Double-zone shell and tube equipment, related plant containing said equipment and process for producing a chemical in said plant"

DESCRIPTION

Field of the invention

The present invention relates to equipment, of the shell and tube type, adapted to conduct indirect heat exchange between the tube-side fluid and the shell-side fluid, with or without tube-side chemical reactions.

The equipment, essentially cylindrical in shape, is equipped with two tube plates and exchanger tubes, preferably straight. The equipment shell is divided into a first and a second zone, which are crossed by portions of the tube bundle, arranged in series along the longitudinal axis of the equipment in such a way that the first zone is in proximity to the first tube plate and the second zone is in proximity to the second tube plate. The two zones are in fluid communication via a perimeter duct surrounding the tube bundle and delimited by the shell. The perimeter duct is not crossed by the tube bundle. A fraction of the shell-side fluid is fed into, or removed from the perimeter duct in such a way that this fraction undergoes partial heat exchange with the tube-side fluid, i.e. in such a way that this fraction passes through only one of the two zones of the shell.

This double zone configuration of the shell allows different heat exchange conditions to be installed on the shell side depending on the temperature profile of the tube-side fluid, allowing the overall heat exchange to be optimised and, in the case of chemical reactions on the tube side, the yield and chemical conversion to be optimised.

More specifically, the equipment covered by the present invention can be part of a plant for the synthesis of chemicals, preferably methanol. Specifically, the equipment can be configured as a reactor preferably for methanol synthesis, cooled by pressurised water circulating on the shell side, characterised by high yield/chemical conversion due to the innovative double-zone configuration of the shell.

The equipment disclosed here can also be used in a formaldehyde synthesis plant, i.e. operate as a formaldehyde synthesis reactor with catalyst in the tubes and shell-side cooling fluid. The equipment of the present invention can also be used in a plant for the synthesis of nitric acid or hydrogen cyanide, in which case the equipment functions as a process boiler, with the cooling fluid circulating on the shell side, installed directly downstream of the catalytic reactor. More generally, the equipment covered by the present invention can also be used as a boiler or process heat exchanger for cooling a hot synthesis gas.

In the system for the synthesis of chemicals, the equipment of the present invention, on the shell side, can be connected to a cylindrical body, preferably placed in an elevated position, to establish the circulation of the shell-side fluid.

State of the art

Equipment of the shell and tube type, suitable for indirect heat exchange between the tube-side fluid and the shell-side fluid, with two tube plates, straight exchanger tubes and the shell divided into two zones, is described in patent documents DE2126979A1, EP1367351 and CN205102639 and patent documents US4074660 and US7784433. Other similar equipment is described in patent documents EP0086162A1 and GB1154809.

Patent documents US4074660 and US7784433 describe a shell divided into two zones, crossed by portions of the tube bundle, by means of a partition wall essentially perpendicular to the longitudinal axis of the equipment. The partition wall does not form any ducts. The two shell zones both have specific connections for inputting and extracting different shell-side fluid currents. In other words, the shell-side fluid is divided into different currents flowing through distinct parts of the tube bundle. The two shell zones are in fluid communication for mechanical reasons.

Specifically, the partition wall intentionally allows leakage of the shell-side fluid from one zone to the other in order to equalise the pressure in the two zones. Consequently, the mixing of the different flows of shell-side fluid is negligible and the equipment is not configured to mix flows or fractions of the shell-side fluid.

Patent documents DE2126979A1, EP1367351 and CN205102639, on the other hand, describe a shell divided into two zones, crossed by portions of the tube bundle, by means of a partition wall perpendicular to the longitudinal axis of the equipment. The two zones are in fluid communication via an opening in the partition wall and via a duct surrounded by the tube bundle and not crossed by the tubes of the tube bundle. The duct extends almost the entire length of at least one of the zones. The shell-side fluid is entirely fed into the first zone via one or more connections, is entirely conveyed into the second zone via the opening and the duct, and is entirely removed from the shell via one or more connections. As a result, both zones of the shell are crossed by all the shell-side fluid. Therefore, the shell-side fluid is not divided into fractions.

Patent document EP0086162A1 describes a shell in which diaphragms and inner walls delimit an annulus surrounding the tube bundle; this annulus has a first end that is open to the passage of shell-side fluid and a second end that is closed.

Patent document GB1154809 describes an inner longitudinal wall forming an annulus with the shell and where said annulus surrounds one of the zones of the tube bundle. This annulus is not in direct fluid communication with any shell-side fluid inlet/outlet connection.

Methanol synthesis processes in shell and tube reactors are also known. Indeed, as described in the literature (Hillestad, “Systematic staging in chemical reactor design”, Chemical Engineering Science, vol. 65, pag. 3301-3312, 2010; Manenti et al., “Dynamic modeling of the methanol synthesis fixed-bed reactor”, Computers and Chemical Engineering, vol. 48, pag. 325-334, 2013), the synthesis of methanol from a process gas rich in carbon oxides (CO, CO_2) and hydrogen using shell and tube reactors cooled by pressurised water circulating on the shell side is achieved by exothermic reactions in the presence of a heterogeneous catalyst loaded into the reactor exchanger tubes. According to the chemical thermodynamics of the synthesis process, the process gas flowing in the tubes must be cooled by the shell-side fluid. However, cooling compromises the reaction kinetics and thus, typically, the yield and conversion of the methanol synthesis process are rather low in the single tube-side pass, around 20% and 40% respectively. These yield and conversion rates force unconverted reagents to be recycled, at a significant energy burden. Research and development relating to thermodynamics and chemical kinetics and reactor technology for methanol synthesis are therefore aimed at increasing the yield and conversion of the synthesis process.

The literature (Manenti et al., "Considerations on the steady-state modeling of methanol synthesis fixed-bed reactor", Chemical Engineering Science, vol. 66, pag. 152-162,, 2011) teaches that methanol synthesis conducted in conventional shell-and-tube reactors, with pressurised water under saturation conditions as the cooling fluid, exhibits a log-normal process gas temperature profile along the catalytic exchanger tubes. Specifically, the process gas flowing in the reactor tubes and undergoing exothermic synthesis reactions rapidly increases its temperature in the first part of the exchanger tubes and then decreases in temperature. The high temperature gradient, or temperature peak, present in the first section of the reactor tubes is due to the high partial pressure of the reactants, i.e. high kinetic and thermodynamic equilibrium constants. This means that the chemical yield/conversion in the first section of the exchanger tubes is not optimised. Moreover, in the first section of the tubes, excessive local temperature peaks cannot be ruled out *a priori*, resulting in premature ageing or damage to the catalyst and/or an increase in parasitic reactions.

Conventional shell-and-tube methanol reactors cooled with pressurised water have almost uniform operating conditions on the shell side because the circulating water on the shell side is in a saturated condition and therefore the water is subjected to vaporisation. Thus, these reactors operate under isothermal conditions on the shell side.

Although the vaporisation of water enables effective cooling to be achieved, the isothermal conditions of the cooling fluid do not allow for different shell-side heat transfer conditions to be installed in conventional methanol reactors depending on the temperature profile of the process gas along the heat exchanger tube. That is, the isothermal conditions of the boiling water do not allow, for example, mild cooling in the first section of the exchanger tubes and simultaneous thorough cooling in the second section of the exchanger tubes, and thus do not allow the yield and chemical conversion of methanol synthesis to be optimised.

Summary of the invention

The present invention relates to a shell and tube equipment, essentially with a cylindrical structure and axisymmetric tube bundle, in which a tube-side fluid and a shell-side fluid flow. Chemical reactions can also take place in the tube-side fluid. The equipment operates as a heat exchanger and, if there are chemical reactions on the tube side, as a chemical reactor. In both cases, the equipment performs indirect heat exchange between the tube-side fluid and the shell-side fluid.

The equipment essentially comprises:

- A first and a second tube plate;
- A tube bundle with straight exchanger tubes connected to the first and second tube plates respectively;
- A shell containing the tube bundle and connected to the tube plates;
- A partition wall inside the shell that divides the shell into a first and second zone crossed by portions of the tube bundle, said partition wall defining

together with the shell a perimeter duct not crossed by the exchanger tubes and having the two ends open and forming a first and second opening.

The shell zones and the perimeter duct essentially have the following structural characteristics:

- The zones are arranged in series along the longitudinal axis of the equipment;
- The perimeter duct has an annular shape and surrounds the second zone;
- The first zone is in fluid communication with the perimeter duct through the first opening of the duct, and the second zone is in fluid communication with the perimeter duct through the second opening of the perimeter duct;
- The second opening of the perimeter duct is in proximity to the second tube plate;
- The first zone, the second zone and the duct are provided with specific inlet or outlet connections for the shell-side fluid.

The partition wall is basically made up of two internal walls, which are juxtaposed or connected to each other.

The equipment described here can be coupled by means of shell-side piping to a cylindrical body, preferably elevated, so as to establish a natural or forced circulation of the shell-side fluid between the equipment and the cylindrical body, defining a system for the synthesis of chemicals.

The purpose of the present invention is therefore to provide a shell and tube equipment capable of optimising and improving tube-side and shell-side heat exchange.

Specifically, the equipment of the present invention is particularly useful if the tube-side fluid has a longitudinal temperature profile characterised by a minimum or a maximum. Such tube-side thermal conditions can be encountered in chemical reactors, for example, in reactors for methanol synthesis. Consequently, the present invention can also be applied to chemical reactors for the synthesis of compounds other than methanol.

It is emphasised that any equipment of the shell and tube type or similar, with a longitudinal thermal profile of the wall of the tubes or elements of the bundle characterised by a minimum or maximum, such as a nuclear reactor or electric heater, is conceptually and advantageously designable in accordance with the present invention.

It is a further purpose of the present invention to provide a plant for the synthesis of chemicals, preferably methanol. In particular, the plant for the synthesis of chemicals, also subject matter of the invention, comprises the equipment according to the present invention coupled to a cylindrical body, preferably elevated. In this case, the equipment is configured to operate as a chemical synthesis reactor, preferably as a methanol synthesis reactor, and even more preferably as a pressurised water-cooled methanol synthesis reactor. The chemical synthesis plant revealed here can also be used for the synthesis of nitric acid, hydrogen cyanide and formaldehyde.

The subject matter of the invention, therefore, also covers an operating process for the synthesis of chemicals, preferably methanol, conducted in the equipment according to the present invention, wherein said equipment is connected to a cylindrical body, preferably elevated, with any cooling fluid, preferably water.

The equipment according to the present invention is essentially different from a structural and functional point of view from the equipment described in the cited patent documents DE2126979A1, EP1367351, CN205102639 EP0086162A1 and GB1154809, in that it comprises a perimeter duct having the two open ends, not crossed by the tube bundle, surrounding the portion of the tube bundle of one of the two zones of the shell and in direct fluid communication with an inlet or outlet shell-side connection, allowing the inlet/removal of a fraction of the shell-side fluid, the mixing/separation of two fractions of the shell-side fluid, the bypass of a fraction of the shell-side fluid.

A purpose of the present invention is therefore to provide a reactor for methanol synthesis in particular that mitigates or eliminates the aforementioned disadvantage of conventional water-cooled shell and tube methanol reactors. In particular, the methanol reactor according to the present invention allows, thanks to the innovative double-zone configuration of the shell, to dampen the peak temperature of the process gas in the first section of the exchanger tubes and simultaneously to install a different temperature and/or heat exchange coefficient on the shell side in the second section of the exchanger tubes, thus enabling the yield/conversion of the synthesis process to be increased. In accordance with a preferred operating procedure, damping is achieved by having a fraction of the cooling fluid at lower temperature and/or with a lower heat transfer coefficient or a fraction of the cooling water under sub-cooled conditions flowing into the area of the shell affected by the gas temperature peak, i.e. exchanging essentially sensible heat with the process gas, while the cooling fluid flows in the remaining zone of the shell at a higher temperature and/or with a higher heat transfer coefficient or water under saturation or incipient saturation conditions, i.e. exchanging essentially latent heat with the process gas. The area of the shell affected by the process gas temperature peak is essentially non-isothermal while the remaining area of the shell is essentially isothermal. As a result, the reactor, preferably for methanol synthesis, according to the present invention is characterised by globally non-isothermal shell-side conditions.

