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(54) Title: MECHANICAL VAPOR RECOMPRESSION ARRANGEMENT

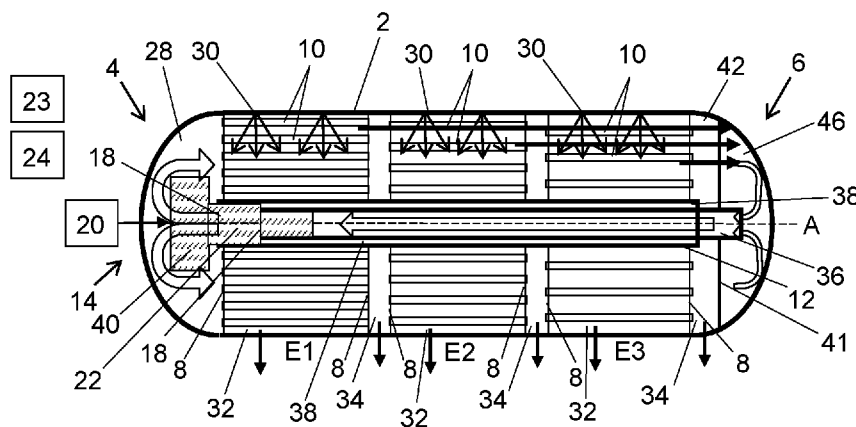


FIG. 3

(57) Abstract: A mechanical vapor recompression (MVR) arrangement, comprising a compound turbine system, a pressure-tight enclosure (2) provided with a first end (4) and a second end (6), having an essentially circular cylindrical elongated shape along a longitudinal axis A, and a central tube (12) having an essentially circular cross-section and running within said enclosure (2) and configured to allow steam to flow from the second end to the first end of the enclosure. The MVR arrangement further comprises at least one evaporation compartment E1. The MVR arrangement further comprises an inner central tube (36) arranged concentrically within said central tube (12) and running from said second end (6) to, or towards, the first end (4), wherein said inner central tube (36) has an outer diameter related to the inner diameter of said central tube (12) such that a steam flow conducting space (38) is provided between an outer surface of the inner central tube (36) and an inner surface of the central tube (12). The compound turbine system comprises a turbine assembly (14) comprising a turbine provided with axial turbine vane members (22) arranged within said inner central tube

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(36) and structured to provide steam to flow in an axial direction along the longitudinal axis A within said inner central tube (36) from said second end (6) towards said first end (4). A flow connection member (50) is arranged, structured to provide a flow connection between said steam flow conducting space (38) and the space within the inner central tube, and wherein the turbine is provided with a flow increasing structure (52) arranged in proximity of said flow connection member (50), such that the flow within the steam flow conducting space (38) and the flow within the inner central tube are combined into one flow.

Mechanical vapor recompression arrangement

Technical field

The present disclosure relates to a mechanical vapor recompression (MVR) arrangement,
5 and more specifically to a highly efficient MVR arrangement, e.g. applicable for heating
and cooling purposes, in liquid purification systems, or in water desalination systems.

Background

Mechanical Vapor Recompression (MVR) is an evaporation method by which a blower,
10 compressor, or jet ejector is used to compress, and resulting from the compression,
increases the pressure, density and temperature of the vapor produced.

As a result, the vapor can serve as the heating medium for its “mother” liquid or solution
being concentrated. Without the compression, the vapor would be at the same temperature
as its “mother” liquid/solution, and no heat transfer could take place.

15 The efficiency and feasibility of this process depend on the efficiency of the compressing
device (e.g., blower, compressor) and the heat transfer coefficient attained in the heat
exchanger contacting the condensing vapor and the boiling “mother” solution/liquid.

Presently used MVR systems suffer from a relatively high energy-consumption.

20

Below some patent documents within the technical field of MVR will be briefly discussed.
US10046249 disclose a compact mechanical vapor recompression evaporator system for
e.g. wastewater treatment. The system has a concentric design with an inner channel and a
radial MVR device at the channel end, which increases the temperature of the vapor.

25 CN103272395A discloses an MVR system with three evaporation compartments
connected in series inside an enclosure. The evaporation compartments have circular
shape and have horizontal tubes running along its interior. In addition, there is a steam
collector partly surrounded by the tube bundle inside the evaporation compartments. The
compressor is positioned outside the enclosure.

30 WO2019020605A1 discloses a unit for desalination of water having three serially
connected evaporator-condensers and a compressor.

DE2928392 relates to a seawater desalination by descending film evaporation and vapor compression in common horizontal tank.

US2016158666 discloses methods for thermal distillation with mechanical vapor compression.

- 5 DE102006056820 relates to a seawater desalination plant comprising a mechanical flow compressor made of radial carbon-fiber-reinforced wheel, a wheel-attachment and housing comprising the wheel.

US3868308 discloses a multiple effect evaporator for use in the distillation of liquids, in general, e.g. for desalination, and of the kind wherein evaporation takes place on the

- 10 outside of substantially horizontal heat exchange tubes as a result of the heating of the inside of the tubes.

The following documents particularly relate to the turbine, or compressor part, of the system.

- 15 US20120189431A1 discloses a compressor arrangement having an axial compressor and a radial compressor that are arranged axially one behind the other.

WO200943487A1 discloses a multi-stage supercharging group having an axial turbine and a radial turbine with a concentric bypass inlet.

- 20 US20070204615A1 discloses a two-shaft turbocharger with an axial compressor and a radial compressor, wherein the radial turbine direct airflow axially toward a first turbine wheel.