More generally, the object of the present invention is to provide a shell and tube equipment, wherein the double zone shell is configured to feed into the shell, or remove from the shell, a fraction of the shell-side fluid that is subject to partial heat exchange with the tube-side fluid, and to install different thermal conditions in the two zones of the shell depending on the temperature profile of the tube-side fluid.

LIST OF FIGURES

- Fig.1, shows the longitudinal view of the equipment according to the present invention where the directions of the tube-side and shell-side fluid flows are schematically shown in accordance with a preferred configuration;
- Fig.2, shows the longitudinal view of the equipment according to the present invention where the directions of the tube-side and shell-side fluid flows are schematically shown in accordance with a further preferred configuration;
- Fig.3, shows the longitudinal view of an embodiment of the system for the synthesis of chemicals comprising the equipment of Figure 1 connected to a cylindrical body where the tube-side and shell-side fluid flow directions are schematically shown in accordance with a preferred configuration;
- Fig.4, shows the longitudinal view of an embodiment of the system for the synthesis of chemicals comprising the equipment of Figure 2 connected to a cylindrical body and where the tube-side and shell-side fluid flow directions are schematically shown in accordance with a preferred configuration;

Fig. 5 shows a perspective view of the equipment in accordance with an embodiment of the present invention with some parts omitted to better show others;

Fig. 6 shows a perspective view of the equipment in accordance with an embodiment of the present invention with some parts omitted to better show others.

DETAILED DESCRIPTION

Figures 1, 2, 5 and 6 schematically show the longitudinal view of the equipment 1A in accordance with the preferred embodiments of the present invention.

Preferably, the equipment 1A has an essentially cylindrical structure and comprises a tube bundle essentially axisymmetrical with respect to the longitudinal axis 51.

The equipment 1A may be arranged horizontally or vertically, i.e. its longitudinal axis 51 parallel or perpendicular to the ground plane.

The equipment 1A, of the shell and tube type, comprises a tube bundle 2 with exchanger tubes 8, straight and extended between first and second ends 9,10, along the longitudinal axis 51.

The equipment 1A comprises a first and second tube plate 6, 7 mutually spaced along the longitudinal axis 51. Each first and second tube plate 6, 7 comprises respective holes. The first and second ends 9, 10 of the tube bundle 8 are connected to the holes of the first and second tube plate 6, 7 respectively.

The equipment 1A comprises a shell 3 containing the tube bundle 2 and delimited by the first and second tube plates 6, 7. Preferably, this shell 3 is connected to the first and second tube plates 6, 7.

The equipment 1A comprises a first and a second distributor 4, 5 connected respectively to the first and second tube plate 6, 7 on the opposite side to the shell 3. The first and second distributors 4, 5 are in fluid communication via the tube bundle 8.

The equipment 1A comprises a first and a second tube-side connection 11, 12 located on the first and second distributor 4, 5 respectively, for feeding or removing fluid on the tube-side 16. The equipment 1A further comprises at least one first connection 13 in both Figures 1 and 2, at least one second connection 14 in both Figures 1 and 2 and at least one third connection 15 in both Figures 1 and 2 associated with the shell 3 for feeding or removing the shell-side fluid 48, 49, 50 of Figure 1 and 52, 53, 54 of Figure 2.

The first tube-side connection 11, the first distributor 4 and the first tube ends 9 are in fluid communication as are the second tube-side connection 12, the second distributor 5 and the second tube ends 10.

As illustrated in the figures, the equipment 1A comprises a partition wall 58 on the shell side configured to divide the shell 3 into a first and a second zone 18, 19 crossed by portions of said tube bundle 2 and arranged longitudinally in series in proximity to said first and second tube plates 6, 7, respectively. The partition wall 58 defines a perimeter duct 21 of essentially annular shape not crossed by the tube bundle 2, but on the contrary surrounding it, presenting at its ends a first and a second opening 23, 24 respectively arranged in proximity to said first and second tube plates 6 and 7 configured to place in fluid communication the first and second zones 18, 19 through the perimeter duct 21. Preferably, the perimeter duct 21 surrounds the portion of the tube bundle 2 that penetrates into the second zone 19 for almost its entire length, i.e. until it extends in proximity to the second tube plate 7.

This equipment is characterised in that said essentially annular-shaped perimeter duct 21 surrounds the portion of the tube bundle passing through said second zone 19 in such a way that said first shell-side connection 13 of Figure 1 and Figure 2 and said third shell-side connection 15 of Figure 1 and Figure 2 are respectively directly connected to the first zone 18 and to the second zone 19 and said second connection 14 on the shell side is directly connected to the perimeter duct 21.

In the equipment 1A the partition wall 58 comprises a first and second wall 17, 20. The first wall 17 is orthogonal to the longitudinal axis 51 and preferably comprises or consists of a disc with an area greater than or equal to the cross-sectional area of the tube bundle 2.

Specifically, the first wall 17 and the second wall 20 subdivide the shell 3 into the two zones 18, 19 both crossed by portions of the tube bundle 2 arranged in series with respect to the longitudinal axis 51 in such a way that the first zone 18 is in proximity to the first tube plate 6, or is in contact with the first tube plate 6, and the second zone 19 is in proximity to the second tube plate 7, or is in contact with the second tube plate 7. Preferably, the first zone 18 extends between the first tube plate 6 and the first wall 17 while the second zone 19 extends between the first wall 17 and the second wall 20.

It should be noted that the first wall 17 is provided with third holes in order to be crossed by the exchanger tubes 8.

The second wall 20 surrounds the tube bundle longitudinally. Specifically, the second wall 20 is not crossed by the exchanger tubes 8. Preferably, the second wall 20 has an essentially cylindrical shape and is concentrically arranged with respect to the shell 3.

In detail, the second wall 20 surrounds the portion of the tube bundle 2 that passes through the second zone of the shell 19 and extends longitudinally for at least part of the length of the second zone 19 along the axial direction 51.

In accordance with a preferred embodiment, the second wall 20 defines with the shell 3 a perimeter duct 21 preferably essentially annular around the tube bundle. Specifically, the perimeter duct 21 is not crossed by the tube bundle 2. Specifically, this perimeter duct 21 surrounds the portion of the tube bundle crossing said second zone 19.

It should be noted that the second wall 20 has a third and a fourth end 25, 26, corresponding to the edges of this wall, respectively facing the first and second tube plate 6, 7.

In accordance with a preferred embodiment, the first wall 17 and the second wall 20 are mutually adjacent or radially connected to the outside of the tube bundle 2 and in proximity to the third end 25 of the second wall 20. Preferably, the first wall 17 and the second wall 20 form the partition wall 58 on the shell side once coupled. The juxtaposition or connection between the first and second walls 17, 20 is leakproof or configured to have leakage, i.e. configured to avoid significant fluid passage on the shell side.

In accordance with a preferred configuration, the third holes in the first wall 17 allow for leakage of the shell-side fluid, i.e. the passage of a small or negligible fraction of the shell-side fluid. In other words, there is a small gap between the third holes and the exchanger tubes 8. In accordance with another preferred configuration, the exchanger tubes 8 are juxtaposed or attached to the third holes in an essentially leakproof manner. The coupling or connection between exchanger tubes 8 and third holes is preferably carried out by tube rolling.

Accordingly, the partition wall 58 divides the two shell-side zones 18, 19 in an essentially leakproof manner. In other words, the fraction of shell-side fluid passing from one zone to the other, through the partition wall 58, is zero or marginal.

In accordance with an embodiment illustrated in the figures, the first wall 17 is radially distanced from the shell 3 so as to form a first essentially annular opening 23 with the shell 3 and positioned radially outwardly with respect to the second wall 20. It should be noted that the first opening 23 places the first zone 18 in fluid communication with the duct 21. In accordance with an alternative preferred configuration illustrated, for example, in Figure 6, the first wall 17 has a diameter essentially identical to the internal diameter of the shell 2 and comprises windows or holes 100, configured to bring the first and second zones into fluid communication and defining the first opening 23 as the sum of windows or holes 100. The latter are placed radially outwardly with respect to the second wall 20 and radially spaced from each other.

The second wall 20 has the fourth end 26 spaced from the second tube plate 7 so as to form a second opening 24. Specifically, the second opening 24 places the second zone 19 in fluid communication with the perimeter duct 21.

In accordance with an alternative preferred configuration not shown in the figure, the second wall 20 has the fourth end 26 very proximal to or juxtaposed or attached to the second tube plate 7 and is provided with windows or holes, located in proximity to the second tube plate 7, forming the second opening 24 essentially in the manner described above.

According to a preferred embodiment shown in Fig.1 and Fig. 5, the first zone 18 is in fluid communication with the first shell-side connection 13. Preferably, the first shell-side connection 13 is in proximity to the first tube plate 6, or also arranged longitudinally between the first tube plate 6 and the first wall 17. The first zone 18 is in fluid communication with the perimeter duct 21 via the first opening 23. In accordance with said preferred embodiment illustrated in Fig.1 and Fig. 5, the second zone 19 is in fluid communication with the third shell-side connection 15. Preferably, the third shell-side connection 15 is in proximity to the first wall 17 and fluid-dynamically connected to the second wall 20. The second zone 19 is also in fluid communication with the perimeter duct 21 via the second opening 24. The perimeter duct 21 is also in fluid communication with the second shell-side connection 14. It should be noted that the first zone 18 and the second zone 19 are in fluid communication with each other essentially through the perimeter duct 21, net of any fluid leakage on the shell side through the partition wall 58.

In accordance with a preferred embodiment, illustrated in Fig.1, the first and second shell zones 18, 19 are, respectively, provided with first and second diaphragms 27, 28 to support the exchanger tubes 8 and/or to divert the fluid flow on the shell side and thereby improve the heat transfer. Preferably, the diaphragms 27, 28, have a portioned disc shape as illustrated in Fig.5 and Fig. 6 but they can be of any type, for example single or double segments, or disc and ring. Preferably, at least a second diaphragm 28 installed in the second zone 19 is placed in proximity to the fourth end 26 of the second wall 20 in order to realise a radial passage or flow of the shell-side fluid on the second tube plate 7, from the outside towards the inside of the tube bundle 2 i.e. from the perimeter duct 21 to the second zone 19. This diaphragm 28 contributes to the division of the tube bundle 2 into two zones and can therefore conceptually be considered an integral part of the partition wall 58.

In accordance with a preferred embodiment, the perimeter duct 21 is preferentially provided with diverter elements 22, i.e., elements that divert the flow, increase turbulence, and improve mixing between the fractions of the shell-side fluid flowing in the perimeter duct 21. Preferably, such diverter elements 22 can be installed on the shell 3 and/or the second wall 20.

In accordance with the embodiment in Fig.1, the tube-side fluid 16 enters the first distributor 4 from the first tube-side connection 11, distributes itself and enters the exchanger tubes 8, flows along the exchanger tubes 8 towards the second tube plate 7 undergoing indirect heat exchange with the shell-side fluid, possibly in the presence of chemical reactions, exits the exchanger tubes 8 and enters the second distributor 5, then exits the equipment 1A via the second tube-side connection 12. In accordance with another preferred configuration (not shown in the figure), the shell-side fluid has the same direction as the shell-side flows in Figure 1 and the tube-side fluid has the opposite direction to the direction of the tube-side flows in Figure 1; in other words, the tube-side fluid 16 enters the equipment 1A from the second inlet connection 12, distributes itself in the second distributor 5 and enters the exchanger tubes 8, flows along the exchanger tubes 8 towards the first tube plate 6 undergoing indirect heat exchange with the shell-side fluid, possibly in the presence of chemical reactions, exits into the first distributor 4 and exits the equipment 1A via the first tube-side connection 11.

In accordance with the embodiment in Fig.1, a first fraction 48 of the shell-side fluid enters the first zone 18 from the first shell-side connection 13. The first fraction 48 passes through the portion of tube bundle 2 of the first zone 18, indirectly exchanges heat with the tube-side fluid and then flows through the first opening 23 and the perimeter duct 21 to the second zone 19. A second fraction 49 of the shell-side fluid enters the perimeter duct 21 via the second shell-side connection 14 and flows to the second shell zone 19. The first and second fractions 48, 49 are mixed in the perimeter duct 21. It should be noted that the duct 21 is therefore a zone of the shell configured to mix the two fractions 48, 49 of the shell-side fluid. The duct has an adequate length to ensure good mixing and is preferably provided with the diverter elements 22. A third fraction 50 of the shell-side fluid corresponding to the total of the shell-side fluid, i.e. the sum of the first and second fractions 48, 49, exits the perimeter duct 21 and enters the second zone 19 delimited by the first and second walls 17, 20, through the second opening 24. The third fraction 50 flows through the portion of the tube bundle 2 of the second zone 19, indirectly exchanges heat with the tube-side fluid and exits from the shell 3 through the third shell-side connection 15. Consequently, the first zone 18 is configured to be crossed by only a fraction 48 of the shell-side fluid, while the second zone 19 is configured to be crossed by all the shell-side fluid. In other words, the second fraction 49 fed into the duct 21 via the second shell-side connection 14 undergoes partial heat exchange with the tube-side fluid. The first and second fractions 48, 49 of the shell-side fluid, fed with the first and second shell-side connections 13, 14, respectively, can have both comparable and different temperatures. As a result, different heat transfer conditions can be established in the two shell zones 18, 19. This makes it possible to establish different heat exchange conditions in the two shell zones based on the temperature profile of the tube-side fluid along the heat exchanger tubes, and thus to optimise the overall heat exchange.

In accordance with a preferred alternative embodiment to the above and illustrated in Fig.2, the equipment 1A is structurally equivalent to the equipment 1A shown in Fig.1 and described above but differs from Fig.1 in terms of the direction of the shell-side and tube-side fluid flows and consequently in terms of a different operating process. Specifically, the equipment 1A in Fig.1 and equipment 1A in Fig.2 are essentially equivalent in terms of their construction elements and details, and their numbering.

It should also be noted that in Fig.1 for the shell-side flow circulation, the first wall 17 is spaced along the longitudinal axis 51 from the first plate 6 by a first distance and from the second plate 7 by a second distance. In contrast, the equipment 1A in Fig. 2 due to the different flow circulation on the shell side and the resulting heat exchange the first wall 17 is spaced along the longitudinal axis 51 from the first plate 6 by a third distance and from the second plate 7 by a fourth distance where the first distance is preferably less than the third distance and the second distance is preferably greater than the fourth distance.

For the sake of simplicity of description, the structural description of the equipment 1A shown in Fig.2 is omitted below, referring to Fig.1 for the structural description, and only its operating process is described.

In accordance with an alternative embodiment to the preceding one and illustrated in Fig.2, the tube-side fluid 16 enters the second distributor 5 of the equipment 1A from the second tube-side connection 12, distributes itself and enters the exchanger tubes 8, flows along the exchanger tubes 8 towards the first tube plate 6 undergoing indirect thermal exchange with the shell-side fluid, possibly in the presence of chemical reactions, exits the exchanger tubes 8 and enters the first distributor 4, and then exits the equipment 1A via the first tube-side connection 11.

According to another preferred configuration (not shown in the figure), the shell-side fluid has the same direction as the shell-side flows in Figure 2 and the tube-side fluid has the opposite direction to the direction of the tube-side flows in Figure 2; in other words, the tube-side fluid 16 enters the equipment 1A from the first tube-side connection 11, distributes itself in the first distributor 4 and enters the exchanger tubes 8, flows along the exchanger tubes 8 towards the second tube plate 7 undergoing indirect heat exchange with the shell-side fluid, possibly in the presence of chemical reactions, exits in the second distributor 5 and exits the equipment 1A via the second tube-side connection 12.

According to the embodiment in Figure 2, a first fraction 52 of the shell-side fluid enters the second zone of the shell 19 from the third shell-side connection 15.

The first fraction 52 passes through the portion of the tube bundle 2 of the second zone 19, indirectly exchanges heat with the tube-side fluid and then flows through the second opening 24 and the perimeter duct 21 to the first zone of the shell 18. A second fraction 53 of the shell-side fluid enters the perimeter duct 21 via the second shell-side connection 14 and flows to the first shell zone 18. The first and second fractions 52, 53 of the shell-side fluid are mixed in the perimeter duct 21. The duct 21 is thus a shell zone configured to mix the two fractions 52, 53 of the shell-side fluid. The perimeter duct 21 has an adequate length to ensure good mixing and is preferably fitted with the diverter elements 22. A third fraction 54 of the shell-side fluid corresponding to the total of the shell-side fluid, i.e. the sum of the first and second fractions 52, 53, exits the perimeter duct 21 and enters the first zone 18 through the first opening 23. The third fraction 54 flows through the portion of the tube bundle 2 of the first zone 18, indirectly exchanges heat with the tube-side fluid and exits from the shell 3 through the first shell-side connection 13. Consequently, the second zone 19 is crossed by only one fraction 52 of the shell-side fluid, while the first zone 18 is crossed by all of the shell-side fluid. In other words, the second fraction 53 entering the duct 21 via the second shell-side connection 14 undergoes partial heat exchange with the tube-side fluid. The first and second fractions 52, 53, fed respectively with the third and second shell-side connections 15, 14, can have both comparable and different temperatures. As a result, different heat exchange conditions can be established in the two shell zones 18,19. This makes it possible to establish different heat exchange conditions in different zones of the shell based on the temperature profile of the tube-side fluid along the exchanger tubes and thus to optimise the overall heat exchange.

From the accompanying Fig.1 and Fig.2 and the related descriptions, a person skilled in the art can easily understand that the direction of the fluid flows on the shell side can be further modified from Fig.1 and Fig.2 without essentially modifying the structure of the equipment according to the present invention and without essentially departing from the inventive concepts described herein.

As a first example of a change in the direction of the shell-side flows, with reference to Fig.1, the second fraction 49 exits the shell 3 through the second shell-side connection 14 instead of entering the shell 3 and the first fraction 48 injected through the first shell-side connection 13 corresponds to the total shell-side fluid. Consistently, the first fraction 48, i.e. the total fluid, enters the first zone 18 from the first shell-side connection 13, flows through the portion of the tube bundle 2 of the first zone 18 exchanging heat, enters the perimeter duct 21 through the first opening 23 and in the perimeter duct 21 is divided into the second and third fractions 49, 50. The second fraction 49 is extracted from the shell 3 through the second shell-side connection 14 while the third fraction 50 continues in the perimeter duct 21, enters the second zone of the shell 19 through the second opening 24, passes through the portion of tube bundle 2 of the second zone 19 exchanging heat and exits shell 3 through the third shell-side connection 15. The first zone 18 is crossed by the total shell-side fluid, while the second zone 19 is crossed by a fraction. The perimeter duct 21 is thus configured to separate two fractions 49, 50 of the shell-side fluid. The second and third fractions 49, 50 exit the shell with different temperature and/or vapour titre. In other words, the second fraction 49 exiting the second shell-side connection 14 bypasses part of the tube bundle 2 and thus undergoes partial heat exchange with the tube-side fluid.

As a second example of a change in the direction of the shell-side flows, with reference to Fig.2, the second fraction 53 exits the shell 3 through the second shell-side connection 14 instead of entering the shell 3, and the first fraction 52 entering from the third shell-side connection 15 corresponds to the total shell-side fluid. Consistently, the first fraction 52, i.e. the total fluid, enters the second zone 19 from the third shell-side connection 15, flows through the portion of the tube bundle 2 of the second zone 19 exchanging heat, enters the perimeter duct 21 through the second opening 24 and in the perimeter duct 21 is divided into the second and third fractions 53, 54. The second fraction 53 is extracted from shell 3 through the second shell-side connection 14 while the third fraction 54 continues in the perimeter duct 21, enters the first zone of the shell 18 through the first opening 23, passes through the portion of tube bundle 2 of the first zone 18 exchanging heat and exits shell 3 through the first shell-side connection 13. The first zone 18 is crossed by a fraction of the shell-side fluid, while the second zone 19 is crossed by the total fluid. The duct 21 is thus configured to separate two fractions 53, 54 of the shell-side fluid. The second and third fractions 53, 54 emerge from the shell 3 with different temperature and/or vapour titre. In other words, the second fraction 53 exiting the second shell-side connection 14 bypasses part of the tube bundle 2 and thus undergoes partial heat exchange with the tube-side fluid.

It should be noted that the second shell-side connection 14 in fluid communication with the perimeter duct 21 functions as a bypass connection, i.e. it allows a fraction 49, 53 of the shell-side fluid to be fed into or removed from the shell 3. In other words, the second fraction 49, 53 fed into or removed from the shell 3 via the second shell-side connection 14 bypasses a part of the tube bundle 2 and is thus partially subjected to heat exchange with the tube-side fluid. As already mentioned, this configuration advantageously allows different heat exchange conditions to be installed in different areas of the shell and thus optimise these conditions according to the temperature profile of the tube-side fluid. Furthermore, it is emphasised that by increasing or decreasing the flow of the bypass fraction, i.e. the flow of the second fraction 49, 53 flowing into the second shell-side connection 14, the temperature of the shell-side fluid and the tube-side fluid exiting the equipment 1A can be modified. This advantageously allows the thermal performance of the equipment 1A to be adjusted on the basis of work load or following short/long transients (e.g. start-up, increasing fouling, catalyst ageing).

Preferably, the equipment 1A may comprise at least one flow rate control system, or part thereof, for measuring and/or regulating the flow rate of the shell-side fluid passing through said second shell-side connection 14.

In accordance with an embodiment, the second shell-side connection 14 in fluid communication with the perimeter duct 21 of the equipment 1A, according to the present invention, i.e., the shell-side bypass connection, may be provided with a flow rate control system or part thereof, for example a control valve.

It should be noted that the second shell-side connection 14 can be in fluid communication with an external pipe, as for example described below. Preferably, a flow rate control system described below can be associated with this second shell-side connection 14.

It is further subject matter of the present invention to provide a plant for the synthesis of chemicals, preferably methanol, comprising the equipment 1A described above coupled to a cylindrical body containing the shell-side cooling fluid. It should be noted that in accordance with a preferred embodiment, the equipment 1A is a shell and tube reactor for methanol synthesis, preferably cooled by pressurised water circulating on the shell side, and connected to a cylindrical body. It should also be noted that in accordance with an alternative and preferred embodiment, the equipment 1A is a formaldehyde synthesis reactor or boiler or process exchanger, of the shell and tube type, where a hot synthesis gas is cooled, preferably with pressurised water circulating on the shell side, and connected to a cylindrical body. Synthesis gas, among other uses, can be used for the production of nitric acid or hydrogen cyanide.

Other cooling fluids, alternative to water, may however be used in accordance with the present invention, for example, diathermic oils or molten salts or molten metals or even process fluids.

As explained below, it is a further object of the present invention to provide an operating process conducted in the plant as further subject matter of the present invention. As anticipated, the shell and tube equipment shown in Fig.3 and Fig.4 1A can be used as reactors, for the synthesis of methanol in particular, preferably cooled by water and connected to a cylindrical body 32; alternatively, the equipment shown in Fig.3 and Fig.4 1A can be used as formaldehyde synthesis reactors or as boilers or process heat exchangers useful for cooling a hot synthesis gas. It should be noted that such equipment has the technical characteristics of the equipment 1A previously described in accordance with the relevant embodiments of Fig. 1 and Fig.2.

In Fig.3, a preferred form of the system according to the present invention is shown in which the equipment in Figure 1A is identical to that shown in Figure 1. Specifically, the equipment 1A is in a vertical position, with the first tube plate 6 placed at the top. The cylindrical body 32 is placed at some distance from the equipment 1A and preferably in an elevated position. The equipment 1A shown in Fig.3 is structurally identical to the equipment 1A shown in Fig.1, described above, in terms of its elements, construction details, relative numbering and also in terms of the flow direction of the shell-side fluid 48, 49, 50 of the tube-side fluid 16 and the related numbering. Consequently, for ease of description, the description of the equipment 1A in Fig.3 is omitted below.