- 25 When designing an MVR arrangement, it is essential that it consumes less energy than presently used systems, and that it is robust, easy to operate and maintain. To achieve that, it is essential that the MVR arrangement comprises a high efficiency turbine assembly to provide the flow of steam within the enclosure of the system and thus to achieve an improved MVR arrangement consuming less energy than the presently used system.

Thus, the object of the present invention is to achieve an improved MVR arrangement in particular with regard to energy efficiency.

Summary

The above-mentioned object is achieved by the present invention according to the independent claim.

- 5 Preferred embodiments are set forth in the dependent claims.

The MVR arrangement according to the present invention is advantageous, in that the mechanical and structural integrity of the system will improve, due to circular symmetry, and also the thermal efficiency due to complex turbine design and advantageous material
10 conductivity. Furthermore, and most prominently; the double-tube concentric arrangement of the tubes allows the recuperation of not only the remaining heat, but also, according to various embodiments, the remaining kinetic energy of highly pressurized residual flow of steam exiting a horizontal pipe arrangement, through compartment in the compounded low pressure/high pressure axial turbine arrangement. The super-heated steam recuperation,
15 via the conducting space, will furthermore facilitate a positive heat transfer to the low vacuum generated vapor emanating from a compartment through the inner central tube, and thereby an extra level of redundancy against water droplet condensation and impact damage on the sensitive, low pressure turbine blades in the low pressure region of the turbine. By deliberately choosing to lead the low pressure steam inside the inner central
20 tube, surrounded by the highly pressurized residual steam, the inner central tube may still be manufactured in a slender and weight optimized way since it only receives hydrostatic pressure on the outside (the strongest load-carrying configuration of a circular pipe).

According to one embodiment, the MVR arrangement comprises e.g. three evaporation
25 compartments (E1-E3) provided with horizontal pipes arranged within the enclosure. The number of horizontal pipes is preferably highest in the first compartment E1 and is then gradually fewer in the two other compartments in order to retain pressure and temperature even though constant loss of mass due to condensation. The central tube runs along the longitudinal axis of the enclosure, through the centers of three evaporation compartments.
30 Further, a velocity- and pressure compounded, axial turbine assembly, arranged in an inner central tube, compresses the steam running along the tube, thereby increasing the

pressure, density and temperature of the steam. The steam is then lead through the horizontal pipes.

5 An important technical feature that contributes to the low energy consumption, but also to the small footprint and excellent scalability of the system, is the symmetrical arrangement of the central tube, the compact turbine and the arrangement of the horizontal pipes, with regard to the longitudinal axis.

10 In one embodiment, the compounded axial turbine is arranged in the inner central tube having the diameter equal throughout its entire length and to compensate for the second, and lately introduced, volume flow of high pressure, uncondensed and thus highly energetic steam by making a contraction of the inner radius of the rotor, in the axial turbine. A robust solution is thereby achieved.

15 All produced overheated steam will, due to probability reasons, during its journey through the condensation pipes in the evaporation compartment(s) neither approach a free wall nor have the required time there to release all its evaporation heat and condensate fully. This highly energetic steam remainder would lose all internal energy by a re-introduction to the initial low pressure compressor step in the compressor – thus the inevitable loss of all pre-
20 invested energy and system efficiency. Instead, it gets the opportunity to retain pressure, temperature as well as kinetic energy and become reintroduced in the final booster module obtained by the combined high pressure steam flow and low pressure steam flow only to compensate for the energy lost due to pipe friction, direction change (loss of momentum) and energy dissipation through insulation.

25

Brief description of the drawings

Figure 1 is a schematic illustration of an embodiment of an MVR arrangement according to the present invention.

Figure 2 is a schematic illustration of part of an embodiment of the MVR arrangement

30 Figure 3 is a schematic illustration of an embodiment of the MVR arrangement according to the present invention.

Figure 4 is a schematic illustration of part of an embodiment of the MVR arrangement according to the present invention.

Figure 5 is a schematic cross-sectional view of the embodiment shown in figure 4.

Figure 6 is a schematic illustration of an embodiment of an MVR arrangement disclosed
5 herein.

Figure 7 is a schematic cross-sectional view of part of an embodiment of the MVR arrangement according to the present invention.

Detailed description

10 The mechanical vapor recompression (MVR) arrangement comprising the compound turbine system will now be described in detail with references to the appended figures. Throughout the figures, the same, or similar, items have the same reference signs. Moreover, the items and the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

15 With references in particular to the figures, and in particular figures 1, 3, and 6, a mechanical vapor recompression (MVR) arrangement is provided, comprising a compound turbine system, a pressure-tight enclosure 2 provided with a first end 4, and a second end 6. The enclosure has an essentially circular cylindrical elongated shape along a
20 longitudinal axis A, and being essentially horizontally oriented during operation of the arrangement.

The MVR arrangement further comprises a central tube 12 having an essentially circular cross-section and running within the enclosure 2 along the longitudinal axis A, and is
25 configured to allow gaseous compounds to flow from the second end to the first end of the compound turbine system. In the figures, the flows of gaseous compounds are illustrated by block arrows.

The MVR arrangement further comprises at least one evaporation compartment E1 (see
30 figures 1, 3, and 6), arranged within the enclosure 2 along the longitudinal axis A. The at least one evaporation compartment comprises two essentially planar and circular sidewalls 8, and is provided with a plurality of longitudinal pipes 10 running from one sidewall 8 to

the other sidewall 8, and that the circular sidewalls are provided with openings for said plurality of pipes. This is in particular illustrated in figure 3, but is also applicable in the embodiments illustrated in figures 1 and 6. Note that figures 1 and 6 are simplified illustrations of two embodiments of the MVR arrangement, where e.g. the plurality of longitudinal pipes are left out.

The MVR arrangement further comprises an inner central tube 36 arranged concentrically within the central tube 12 and running from the second end 6 to (see figure 6), or towards (see figure 1 and 3), the first end 4. The inner central tube 36 has an outer diameter related to the inner diameter of the central tube 12 such that a steam flow conducting space 38 is provided between an outer surface of the inner central tube 36 and an inner surface of the central tube 12. The space 38 may have a size in a radial direction of approximately 0.05-0.25 times the outer radius of the central tube 12.

The MVR arrangement comprises a turbine assembly 14 comprising a turbine 22 provided with axial turbine vane members arranged within said inner central tube 36 and structured to provide steam to flow in an axial direction along the longitudinal axis A within the inner central tube 36 from the second end 6 towards the first end 4.

A flow connection member 50 is arranged, structured to provide a flow connection between the steam flow conducting space 38 and the space within the inner central tube. and wherein the turbine is provided with a flow increasing structure 52 arranged in proximity of the flow connection member 50, such that the flow within the steam flow conducting space 38 and the flow within the inner central tube are combined into one flow.

In one embodiment, illustrated by figures 6 and 7, the flow connection member 50 is achieved by providing openings in the wall of the inner central tube allowing steam to pass into the inner space of the inner central tube.

In other embodiments illustrated by figures 1-5, the inner central tube does not run all the way to the first end, but ends within the central tube, whereas the flow connection member 50 then is achieved by the opening of the end part of the inner central tube.

These various embodiments will now be disclosed more in detail.

In one embodiment, the inner central tube 36 is arranged concentrically within the central tube 12 and running from the second end 6 towards the first end 4 to a predetermined position P a distance L from an opening 18 of the central tube 12 at the first end 4.

The turbine assembly 14 also comprises a motor 20 for rotating the turbine at a variable rotational speed and thereby provide the flow, which is applicable to all embodiments disclosed herein. An arrow pointing from the motor 20 to the turbine schematically illustrates the rotatable movement applied to the turbine. Preferably, a gearbox and a coupling device are arranged between the motor 20 and the turbine. In an exemplary variation, the motor 20 is an electrical motor provided with the gearbox and the coupling device. A bearing and a magnetic disc are arranged in connection with the enclosure adapted to transfer the rotational movement from the motor to the turbine within the enclosure. The bearings provided in relation to the present invention may e.g. be of a rolling element-, hybrid-, hydrostatic-, sliding-, magnetic type or combinations thereof and are designed to become lubricated with the air/steam/gas/gaseous compounds flow through the central tube.

According to an embodiment, the MVR arrangement comprises a first steam connection arrangement structured to provide a low pressure steam flow from said at least one evaporation chamber(s) to enter the inner central tube at the second end, and a second steam connection arrangement structured to provide a high pressure steam to enter the steam conducting space at the second end. The low pressure steam and high pressure steam are combined into one steam flow in the proximity of the flow connection member 50.

The first steam connection arrangement may comprise pipes or tubes from the at least one evaporation chamber arranged within the wall of the enclosure or at the outside of the enclosure. These pipes or tubes are schematically illustrated as filled block arrows in figure 3.

The second steam connection arrangement is provided by the plurality of longitudinal pipes 10 illustrated in figure 3.

According to another embodiment, illustrated by figures 6 and 7, the inner central tube 36 runs from said second end 6 to the first end 4. The flow connection member 50 includes at least one opening in the inner central tube wall, e.g. a plurality of openings

- 5 circumferentially and symmetrically arranged in the inner central tube wall provided to achieve a steam flow into the inner central tube. The openings may have many different shapes, e.g. circular, or rectangular.

10 With reference to figure 7, the flow increasing structure may be embodied as a smaller diameter section of a turbine axle of the turbine at a position where the steam flow from the steam flow conducting space being combined with the steam flow of the inner central tube 36. The smaller diameter section will provide a decreased pressure forcing at least a part of the steam flow in the conducting space 38 into the inner central tube.

- 15 According to another embodiment illustrated by figures 1-5, the flow connection member 50 is provided by that the inner central tube 36 ends at a predetermined position P a predetermined distance L from an opening of the central tube 12 at the first end 4. The flow increasing structure is provided by the axial turbine vane members 22 comprising two types of vane members, a first type arranged within the central tube 12 but not within
20 the inner central tube 36, and a second type arranged within the inner central tube 36. The first type of axial turbine vane members 22 has a larger radial extension in comparison to the radial extension of vane members of the second type.

25 In a further variation, the outer diameter of the central tube 12 is essentially constant along the central tube between the first and second ends. This embodiment is schematically illustrated in figure 1, and more in detail in figures 4-7.

Figure 4 is a schematic illustration along the longitudinal axis A. The axial turbine vane members 22 are mounted on an axis 21 driven by the motor 20 and comprises high-
30 pressure vane members 23 having larger outer radial extensions than the low-pressure vane members 25 being arranged within the inner central tube. The reason is to compensate for the increased mass flow where the flow from the gaseous compounds

conducting space 38 is added to the flow from the interior of the inner central tube 36. In relation to the rotatable high-pressure vane members 23 and low-pressure vane members are also provided fixed stator members extending inwardly from the respective inner surface walls of the central tube 12, and the inner central tube 36, respectively. These
5 fixed stator members are not shown in the figure, however; the individual vane pitch-angles (both rotary and stationary) are varying in each step in order to produce an optimally efficient compression, to the local and factual mass flow, regardless of vane radial extension.