In accordance with the embodiment of the system in Fig.3, the cylindrical body 32 is in fluid communication with the equipment 1A by means of a first, a second and a third pipe 29, 30, 31 which are connected respectively to the first, to the second and to the third shell-side connections 13, 14, 15 of the equipment 1A. The shell-side fluid of the equipment 1A then circulates in the cylindrical body 32 and in the first, second and third pipes 29, 30, 31. The cylindrical body 32, shown in Fig.3 in a longitudinal view, is configured to form within it a liquid level 33 of the shell-side fluid and, consequently, a liquid chamber 35 and an overlying vapour chamber 36.

In accordance with a preferred embodiment, the cylindrical body 32 comprises connections for the first, second and third pipes 29, 30, 31, connections for a vapour outlet or vent tube 37, connections for a purge or drain tube 39, possible connections for an auxiliary replenishing pipe 41, connections for level devices 34 adapted to control the liquid level 33, and possibly separation devices 38, internal to the cylindrical body 32, adapted to separate the liquid and vapour phases of the shell-side fluid. Preferably, the first and second pipes 29, 30 are provided with a first and second flow rate control system 42, 43 of the shell-side fluid, respectively.

In accordance with a preferred embodiment, the first pipe 29 is in fluid communication with a replenishing pipe 40 of the shell-side fluid via a first fitting 46. The cylindrical body 32 is in fluid communication with the replenishing pipe 40 via an auxiliary replenishing pipe 41 which can be disconnected from the replenishing pipe 40 via a second fitting 47. The replenishing pipe 40 and the auxiliary replenishing pipe 41 are equipped with a third and fourth flow rate control system 44, 45, respectively, of the shell-side fluid.

Further subject matter of the present invention is a process for the synthesis of chemicals made in the system for the synthesis of chemicals, for example shown in Figure 3. The process comprises the steps of:

- feeding the process gases on the tube side 16, and in the case of methanol synthesis these gases are rich in carbon oxides and hydrogen, into the equipment 1A via the first tube-side connection 11, and then into the exchanger tubes 8 via the first distributor 4 and the first tube end 9;

- flushing the process gases on the tube side (16) along the exchanger tubes 8, possibly in the presence of a heterogeneous catalyst loaded into the exchanger tubes 8 where synthesis takes place. During this outflow, cooling of the process gas occurs through indirect heat exchange with the water, or cooling fluid, flowing on the shell side;

- removing the process gases from the equipment 1A, in the case of methanol synthesis said reacted gases are rich in methanol, from the exchanger tubes 8 through the second tube end 10, the second distributor 5 and through the second connection on the tube side 12;

The heat exchange between the shell side and the tube side comprises the following steps, which are not necessarily sequential:

- feeding a first fluid fraction, preferably water, preferably pressurised, 48 essentially in the liquid phase, sub-cooled to temperature T1, into the first shell zone 18 via the first pipe 29 and the first shell-side connection 13;

- flushing the first fluid fraction 48 through the portion of the tube bundle 2 of the first zone 18 and in this way heating the first water fraction 48 by indirect exchange of essentially sensible heat with the reactant process gas passing through the tube side 16;

- flushing the first fraction of water 48 at temperature T2 and essentially in the liquid phase, under saturation or incipient saturation or sub-cooled conditions, from the first zone 18 to the perimeter duct 21 through the first opening 23;

- feeding a second fraction of water 49 essentially in the liquid phase at a temperature T3 greater than temperature T1, under saturation or incipient saturation conditions, into the perimeter duct 21 through the second pipe 30 and the second shell-side connection 14;

- flushing and mixing the first and second fractions of water 48, 49 in the perimeter duct 21, and flushing the third fraction of water 50 corresponding to the total water, obtained by mixing said first and second fractions 48, 49, essentially in the liquid phase and in incipiently saturated or sub-cooled conditions, from the perimeter duct 21 into the second zone 19 through the second opening 24;

- flushing the third water fraction 50, i.e. the total water, through the portion of the tube bundle 2 of the second zone 19 where heating and/or partial vaporisation of the water occurs by indirect exchange of essentially latent heat with the process gas;

- removing the third water fraction 50, in liquid and vapour phase at temperature T3 and under saturated conditions, from the equipment 1A through the third shell-side connection 15;

- flushing said fluid exiting the third connection 15 through the third pipe 31 by means of natural or forced circulation in the third pipe 31 towards the cylindrical body 32 and feeding the third water fraction 50 into the cylindrical body 32;

- separating the liquid and vapour phases of the third fraction 50 in the cylindrical body 32 by means of separation devices 38;

- removing from the cylindrical body 32 a fraction of said fluid water in the vapour phase, through the vapour line 37, and removing a fraction of water in the liquid phase, through the purge pipe 39;

- feeding a fourth fraction of said fluid 55 essentially in liquid phase at temperature T3, under saturation or incipient saturation conditions, into the first pipe 29 connected to said cylindrical body 32;

- feeding a fifth fluid fraction 56 sub-cooled to temperature T4, less than temperature T3, into the first pipe 29 via the replenishing pipe 40;

- mixing the fourth and fifth water fractions 55, 56 in the first pipe 29 to obtain the first water fraction 48 essentially in liquid phase at temperature T1, and flushing by natural or forced circulation the first water fraction 48 along the first pipe 29 to the equipment 1A;

- feeding the second fraction of water 49 essentially in liquid phase at temperature T3, under saturation or incipient saturation conditions, into the second pipe 30 connected to the cylindrical body 32 and flushing by natural or forced circulation along the second pipe 30 towards the equipment 1A;

- optionally feeding a sixth fraction of water 57 sub-cooled to temperature T4, less than temperature T3, into the cylindrical body 32 via the auxiliary replenishing pipe 41 and mixing the sixth fraction of water 57 with the water in the cylindrical body 32;

- checking the water level 33 inside the cylindrical body 32 by means of the level devices 34;

- regulating the flow rate of the fourth, second, fifth and optionally sixth water fractions 55, 49, 56, 57 by means of the first, second, third and optionally fourth flow rate control systems 42, 43, 44, 45, respectively.

In accordance with an alternative embodiment to the above and illustrated in Fig.4, the system according to the present invention for the synthesis of methanol comprises the equipment 1A, connected to a cylindrical body 32. In this case, the equipment 1A of Fig.4 is in a vertical position, with the first tube plate 6 placed at the top, the cylindrical body 32 is placed at a certain distance above the equipment 1A.

The equipment 1A shown in Fig.4 is essentially structurally identical to the equipment 1A shown in Fig.2 and described above. The equipment 1A in Fig.4 and the equipment 1A in Fig.2 are essentially identical in terms of the elements and construction details, and their numbering. The equipment 1A in Fig.4 and the equipment 1A in Fig.2 are also essentially identical in terms of the flow direction of the shell-side fluid 52, 53, 54 and the tube-side fluid 16 and the numbering thereof; consequently, the equipment 1A in Fig.4 and the equipment 1A in Fig.2 are also essentially equivalent in terms of their operating principles. For simplicity of description, the structural description of the above-mentioned equipment 1A shown in Fig.4 is omitted below, referring to Fig.2 for the structural description.

In accordance with Fig.4, the cylindrical body 32 is in fluid communication with the equipment 1A by means of a first, second and third pipe 29, 30, 31 connected respectively to the third, second and first shell-side connections 15, 14, 13 of the equipment 1A. The shell-side fluid of the equipment 1A then circulates in the cylindrical body 32 and in the first, second and third pipes 29, 30, 31. The cylindrical body 32, shown in Fig.4 in a longitudinal view, is configured to form within it a liquid level 33 of the shell-side fluid and, consequently, a liquid chamber 35 and an overlying vapour chamber 36. The cylindrical body 32 comprises connections for the first, second and third pipes 29, 30, 31, connections for a vapour outlet or vent tube 37, connections for a purge or drain tube 39, possible connections for an auxiliary replenishing pipe 41, connections for level devices 34 adapted to control the liquid level 33, and possible separation devices 38, internal to the cylindrical body 32, adapted to separate the liquid and vapour phases of the shell-side fluid.

Preferably, the first and second pipes 29, 30 are provided with a first and second flow rate control system 42, 43 of the shell-side fluid, respectively.

In accordance with a preferred embodiment, the first pipe 29 is in fluid communication with a replenishing pipe 40 of the shell-side fluid via a first fitting 46. The cylindrical body 32 is in fluid communication with the replenishing pipe 40 via an auxiliary replenishing pipe 41 which can be disconnected from the replenishing pipe 40 via a second fitting 47. The replenishing pipe 40 and the auxiliary replenishing pipe 41 are equipped with a third and fourth flow rate control system 44, 45, respectively, of the shell-side fluid.

Further subject matter of the present invention is a process for the synthesis of chemicals in the plant, for example, shown in Fig. 4. The process comprises the steps of:

- feeding the tube-side process gases 16, which in the specific case of methanol synthesis are rich in carbon oxides and hydrogen, into the equipment 1A via the second tube-side connection 12, then into the tube exchangers 8 via the second distributor 5 and the second tube end 10;
- flushing along the exchanger tubes 8, possibly loaded with a catalyst to perform a synthesis, the process gas 16, which during flushing transfers heat

indirectly to the shell-side fluid, preferably water;

- removing the process gases 16, which in the case of methanol synthesis are rich in methanol, from the exchanger tubes 8 through the first tube end 9 and the first distributor 4, and through the first tube-side connection 11;

Heat exchange between the tubes of the tube bundle and the shell-side fluid comprises the following operating steps:

- feeding a first fraction of water 52 essentially in the liquid phase sub-cooled to temperature T1 into the second shell zone 19 via the first pipe 29 and the third shell-side connection 15;

- flushing the first fraction of water 52 through the portion of the tube bundle 2 of the second zone 19 and consequently heating the first fraction of water 52 by indirect exchange of essentially sensible heat with the reacted process gases 16.

- flushing the first fraction of water 52 at temperature T2 and essentially in the liquid phase, under saturation or incipient saturation or sub-cooled conditions, from the first zone 19 to the perimeter duct 21 through the first opening 24;

- feeding a second fraction of water 53 essentially in the liquid phase at a temperature T3 greater than temperature T1, under saturation or incipient saturation conditions, into the perimeter duct 21 through the second pipe 30 and the second shell-side connection 14;

- flushing and mixing the first and second fractions of water 52, 53 in the perimeter duct 21, and obtaining a third fraction 54 of water corresponding to the total of the first and second fractions 52 and 53;

- flushing said third fraction of water 54 corresponding to the total amount of water, obtained by mixing the first and second fractions 52, 53, essentially in the liquid phase and in incipient saturated or sub-cooled conditions, from the perimeter duct 21 to the first zone 18 through the first opening 23;

- flushing the third fluid fraction 54 through the portion of the tube bundle 2 of the first zone 18 and evaporating at least partially, and/or heating, the shell-side fluid by indirect exchange of essentially latent heat with the process gases reacted in the tubes 8;

- removing the third water fraction 54 in the liquid and/or vapour phase at temperature T3, under saturated conditions, from the equipment 1A via the first shell-side connection 13 and the third pipe 31,

- flushing by natural or forced circulation in the third pipe 31 towards the cylindrical body 32 and feeding the third water fraction 54 into the cylindrical body 32;

- separating the liquid and vapour phases of the third fraction 54 in the cylindrical body 32 by means of separation devices 38;

- partially removing water in the vapour phase from the cylindrical body 32, through the vapour pipe 37, and partially removing water in the liquid phase, through the purge pipe 39;

- feeding a fourth fraction of water 55 essentially in the liquid phase at temperature T3, under saturation or incipient saturation conditions, from said cylindrical body 32 into the first pipe 29;

- feeding a fifth water fraction 56 sub-cooled to temperature T4, less than temperature T3, into the first pipe 29 via the replenishing pipe 40 and the first connection 46;

- mixing the fourth water fraction and the fifth water fraction 55, 56 in the first pipe 29, to obtain the first water fraction 52 preferably sub-cooled to temperature T1, and flushing it by natural or forced circulation along the first pipe 29 to the equipment 1A;

- feeding the second fraction of water 53 from the cylindrical body 32 essentially in liquid phase at temperature T3, under saturation or incipient saturation conditions, into the second pipe 30 and flushing it by natural or forced circulation along the second pipe 30 to the equipment 1A;

- optionally introducing a sixth fraction of water 57 sub-cooled to temperature T4, less than temperature T3, into the cylindrical body 32 via the auxiliary replenishing pipe 41 and mixing the sixth fraction of water 57 with the water in the cylindrical body 32;

- checking the water level 33 inside the cylindrical body 32 by means of the level devices 34;

- regulating the flow rate of the fourth, second, fifth and optionally sixth water fractions 55, 53, 56, 57 by means of the first, second, third and fourth flow rate control systems 42, 43, 44, 45, respectively.

As mentioned above, the shell-side fluid is preferably water. In this case, the water pressure within the plant according to the invention is preferably comprised between 1600 and 7000kPa(a), more preferably between 1600 and 4000kPa(a). At the above preferred pressure conditions, T1 is preferably comprised between approximately 170 and 270°C; T2 is approximately comprised between 185 and 285°C; T3 is approximately comprised between 200 and 285°C; T4 is approximately comprised between 120 and 220°C.

At the aforesaid most preferable pressure conditions, T1 is preferably comprised between approximately 170 and 235°C; T2 is preferably approximately comprised between 185 and 250°C; T3 is approximately comprised between 200 and 250°C; T4 is approximately comprised between 120 and 190°C.

For the purposes of the present invention, flow rate control system 42, 43, 44, 45 means any system comprising one or more instruments and/or valves for measuring and/or regulating the amount of fluid flowing in the pipe. The control system may, for example, correspond to or include a calibrated orifice or a venturi meter and valve.

It is emphasised that the operating process conducted in the plant in Fig.3 and

Fig.4 as described above is preferably a continuous process.

As anticipated, the operating processes relating to Fig.3 and Fig.4 may provide that the sixth fraction of water 57, i.e. the fraction of water fed into the cylindrical body 32 via the auxiliary replenishing pipe 41, is negligible or null. In this case, the fifth fraction of water 56 flowing into the first pipe 29 corresponds to the total water flowing in the replenishing pipe 40.

In accordance with an alternative configuration of Fig.3 and Fig.4, not shown, the auxiliary replenishing pipe 41, connected to the cylindrical body 32 and provided with the corresponding fourth flow rate control system 45, is an independent line from the replenishing pipe 40, possibly having different operating temperature conditions from those of the replenishing stream 40, and the second fitting 47 is not present in the system.

In accordance with an alternative configuration of Fig.3 and Fig.4, not shown in the figure, the auxiliary replenishing pipe 41 and the associated fourth flow rate control system 45 are not installed. Specifically, the cylindrical body 32 is not connected to any auxiliary replenishing pipe 41. Thus, no replenishing water fraction is directly fed into the cylindrical body 32. In this case, the operating processes relating to Fig.3 and Fig.4 do not comprise the step relating to the introduction of a sixth fraction of water 57 sub-cooled to temperature T4 in the cylindrical body 32 via the auxiliary replenishing pipe 41.

Preferably, the process of the invention concerns the synthesis of methanol; in this case:

- the tube-side fluid fed into said exchanger tubes 8 is a pressurised process gas rich in carbon oxides and hydrogen, where a heterogeneous catalyst is loaded into said exchanger tubes 8 to conduct exothermic chemical reactions;
- the fluid removed from heat exchanger tubes 8 is rich in methanol, and
- the shell-side fluid is pressurised water, at the preferred and most preferred

pressures stated above.

With reference to Fig.3 and Fig.4 and the related operating processes described above, it can be seen that, in particular, the methanol synthesis plant has the following main functional characteristics:

a) The part of the tube bundle affected by thermodynamically/kinetically highly favoured chemical synthesis reactions and thus a high gas temperature gradient, i.e. the initial part of the tube bundle from which the reactant process gas enters, corresponds to the shell zone where water flows under sub-cooled conditions, essentially in the liquid phase. Water enters this zone of the shell at a temperature T1 lower than the temperature T3 of the water in saturation or incipient saturation present in the cylindrical body 32. Water exits this zone of the shell essentially in the liquid phase, in incipient saturated or sub-cooled conditions. Consequently, the shell zone affected by the peak temperature of the process reactant gas on the tube side is characterised by indirect heat exchange essentially consisting of sensible heat, and is therefore characterised by a lower shell-side heat exchange coefficient, and is essentially the “cold” zone of the methanol reactor.

b) The part of the tube bundle where the chemical synthesis reactions have milder thermal gradients, i.e. the central and terminal part of the bundle, corresponds to the zone of the shell where the water basically flows under saturation conditions, close to or equivalent to the operating conditions of the cylindrical body 32, and therefore where the water partially vaporises. Consequently, the shell zone not affected by the gas temperature peak is characterised by indirect heat exchange essentially consisting of latent heat, thus characterised by a higher shell-side heat exchange coefficient, and is essentially the “hot” zone of the methanol reactor.

c) The flow rate control systems 42, 43, 44, 45 of the water in liquid phase allow the water quantities flowing in the water replenishing pipe 40, in the auxiliary replenishing pipe 41 and in the first and second pipes 29, 30 of water supply to the relevant equipment 1A to be proportioned. In other words, the flow rate control systems 42, 43, 44, 45 increase or decrease the amount of water and/or the temperature of the water flowing in the specific pipes 40, 41, 29, 30 in order to regulate the heat exchange in the relevant equipment 1A, i.e. the operation of the relevant equipment 1A. According to a first example of operating control of the methanol reactor, with reference to Fig.3 and at overall and essentially stationary operating conditions, the flow of the first water fraction 48 flowing in the first pipe 29 and entering the equipment 1A from the first shell-side connection 13 is kept constant, the flow of the fifth water fraction 56 at temperature T4 fed into the first pipe 29 via the replenishing pipe 40 is decreased and the flow of the fourth water fraction 55 at temperature T3, greater than temperature T4, fed into the first pipe 29 via the cylindrical body 32 is increased: the temperature T1 of the first water fraction 48 at the inlet of the methanol reactor 1A is increased and the heat exchange in the first shell zone 18 is consequently modified. According to a second example of operating control of the methanol reactor, with reference to Fig.3 and at overall and essentially stationary conditions, the flow of the third water fraction 50, i.e. the total flow of water through the reactor 1A, exiting from the third shell-side connection 15 and flowing in the third pipe 31 is kept constant while the flow of the second water fraction 49 flowing in the second pipe 30 is decreased: the flow of the first water fraction 48 flowing in the first pipe 29 and entering the reactor 1A via the first shell-side connection 13 is increased and consequently the heat exchange in the first zone of the shell 18 is modified.

The operating advantages offered by the additional methanol synthesis plant according to this invention, shown in Fig.3 and Fig.4, clearly emerge from points a), b) and c) above and can be summarised as follows:

- The “cold” zone of the shell, as a zone with sub-cooled water, makes it possible to control the initial temperature gradient on the gas side, i.e. to dampen the gas temperature peak, without over-cooling, resulting in an increase in overall chemical yield/conversion and mitigation/elimination of the risk of damage or ageing of the catalyst located in the first section of the tubes and mitigation/elimination of parasitic reactions;

- If the process gas enters the reactor from the top of the reactor as in Figure 2 and 4, as is usual in conventional methanol reactors, the “cold” zone is in contact with the upper tube plate and thus the vaporisation of water on the upper tube plate and the associated risk of the Leidenfrost effect is prevented;

- The “cold” zone of the shell, where sensible heat exchange takes place, and the flow rate control systems of the water tubes allow effective operating control of the reactor both during transients and over the life of the catalyst. In particular, the innovative methanol reactor according to the present invention enables optimisation of yield and chemical conversion throughout the life of the catalyst thanks to the possibility of changing the temperature and/or flow of the sub-cooled water flowing in the “cold” zone.

- The “hot” zone of the shell, which in practice corresponds to a large portion of the tube bundle 2, as a zone with vaporising water allows efficient heat exchange overall, resulting in optimised reactor size and chemical yield/conversion.

Some of the above-mentioned advantages, relating to the methanol synthesis plant disclosed herein, are also valid for other synthesis plants, such as the synthesis of nitric acid, hydrogen cyanide and formaldehyde; specifically, the invention described herein makes it possible to mitigate or eliminate potential shell-side phenomena such as the Leidenfrost effect or vapour flooding, typical of conventional process boilers operating downstream of catalytic reactors or reactors discharging synthesis gases at high temperature.

In conclusion, according to the accompanying Fig.1 and Fig.2 and the related descriptions, the present invention provides a shell and tube equipment 1A, with the shell having a double zone, capable of operating under different thermal conditions in the two zones of the shell depending on the longitudinal temperature profile of the tube-side fluid, and capable of bypassing a fraction of the shell-side fluid and adjusting its flow according to the workload of the equipment or in response to short/long operating transients (e.g., start-ups, increased fouling).

Advantageously, the equipment 1A of Fig.1 and Fig.2 allows for superior heat exchange and control performance compared to other conventional shell and tube equipment for indirect heat exchange between the shell-side fluid and the tube-side fluid; advantageously, the equipment 1A of Fig.1 and Fig.2 also prevents or mitigates the Leidenfrost effect on the heating surfaces or vapour flooding related to the shell-side cooling fluid.

Similarly, in accordance with the accompanying Fig.3 and Fig.4 and the related descriptions, the present invention provides a plant for the synthesis of methanol, or alternatively nitric acid, hydrogen cyanide or formaldehyde, comprising the above-mentioned pressurised water-cooled shell and tube equipment 1A, with the shell having a double zone, connected to a raised cylindrical body 32, capable of operating with different thermal conditions in the two zones of the shell based on the longitudinal temperature profile of the process gas flowing in the exchanger tubes, capable of dampening the temperature peak of the process gas with a consequent increase in chemical yield/conversion, and capable of regulating the flow and/or temperature of the water fractions entering the reactor based on the reactor workload or in response to short/long operating transients (e.g. start-ups, increased fouling, catalyst aging).

Advantageously, the methanol synthesis plant in Fig.3 and Fig.4 achieves higher chemical yields/conversions and better control than conventional pressurised water-cooled shell and tube methanol reactors. However, it is emphasised that the equipment 1A in the accompanying Fig.3 and Fig.4, connected to a cylindrical body

32, can operate like any chemical reactor adapted to synthesise compounds other than methanol.

CLAIMS

1. Equipment (1A) of essentially cylindrical shape comprising

- a tube bundle (2) and the related shell (3) for indirect heat exchange between a tube-side fluid and a shell-side fluid,

- a first and second tube plate (6, 7) with first and second holes respectively and spaced along a longitudinal axis (51),

- said tube bundle (2) comprising straight exchanger tubes (8) extending along the longitudinal axis and having first and second ends (9,10) respectively connected to said first and second holes,

- said shell (3) containing said tube bundle (2) connected to said first and second tube plates (6, 7) and delimited by said first and second tube plates (6, 7), said shell (3) being provided with at least one first (13), at least one second (14) and at least one third connection (15) on the shell side (13, 14, 15) for feeding and removing said shell-side fluid,

- a first distributor (4) connected to said first tube plate (6) on the opposite side with respect to the shell (3) and provided with at least a first tube-side connection (11) for the inlet or outlet of said tube-side fluid, said first distributor (4) being in fluid communication with said exchanger tubes (8) via said first ends (9),

- a second distributor (5) connected to said second tube plate (7) on the opposite side with respect to the casing (3) and provided with at least a second tube-side connection (12) for the inlet or outlet of said tube-side fluid, said second distributor (5) being in fluid communication with said exchanger tubes (8) via said second ends (10),

- a shell-side partition wall (58) configured to divide said shell (3) into a first and a second zone (18, 19) crossed by portions of said tube bundle (2) and arranged longitudinally in series respectively in proximity to said first and second tube plates (6, 7), said partition wall (58) being configured to render null or negligible the fraction of shell-side fluid passing from one zone to the other (18, 19) through said partition wall (58), said partition wall (58) defining a perimeter duct (21) having at its ends a first and a second opening (23, 24) respectively arranged in proximity to said first and second tube plate (6, 7) and configured to place in fluid communication said first and said second zones (18, 19) via the perimeter duct (21);

- first and second diaphragms (27, 28) installed in said first and second zones (18, 19) respectively, adapted to support said exchanger tubes (8) and/or to perform flow deviations of said shell-side fluid to increase heat exchange,

said equipment 1A being characterised in that: said perimeter duct (21) is essentially annular in shape and is not crossed by the tube bundle (2) but surrounds the portion of the tube bundle crossing said second zone (19) in such a way that said first (13) and third shell-side connections (15) are respectively directly connected to the first zone (18) and to the second zone (19) and said at least one second shell-side connection (14) is directly connected to the perimeter duct (21).