Figure 5 is a schematic illustration of a cross-sectional view along A-A in figure 4. In
10 figure 5 is shown inwardly extending splines 37 arranged at the inner surface of the central tube 12 to position the inner central tube 36 symmetrically within the central tube 12 in order to provide the conducting space 38.

According to another embodiment, schematically illustrated in figure 2, the outer diameter
15 of the central tube 12 has a first diameter $D1$ at the second end 6, and a second diameter $D2$ at the first end 4, wherein $D1 > D2$. The diameter decreases gradually from $D1$ to $D2$, preferably in a longitudinal section including the position P where the inner central tube 36 ends.

20 In still another variation, the predetermined position P is determined in dependence of the pressures of the flows in the inner central tube 36 and in the conducting space 38 such that the pressures are essentially equal, i.e. the pressures should differ less than 10%.

The hot gasses (containing both residual heat, increased density and kinetic energy) within the conducting space 38 are lead into the axial part of the turbine at or around the position
25 P. This "low-pressure bypass" is essential to reinvest waste energy and thereby to increase overall system efficiency.

According to another embodiment, which is illustrated by figure 1 the turbine is also provided with radial turbine vane members 40 structured to provide gaseous compounds to
30 flow in essentially radial directions from the opening 18 at the first end 4 of the central tube 12. Block arrows illustrate that flow.

Preferably, the radial turbine vane members 40 are concentrically arranged at the longitudinal axis A, in close relation to the opening of the central tube 12 at the first end 4.

5 The turbine, including both the axial turbine vane members 22 and the radial turbine vane members, is rotated by the motor 20 by means of the axis 21 (see figure 4), and these vane members are configured to rotate by the same rotational speed.

The MVR arrangement according to the present invention may be applied in many different applications.

10 In one application the MVR arrangement is applied for heating and/or cooling purposes, where hot water obtained in purified liquid collecting spaces 34 (see figure 3) are led via pipes/tubes through heat exchangers to heat e.g. housings, vehicles, etc. The outflow is indicated in figure 3 by vertical arrows.

15 In another application the MVR arrangement may be used for liquid purification purposes. In the following, embodiments will be described with references to figure 3, and being related to apply the MVR arrangement for liquid purification. Parts of the arrangement illustrated in figure 3 have already been discussed above with references to figures 1 and 2, and will therefore not be discussed again in order to avoid unnecessary repetition.

20

In one embodiment the MVR arrangement comprises numerous, particularly three, evaporation compartments E1-E3, arranged within the enclosure 2 along the longitudinal axis A. The first evaporation compartment E1 is arranged in relation to the first end 4 of the enclosure and the last evaporation compartment E3 is arranged in relation the second
25 end 6 of the enclosure. The evaporation compartments are connected in series and have essentially circular cylindrical shapes. Each evaporation compartment comprises of two essentially planar and circular sidewalls 8, and each evaporation compartment is provided with a plurality of longitudinal pipes 10 running from one sidewall 8 to the other sidewall 8, and that the circular sidewalls are provided with openings for the plurality of pipes. The
30 central tube 12, provided with the inner central tube 36, is arranged to run along the longitudinal axis A of the enclosure 2, through the centers of the evaporation compartments E1-E3, and configured to allow steam to flow from the second end to the

first end of the enclosure. Nozzles 30 are provided in the evaporation compartments to spray the liquid into the compartment.

Advantageously, the compound turbine further comprises a low vacuum generating member 23 arranged to generate partial vacuum in the evaporation compartments, and a control unit 24 configured to control operation of the system according to designated performance.

As an alternative, the embodiment illustrated in figures 6 and 7 regarding the structure of the flow connection member 50 and the flow increasing structure 52 may be applied in the MVR arrangement illustrated in figure 3.

- 10 The control may be achieved by performing a control procedure adapted to:
- generate the partial vacuum in the evaporation compartments,
 - control the motor 20 to operate the turbine at a rotational speed such that an increased temperature is induced to the steam when passing the turbine to achieve desired recycling of specific heat associated to vaporization, and
 - 15 -control a plurality of valves and pumps provided to supply the system with inlet water and to receive purified liquid, e.g. water, from the system.

In a further embodiment, the number of pipes 10 is highest in the first evaporation compartment E1, then gradually fewer in the second E2 and third E3. The pipes 10 are essentially evenly spread in a cross-section perpendicular to the longitudinal axis of the respective evaporation compartment, and the pipes are configured to allow steam to flow from the first end 4 to the second end 6 of the enclosure 2.

Furthermore, a first end space 28 is provided, defined by the sidewall 8 of the first evaporation compartment E1 and the inner surface of the enclosure 2. The first end inner surface has a symmetrical concave shape displaying a predetermined curve-form adapted to guide the steam flow in a radial direction and further into a direction essentially along the longitudinal axis A towards the second end 6 of the enclosure 2.

Each evaporation compartment is preferably provided with an inflow liquid collecting container 32 arranged at the bottom of each evaporation compartment and intended to collect non-vaporized inflow liquid. The collecting container 32 comprises a level sensor configured to measure the level of inflow liquid and to generate a level signal when the

liquid level deviates from a predetermined liquid level interval. Purified liquid collecting spaces 34 are provided between evaporation compartments for collecting purified liquid, and being delimited by sidewalls 8 of the adjacent evaporation compartments, and the inner surface of the enclosure. Vertical arrows indicate outflows of purified liquid, e.g. hot
5 water, via connected outflow pipes/tubes.