2. The equipment (1A), according to claim 1, wherein said partition wall (58) comprises:

- a first wall (17) orthogonal to the longitudinal axis (51) provided with third holes to receive said exchanger tubes (8),

- a second wall (20) essentially cylindrical in shape, arranged concentrically with respect to the shell (3) surrounding said heat exchanger tubes (8) and having a third end (25) facing said first tube plate (6) and a fourth end (26) facing and arranged at said second tube plate (7), said perimeter duct (21) being defined between the second wall (20) and the shell (3);

- said first and second walls (17, 20) being mutually coupled together radially outwardly with respect to said tube bundle (2) and in proximity to said third end (25), said first wall (17) defining said first opening (23) radially outwardly with respect to said second wall (20) and said second wall (20) defining said second opening (24) in proximity to said fourth end (26).

3. The equipment (1A) according to claim 2, wherein said first wall (17) is radially spaced from said shell (3) so as to define said first opening (23).

4. The equipment (1A) according to claim 2 or 3, wherein said first wall (17) has a diameter essentially identical to the internal diameter of said shell (3) and comprises windows and/or holes (100) defining said first opening (23).

5. The equipment (1A) according to any one of claims 1 to 4, wherein said perimeter duct (21) is provided with diverter elements (22) configured to divert the flow and increase the turbulence of the shell-side fluid flowing in said duct (21).

6. The equipment (1A) according to any one of claims 1 to 5, further comprising a flow rate control system or part thereof, for measuring and/or regulating the flow rate of the shell-side fluid passing through said second shell-side connection (14).

7. Chemical synthesis plant comprising:

- an equipment (1A) according to any one of claims 1 to 5;
- a cylindrical body (32) in fluid communication on the shell side with said equipment (1A);
- at least one first pipe (29), at least one second pipe (30) and at least one third pipe (31) configured to place said cylindrical body (32) in fluid communication with the shell side of said equipment (1A);
- said first and second pipes (29, 30) are respectively equipped with a first and second flow rate control system (42, 43) adapted to measure and/or regulate the flow rate of the shell-side fluid.

8. Plant according to claim 7, wherein said cylindrical body (32) is in an elevated position with respect to said equipment (1A).

9. Plant according to claim 7 or 8, wherein said equipment (1A) is placed in an upright position with said first tube plate (6) at the top and said second tube plate (7) facing a base.

10. Plant for the synthesis of chemicals according to any one of claims 7-9, wherein

- said cylindrical body (32) is a liquid/vapour separator comprising an overlying vapour chamber (36) and an underlying liquid chamber (35) separated by the liquid level (33),
- said cylindrical body (32) comprising at least one level device (34) adapted to control said liquid level (33), internal separation devices (38) adapted to perform said liquid/vapour separation,

said cylindrical body (32) comprising a vapour pipe (37) for removing vapour from the cylindrical body (32) and a purge pipe (39) for extracting liquid from the cylindrical body (32).

11. Chemical synthesis plant according to any one of claims 7-10, wherein said first pipe (29) is connected via a first fitting (46) to a replenishing pipe (40) of the shell-side fluid, and wherein the replenishing pipe (40) is provided with a third flow rate control system (44) for measuring and/or regulating the flow rate of the shell-side fluid.

12. Plant according to claim 11, wherein said cylindrical body (32) is in fluid communication with an auxiliary replenishing pipe (41) of the shell-side fluid and wherein said auxiliary replenishing pipe (41) is provided with a fourth flow rate control system (45) for measuring and/or regulating the flow rate of the shell-side fluid.

13. Plant according to claim 12, wherein said auxiliary replenishing pipe (41) is in fluid communication with said replenishing pipe (40) by means of a second fitting (47).

14. Plant according to any one of claims 7 to 13, wherein said first pipe (29) is connected to said first or third shell-side connection (13,15) of the equipment 1A, said second pipe (30) is connected to said second shell-side connection (14) of the equipment (1A) and said third pipe (31) is connected to said third or first shell-side connection (15,13) of the equipment (1A).

15. Process for the synthesis of chemicals carried out in the plant according to claims 7, 11 and 14, said process comprising the steps of:

- feeding tube-side process gases (16) into said exchanger tubes (8) through said first tube-side connection (11), said first distributor (4) and said first ends (9) in said tubes (8);
- flushing the process gases (16) along said exchanger tubes (8), where said gases indirectly release heat to the shell-side fluid,
- removing the process gases from said exchanger tubes (8) via said second ends (10), said second distributor (5) and said second tube-side connection (12);

wherein the heat exchange between the tube side and the shell side comprises the following steps, which are not necessarily sequential:

- feeding a first fraction (48) of the shell-side fluid essentially in liquid phase at temperature T1, sub-cooled, into said first zone (18) via said first pipe (29) and first shell-side connection (13);

- flushing said first fluid fraction (48) through the portion of tube bundle (2) passing through said first zone (18) and consequently heating said first fraction (48) by means of indirect exchange of essentially sensible heat with the tube-side fluid (16)

- flushing said first fraction (48) essentially in liquid phase at temperature T2, under saturation or incipient saturation or sub-cooled conditions, from said first zone (18) to said duct (21) through said first opening (23);

- feeding a second fraction (49) of the shell-side fluid essentially in liquid phase at a temperature T3 greater than temperature T1, under saturation or incipient saturation conditions, into said duct (21) via said second pipe (30) and second shell-side connection (14);

- flushing and mixing in said duct (21) of said first and second fractions (48,49) shell-side fluid to form a third fraction (50), the flushing of said third fraction (50), essentially in liquid phase and in saturation or incipient saturation or sub-cooled conditions, from said duct (21) to said second zone (19) through said second opening (24);

- flushing said third fraction (50) of said shell-side fluid through the portion of the tube bundle (2) passing through said second zone (19) and partial vaporisation, or heating and partial vaporisation, of said third fraction (50) by indirect exchange of essentially latent heat with the tube-side fluid (16) and the reacted process gases;

- removing said third fraction (50) in liquid and vapour phase at temperature T3, under saturation conditions, from said second zone (19) through said third shell-side connection (15),

- flushing said third fraction (50) in said third pipe (31) to said cylindrical body (32) and feeding said third fraction (50) into the cylindrical body (32);

- separating in the cylindrical body (32) the liquid and vapour phases of said third fraction (50) in the cylindrical body (32) by means of said separation devices

(38);

- removing from the cylindrical body (32) a fraction of the shell-side fluid in vapour phase, through said vapour pipe (37), and removing a fraction of the shell-side fluid in liquid phase, through said purge pipe (39);

- feeding a fourth fraction (55) of the shell-side fluid essentially in liquid phase at temperature T3, under saturation or incipient saturation conditions, into said first pipe (29) connected to said cylindrical body (32);

- feeding a fifth fraction (56) of the shell-side fluid sub-cooled to temperature T4, less than temperature T3, into said first pipe (29) via said replenishing pipe (40) and said first fitting (46);

- mixing said fourth and fifth fractions (55,56) in said first pipe (29) to form said first fraction (48) and flushing said first fraction (48) in said first pipe (29) towards said equipment (1A);

- feeding said second fraction (49) essentially in liquid phase at temperature T3, under saturation or incipient saturation conditions, into said second pipe (30) connected to said cylindrical body (32) and flushing said second fraction (49) in said second pipe (30) towards said equipment (1A);

- controlling the fluid level (33) of the shell-side fluid within said cylindrical body (32) by means of said level devices (34);

- regulating the flow rate of said fourth, second and fifth fractions (55, 49, 56) by means of a first, second and third flow rate control system (42, 43, 44) respectively.

16. Process for the synthesis of chemicals conducted in the plant according to claims 7, 11 and 14, said process comprising the steps of:

- feeding the tube-side process gases (16) into said exchanger tubes (8) via said second tube-side connection (12), said second distributor (5) and said second ends

(10);

- flushing process gases (16) along said exchanger tubes (8), where these gases indirectly release heat to the shell-side fluid;

- removing process gases from said exchanger tubes (8) through said first ends (9), said first distributor (4) and said first tube-side connection (11);

wherein the tube-side and shell-side heat exchange comprises the following operating steps:

- feeding a first fraction (52) of the shell-side fluid essentially in liquid phase at temperature T1, sub-cooled, into said second zone (19) via said first pipe (29) and third shell-side connection (15);

- flushing said first fraction (52) through the portion of tube bundle (2) passing through said second zone (19) and consequently heating said first fraction (52) by means of indirect exchange of essentially sensible heat with tube side (16) with the reacted process gases;

- flushing said first fraction (52) essentially in liquid phase at temperature T2, under saturation or incipient saturation or sub-cooled conditions, from said second zone (19) to said perimeter duct (21) through said second opening (24);

- feeding a second fraction (53) of the shell-side fluid essentially in liquid phase at a temperature T3 greater than temperature T1, under saturation or incipient saturation conditions, into said perimeter duct (21) via said second pipe (30) and second shell-side connection (14);

- flushing and mixing in said duct (21) of said first and second fractions (52, 53) to form a third fraction (54) of the shell-side fluid,

- flushing said third fraction (54), essentially in the liquid phase and in saturation or incipient saturation or sub-cooled conditions, from said duct (21) to said first zone (18) through said first opening (23);

- flushing said third fraction (54) through the portion of tube bundle (2) passing through said first zone (18) and partial vaporisation, and/or heating, of said third fraction (54) by indirect exchange of essentially latent heat with the reacted gases (8);

- removing said third fraction (54) in liquid and vapour phase at temperature T3, under saturation conditions, from said first zone (18) through said first shell-side connection (13) and said third pipe (31),

- flushing said third fraction (54) by forced or natural circulation in said third pipe (31) towards said cylindrical body (32) and feeding said third fraction (54) into the cylindrical body (32);

- separating the liquid and vapour phases of said third fraction (54) in the cylindrical body (32) by means of said separation devices (38);

- removing from the cylindrical body (32) a fraction of the shell-side fluid in vapour phase, through said vapour pipe (37), and removing a fraction of the shell-side fluid in liquid phase, through said purge pipe (39);

- feeding a fourth fraction (55) of the shell-side fluid essentially in liquid phase at temperature T3, under saturation or incipient saturation conditions, from said cylindrical body (32) into said first pipe (29);

- feeding a fifth fraction (56) of the shell-side fluid sub-cooled to temperature T4, less than temperature T3, into said first pipe (29) via said replenishing pipe (40) and said first fitting (46);

- mixing said fourth and fifth fractions (55, 56) in said first pipe (29) to form said first fraction of water (52) and flushing said first fraction (52) in said first pipe (29) towards said equipment (1A);

- feeding said second fraction (53) essentially in liquid phase at temperature T3, under saturation or incipient saturation conditions, from said cylindrical body (32) into said second pipe (30) and flushing said second fraction (49) in said second pipe (30) towards said equipment (1A);

- controlling the fluid level (33) of the shell-side fluid within said cylindrical body (32) by means of said level devices (34);

- regulating the flow rate of said fourth, second and fifth fractions (55, 53, 56) by means of said first, second and third flow rate control system (42, 42.43, 44), respectively.

17. The process for the synthesis of chemicals according to claim 15 or 16, wherein the heat exchange between the process gases in the tube bundle (2) and in the shell side also comprises the following operating steps:

- feeding a sixth fraction (57) of the shell-side fluid sub-cooled to temperature T4, less than temperature T3, into the cylindrical body (32) via said auxiliary replenishing pipe (41);
- mixing said sixth fraction (57) with the shell-side fluid in the cylindrical body (32);
- controlling the flow rate of said sixth fraction (57) by means of said fourth flow rate control system (45).