In still a further embodiment, the steam produced by evaporation under partial vacuum is lead through the central tube 12, the steam conducting space 38, and the inner central tube 36 to the turbine for compression and subsequently recuperation of evaporation heat.

10

In an example of the relative sizes of some parts of the system, the inner diameter of the central tube 12 is in the range of 0.1-0.5 times of the outer diameter of the enclosure 2, and the inner diameter of a longitudinal pipe 10 is in the range of 0.01-0.1 times of the diameter of the central tube 12.

15

The second end 6 of the enclosure 2 may be provided with a delimitation wall 41 essentially parallel to the sidewall 8 of the evaporation compartment. The delimitation wall 41 is arranged to divide the space defined by the sidewall closest to the evaporation compartment and the outer wall of the enclosure into a second end liquid collecting space
20 42, closest to the evaporation compartment, and an alternative second end space 46. The central tube 12 opens into the second end liquid collecting space 42, and the inner central tube 36 opens into the alternative second end space 46.

The steam produced by evaporation under partial vacuum is lead through the inner central
25 tube 36 to the low-pressure turbine region for initial compression and becomes, at a suitable pressure step inside the axial turbine; compounded with the high-pressure steam collected in second end liquid collecting space 42 and transported to that particular pressure step in the turbine via the steam conducting space 38, that ends immediately before the said compressor step.

30 Subsequently; both mass flows are combined pressurized by the remaining high-pressure region of the axial compressor and further compressed and lead to direction change of its kinetic energy, in the specially designed radial compressor, and lead through the

horizontal pipes 10 for subsequent recuperation of the increased internal energy. The axial turbine vane members 16 are structured to protrude, at least partly, into the inner central tube 36 in order to help sustaining partial vacuum in the evaporation compartments E1-E3, facilitate the flow of steam from the second end 6 to the first end 4 of the enclosure and to
5 bring the low-pressure steam up to practically the same energetic state as the highly pressurized residual steam exiting the horizontal tubes 10 after completing a full cycle of vaporization heat recuperation.

The kinetic energy of the compressed vapor is harvested in the last high-pressure manifold 42 (adjacent to the second end of the enclosure) and lead back to the turbine via the steam
10 conducting space 38 in order to assist rotation of the axial-/radial turbine and thereby increase system efficiency.

Preferably, the turbine, stators and surrounding walls inside the axial turbine assembly are made by a suitable 3D-printing technique, preferably from metallic or composite material, further preferably of thermoplastic nature, and optionally coated for higher resilience. The
15 bearings (rolling element, sliding or hydrodynamic by fluid or gas) in a pivot point inside the inner central tube 36 and in the high pressure turbine compartment are foreseen to become lubricated, preferably with low-pressure steam, and their housing may become externally cooled.

20 The present invention is not limited to the above-described preferred embodiments. Various alternatives, modifications and equivalents may be used. Therefore, the above embodiments should not be taken as limiting the scope of the invention, which is defined by the appending claims.

Claims

1. A mechanical vapor recompression (MVR) arrangement, comprising a compound turbine system, a pressure-tight enclosure (2) provided with a first end (4) and a second end (6), having an essentially circular cylindrical elongated shape along a longitudinal axis A, and being essentially horizontally oriented during operation of the arrangement, and a central tube (12) having an essentially circular cross-section and running within said enclosure (2) along said longitudinal axis A and configured to allow steam to flow from the second end to the first end of the enclosure, the MVR arrangement further comprises at least one evaporation compartment E1, arranged within said enclosure (2) along the longitudinal axis A, said at least one evaporation compartment comprises two essentially planar and circular sidewalls (8), and is provided with a plurality of longitudinal pipes (10) running from one sidewall (8) to the other sidewall (8), and that the circular sidewalls are provided with openings for said plurality of pipes, characterized in that MVR arrangement further comprises an inner central tube (36) arranged concentrically within said central tube (12) and running from said second end (6) to, or towards, the first end (4), wherein said inner central tube (36) has an outer diameter related to the inner diameter of said central tube (12) such that a steam flow conducting space (38) is provided between an outer surface of the inner central tube (36) and an inner surface of the central tube (12), and in that the compound turbine system comprises a turbine assembly (14) comprising a turbine provided with axial turbine vane members (22) arranged within said inner central tube (36) and structured to provide steam to flow in an axial direction along the longitudinal axis A within said inner central tube (36) from said second end (6) towards said first end (4), wherein a flow connection member (50) is arranged, structured to provide a flow connection between said steam flow conducting space (38) and the space within the inner central tube, and wherein said turbine is provided with a flow increasing structure (52) arranged in proximity of said flow connection member (50), such that the flow within the steam flow conducting space (38) and the flow within the inner central tube are combined into one flow.
2. The MVR arrangement according to claim 1, comprising a first steam connection arrangement structured to provide a low pressure steam flow from said at least

one evaporation chamber(s) to enter the inner central tube at the second end, and a second steam connection arrangement structured to provide a high pressure steam to enter the steam conducting space at the second end, wherein the low pressure steam and high pressure steam are combined into one steam flow in the proximity of said flow connection member (50).

3. The MVR arrangement according to claim 1 or 2, wherein said inner central tube (36) runs from said second end (6) to the first end (4), and that said flow connection member (50) includes at least one opening in the inner central tube wall, and wherein said flow increasing structure is a smaller diameter section of a turbine axle of said turbine at a position where said steam flow from the steam flow conducting space being combined with the steam flow of said inner central tube (36).

4. The MVR arrangement according to claim 3, wherein said flow connection member (50) comprises a plurality of openings circumferentially and symmetrically arranged in the inner central tube wall.

5. The MVR arrangement according to claim 1 or 2, wherein said flow connection member (50) is provided by that the inner central tube (36) ends at a predetermined position P a predetermined distance L from an opening of the central tube (12) at the first end (4), and wherein the flow increasing structure is provided by the axial turbine vane members (22) comprising two types of vane members, a first type arranged within said central tube (12) but not within said inner central tube (36), and a second type arranged within said inner central tube (36), wherein the first type of axial turbine vane members (22) has a larger radial extension in comparison to the radial extension of vane members of the second type.

6. The MVR arrangement according to claim 5, wherein the outer diameter of said central tube (12) has a first diameter D1 at the second end (6), and a second diameter D2 at the first end (4), wherein $D1 > D2$, and that the diameter decreases gradually from D1 to D2 in a longitudinal section including said position P.

7. The MVR arrangement according to any of claims 1-6, wherein the turbine is also provided with radial turbine vane members (40) structured to provide gaseous compounds to flow in essentially radial directions from the opening (18) at said first end (4) of said central tube (12).

5

8. The MVR arrangement according to claim 7, wherein said radial turbine vane members (40) are concentrically arranged at said longitudinal axis A in close relation to the opening of the central tube (12) at the first end (4).

10 9. The MVR arrangement according to any of claims 1-8, comprising numerous, particularly three, evaporation compartments E1-E3, arranged within said enclosure (2) along the longitudinal axis A, the first evaporation compartment E1 is arranged in relation to the first end (4) of the enclosure and the last evaporation compartment E3 is arranged in relation the second end (6) of the enclosure, the
15 evaporation compartments are connected in series and have essentially circular cylindrical shapes, each evaporation compartment comprises of two essentially planar and circular sidewalls (8), and each evaporation compartment is provided with a plurality of longitudinal pipes (10) running from one sidewall (8) to the other sidewall (8), and that the circular sidewalls are provided with openings for said plurality of pipes,
20 wherein said central tube (12) is arranged to run along the longitudinal axis A of the enclosure (2) through the centers of said evaporation compartments E1-E3, and configured to allow steam to flow from the second end to the first end of the enclosure.

10. The MVR arrangement according to claim 9, wherein the number of pipes
25 (10) is highest in the first evaporation compartment E1, then gradually fewer in the second E2 and third E3, and wherein the pipes (10) are essentially evenly spread in a cross-section perpendicular to the longitudinal axis of the respective evaporation compartment, and the pipes are configured to allow steam to flow from the first end (4) to the second end (6) of the enclosure (2).

30

11. The MVR arrangement according to any of claims 7 and 8, wherein a first end space (28) is provided, defined by the sidewall (8) of the first evaporation

compartment E1 and the inner surface of the enclosure (2), wherein said first end inner surface has a symmetrical concave shape displaying a predetermined curve-form adapted to guide the steam flow in a radial direction and further into a direction essentially along the longitudinal axis A towards the second end (6) of the enclosure (2).

5

12. The MVR arrangement according to any of claims 9-11, wherein purified liquid collecting spaces (34) are provided between evaporation compartments for collecting purified liquid, and being delimited by sidewalls (8) of the adjacent evaporation compartments, and the inner surface of the enclosure.

10

13. The MVR arrangement according to any of claims 9-12, wherein the steam produced by evaporation under partial vacuum is lead through said central tube (12), said steam conducting space (38), and said inner central tube (36) to the turbine for compression and subsequently recuperation of evaporation heat.

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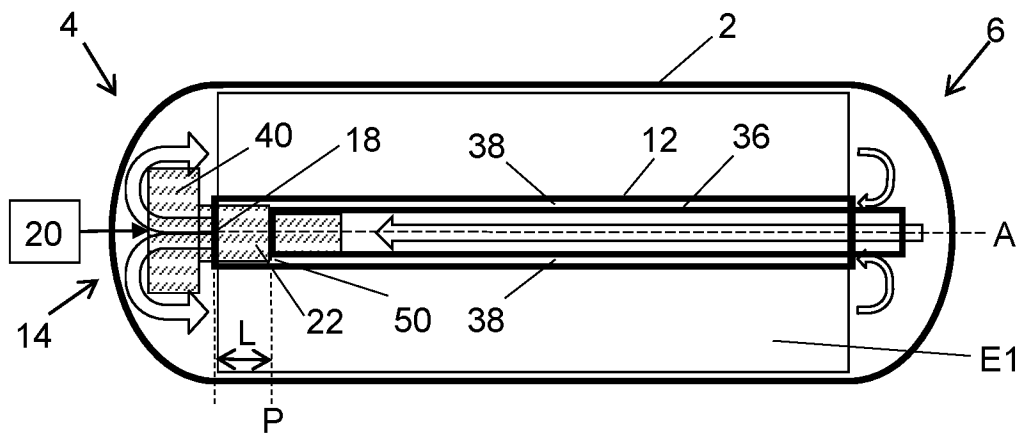