18. The process for synthesising chemicals according to any one of claims 15 to 17, wherein the synthesis product is methanol and the process gases on the tube side are pressurised reactant gases rich in carbon oxides and hydrogen, wherein a heterogeneous catalyst is loaded into said exchanger tubes (8), and the process gases extracted from said exchanger tubes (8) are rich in methanol, wherein the shell-side fluid is pressurised water.

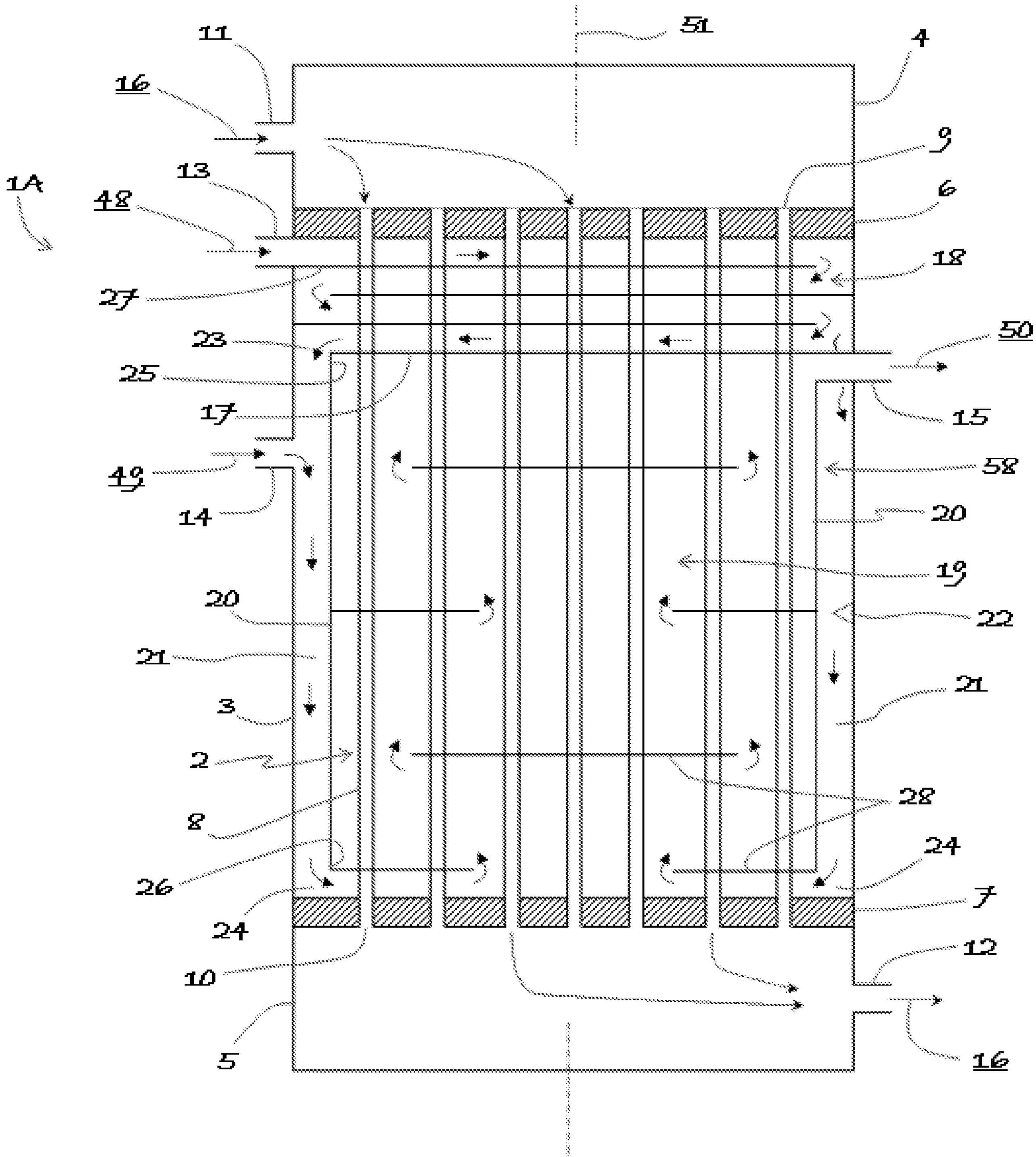
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Fig. 1

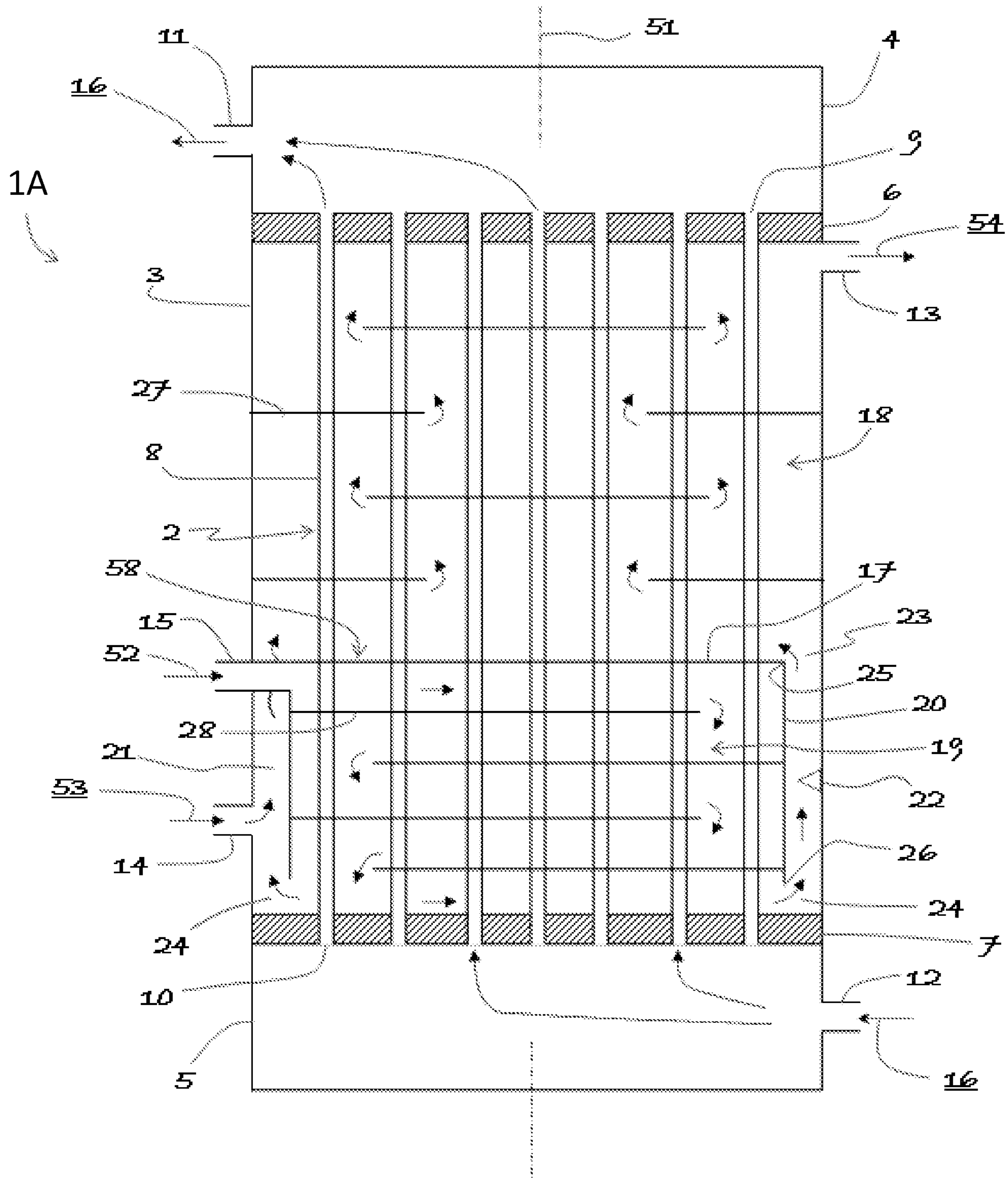
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Fig. 2

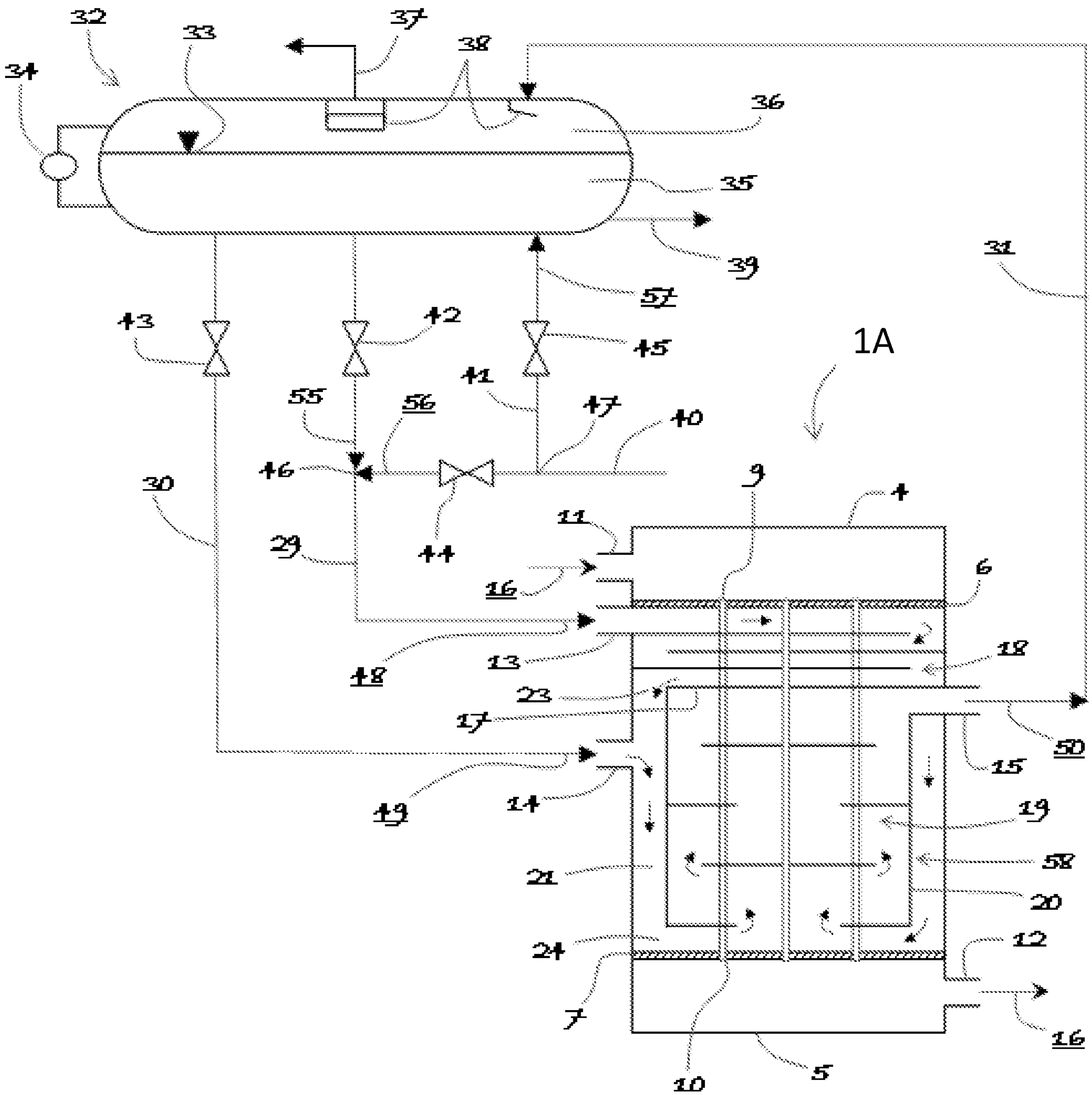
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Fig. 3