FIG. 1

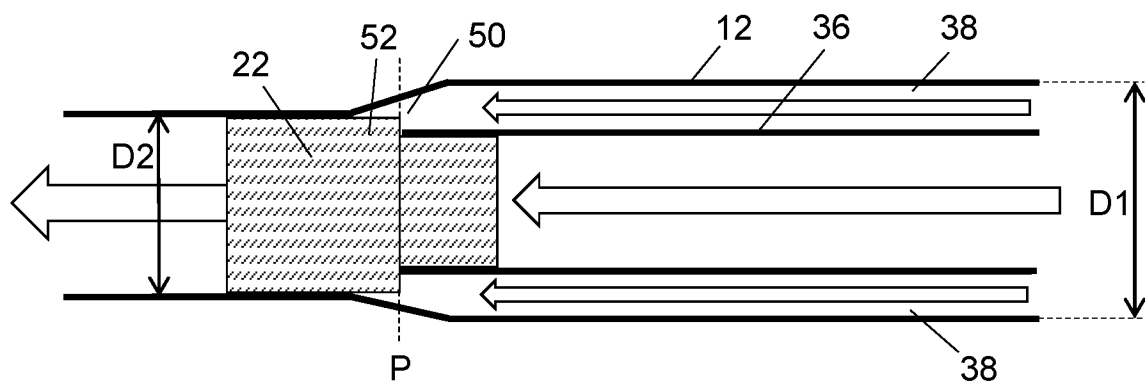


FIG. 2

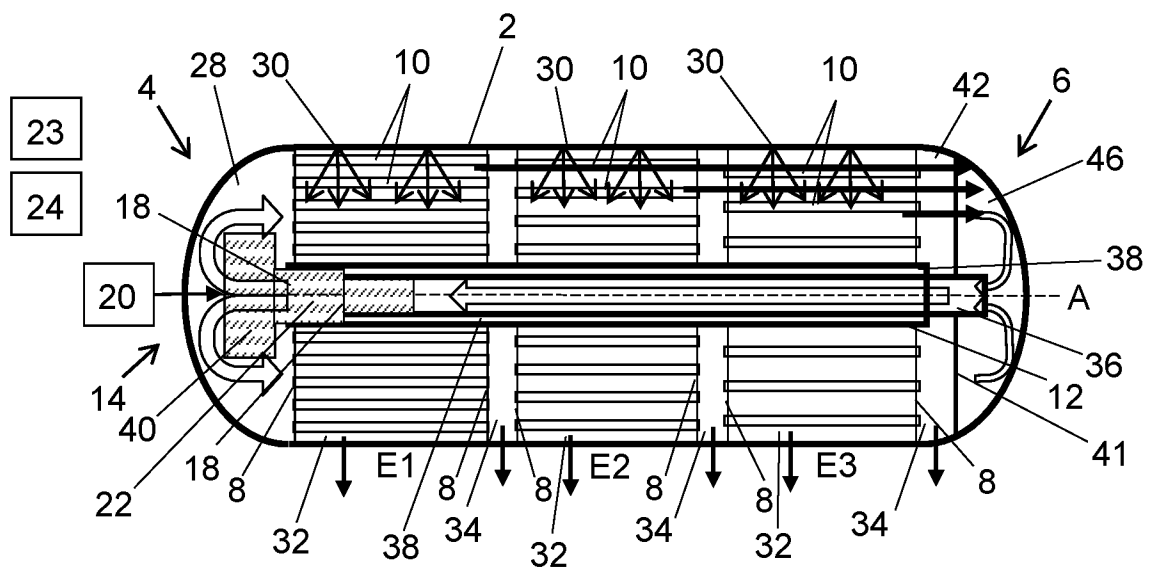


FIG. 3

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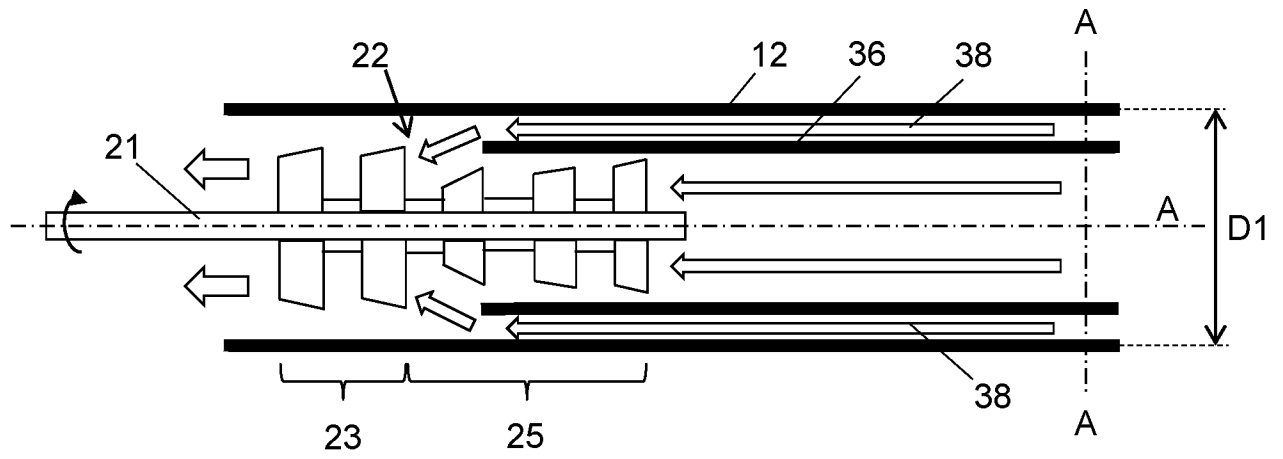


FIG. 4

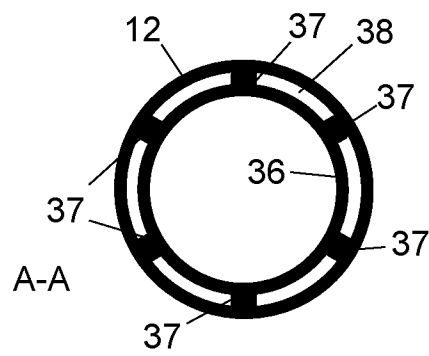


FIG. 5

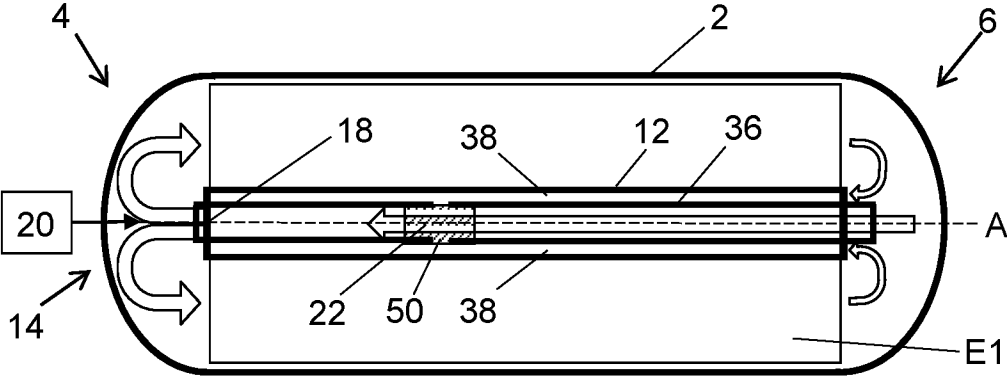


FIG. 6

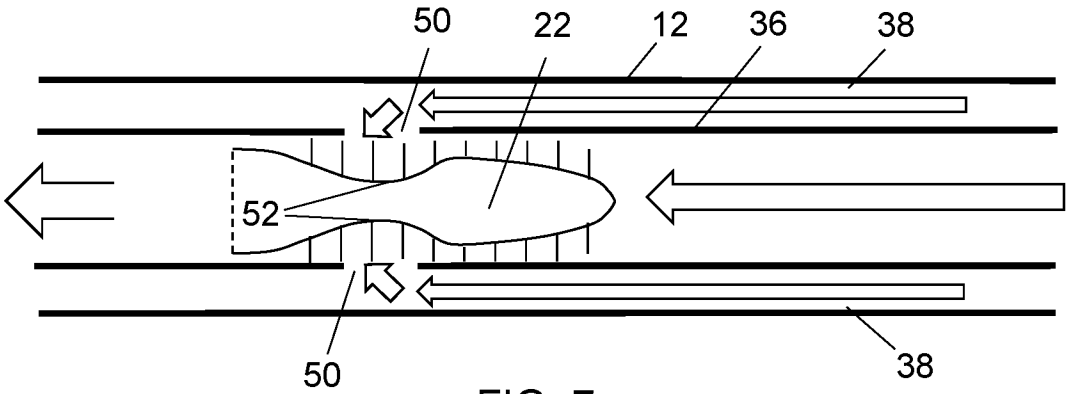


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/063274

A. CLASSIFICATION OF SUBJECT MATTER INV. B01D1/26 B01D1/28 C02F1/04 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) B01D C02F		
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, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 10 046 249 B2 (CALORIS ENG LLC [US]) 14 August 2018 (2018-08-14) cited in the application figures 1-3, 6 -----	1-13
A	US 2016/158666 A1 (WINANDY FRANÇOIS-MATHIEU [GB]) 9 June 2016 (2016-06-09) cited in the application figure 7 -----	1-13
A	CN 108 815 871 A (HORIZON WATER CO LTD) 16 November 2018 (2018-11-16) figures 3, 6 -----	1-13
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "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 26 August 2022		Date of mailing of the international search report 08/09/2022
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Weber, Christian

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2022/063274

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 10046249	B2	14-08-2018	CA 2977657 A1 01-09-2016
		US 2016250563 A1 01-09-2016	
		WO 2016138343 A1 01-09-2016	
US 2016158666	A1	09-06-2016	AU 2014298565 A1 18-02-2016
		BR 112016001729 A2 05-12-2017	
		CA 2918990 A1 05-02-2015	
		CN 105592900 A 18-05-2016	
		CY 1119463 T1 07-03-2018	
		DK 3027288 T3 23-10-2017	
		EA 201690161 A1 30-06-2016	
		EP 3027288 A2 08-06-2016	
		ES 2644465 T3 29-11-2017	
		HR P20171462 T1 29-12-2017	
		HU E034601 T2 28-02-2018	
		JP 6379195 B2 22-08-2018	
		JP 2016528035 A 15-09-2016	
		KR 20160051735 A 11-05-2016	
		LT 3027288 T 27-12-2017	
		MA 38822 A1 31-10-2016	
		MX 369971 B 27-11-2019	
		MY 180236 A 25-11-2020	
		PL 3027288 T3 31-01-2018	
		PT 3027288 T 20-10-2017	
		SG 11201600556T A 26-02-2016	
		SI 3027288 T1 29-12-2017	
		TN 2016000034 A1 05-07-2017	
		US 2016158666 A1 09-06-2016	
		WO 2015014387 A1 05-02-2015	
		WO 2015014840 A2 05-02-2015	
CN 108815871	A	16-11-2018	NONE