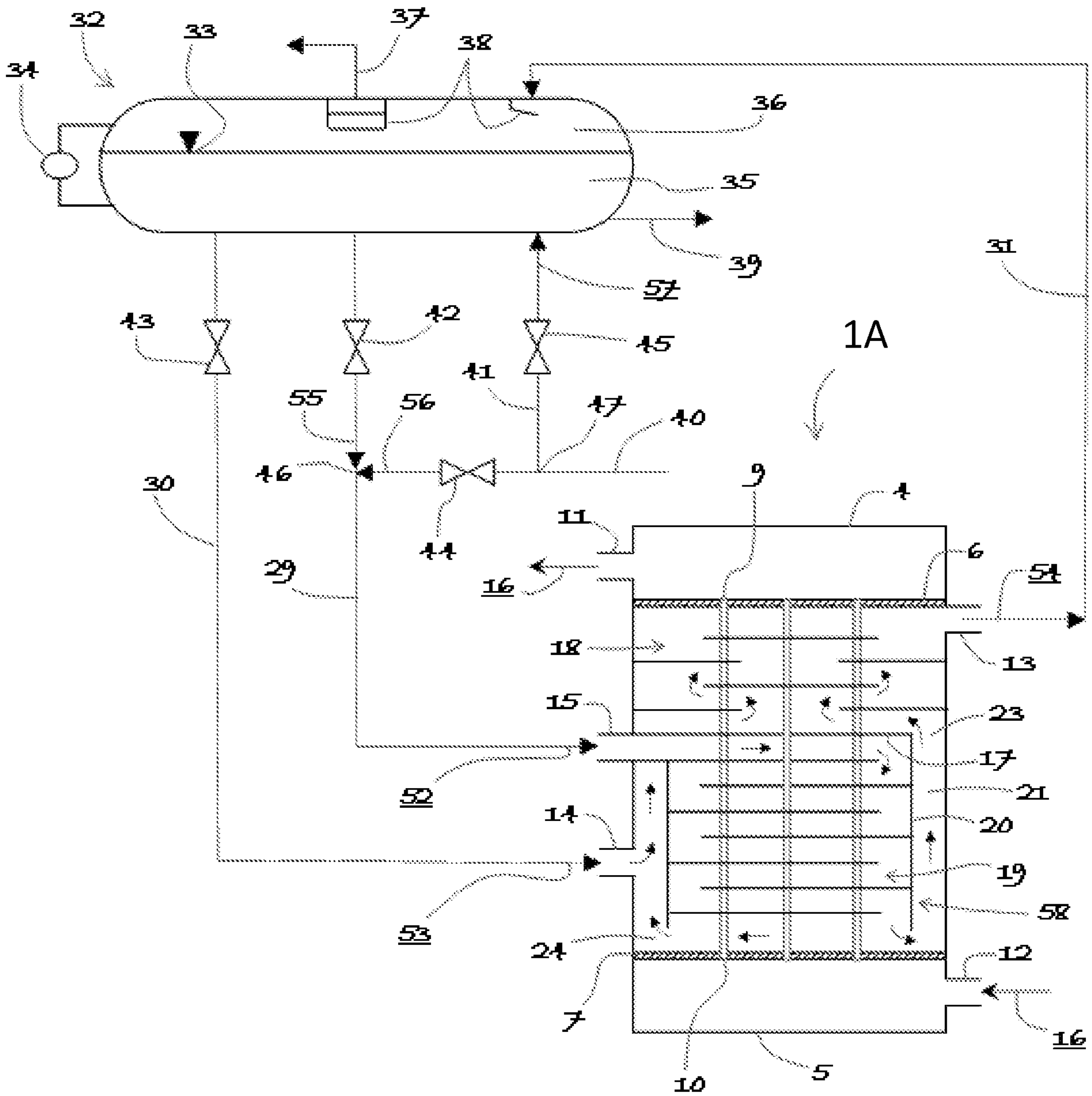
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Fig. 4

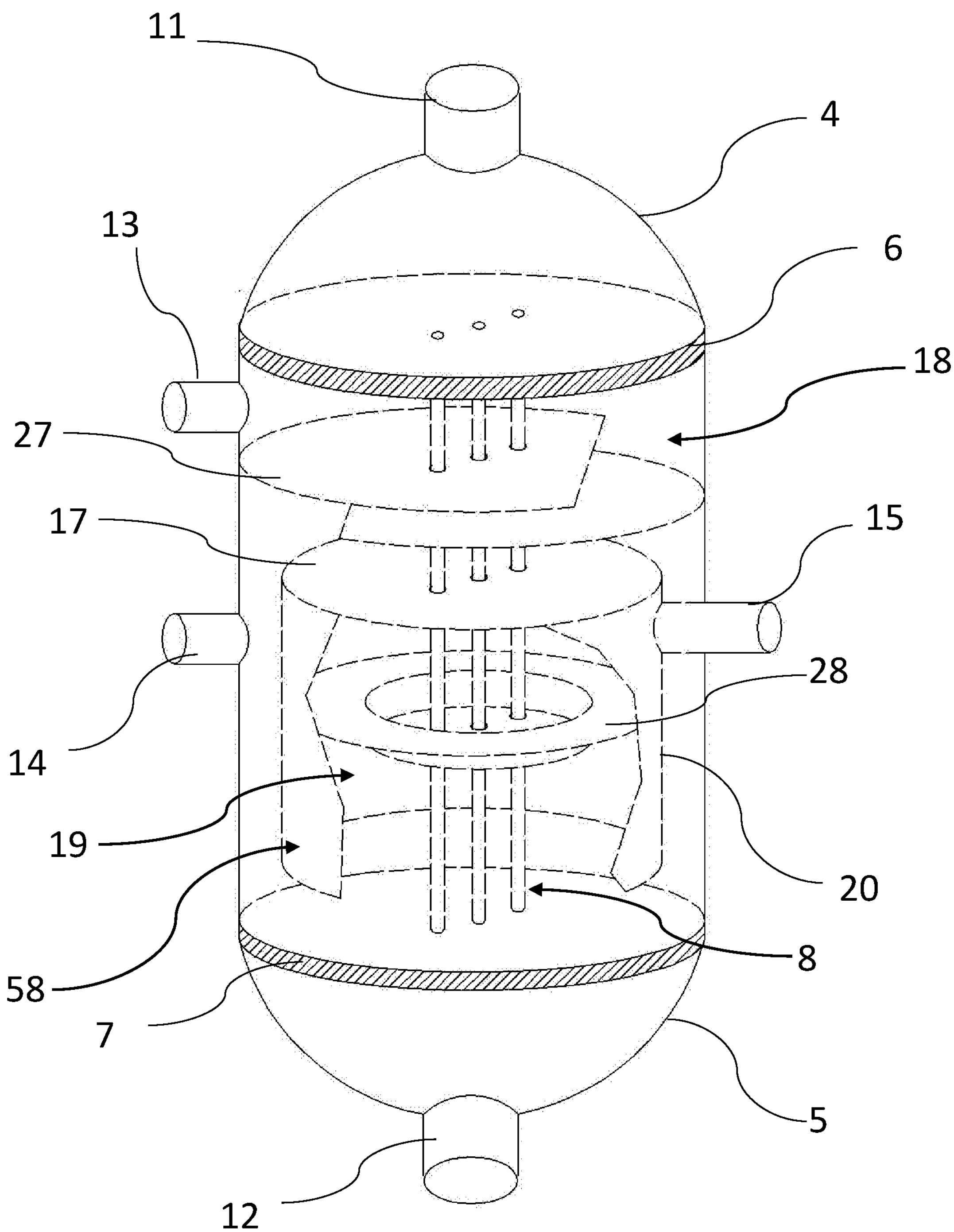

Fig. 5

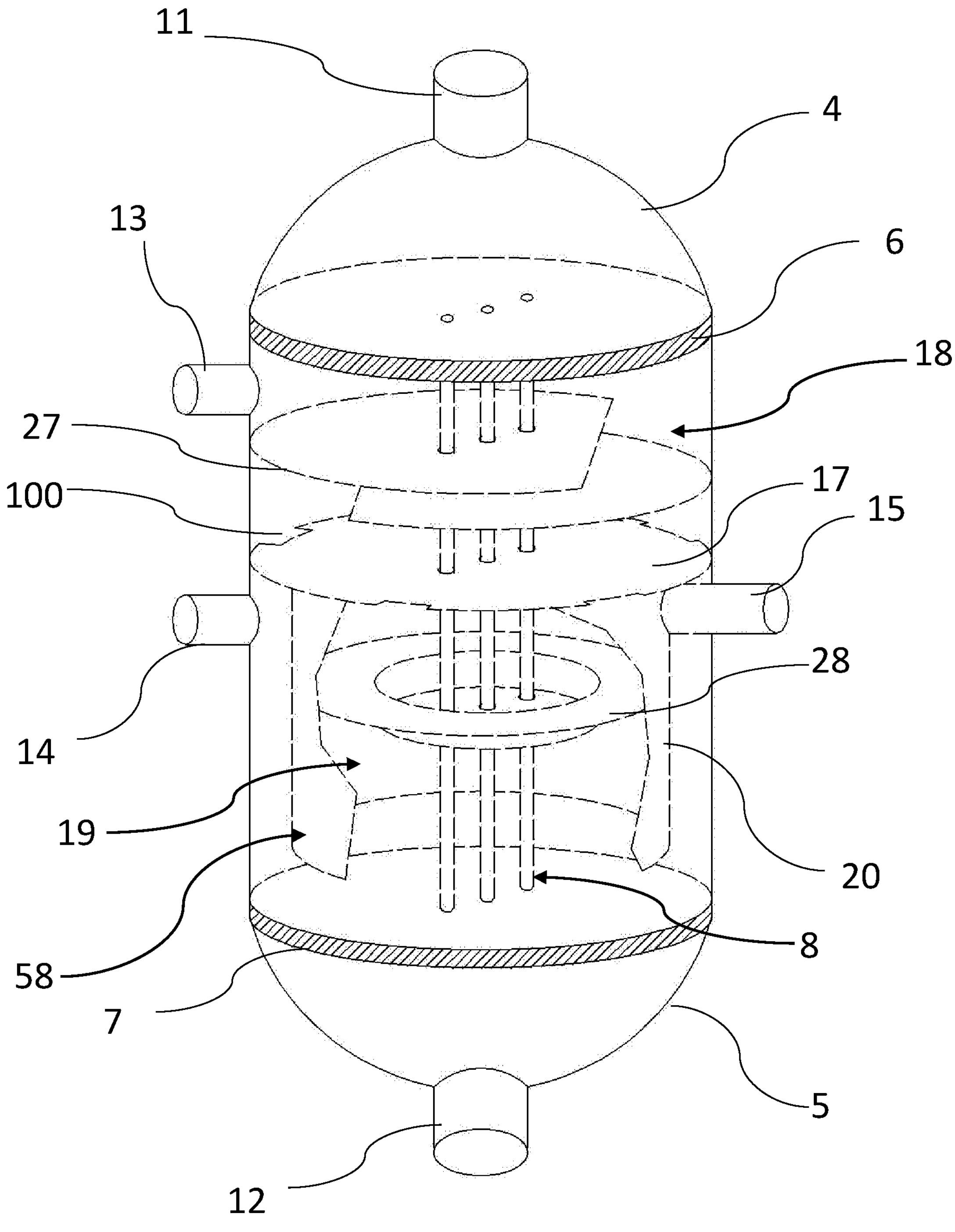

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2024/054982

A. CLASSIFICATION OF SUBJECT MATTER

INV. B01J8/06 F28D7/16 F28D7/00 C07C31/04

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B01J F28D C07C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 086 162 A1 (CREUSOT LOIRE [FR]) 17 August 1983 (1983-08-17) page 2, line 4 - page 4, line 14; figure 1 -----	1-18
A	GB 1 154 809 A (WAAGNER BIRO AG [AT]) 11 June 1969 (1969-06-11) page 2, line 85 - page 3, line 15; figure 2 -----	1-18
A	DE 34 21 746 C2 (APPARATEBAU WIESLOCH GMBH [DE]) 9 June 1994 (1994-06-09) figure 1 -----	1-18
A	WO 2017/019961 A1 (PRIMUS GREEN ENERGY INC [US]) 2 February 2017 (2017-02-02) the whole document -----	1-18

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 September 2024	02/10/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Borello, Ettore

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2024/054982

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DE 3421746	C2	09-06-1994	NONE			
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