(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 April 2017 (06.04.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/055475 A1

(51) International Patent Classification: *F28D 20/00* (2006.01)

(21) International Application Number: PCT/EP2016/073299

(22) International Filing Date: 29 September 2016 (29.09.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15187740.4 30 September 2015 (30.09.2015) EP

(71) Applicant: SIEMENS AKTIENGESELLSCHAFT [DE/DE]; Wittelsbacherplatz 2, 80333 München (DE).

(72) Inventor: STIESDAL, Henrik; Nørrevoldgade 45, 5000 Odense C (DK).

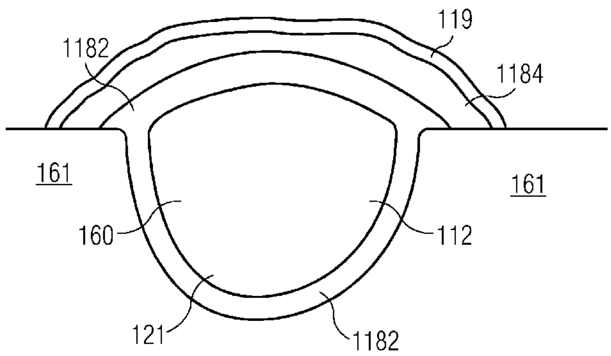
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: HEAT EXCHANGE SYSTEM WITH A HEAT EXCHANGE CHAMBER IN A SOIL EXCAVATION, METHOD FOR MANUFACTURING THE HEAT EXCHANGE SYSTEM AND METHOD FOR EXCHANGING HEAT BY USING THE HEAT EXCHANGE SYSTEM

FIG 7



(57) Abstract: Heat exchange system with a heat exchange chamber in a soil excavation, method for manufacturing the heat exchange system and method for exchanging heat by using the heat exchange system The invention refers to s heat exchange system with at least one heat exchange chamber. The heat exchange chamber comprises es heat exchange chamber boundaries which surround at least one heat exchange chamber interior of the heat exchange chamber. The heat exchange chamber boundaries comprise at least one first opening for guiding in an inflow of at least one heat transfer fluid into the heat exchange chamber interior and at least one second opening for guiding out an outflow of the heat transfer fluid out of the heat exchange chamber interior. At least one heat storage material is arranged in the heat exchange chamber interior such that a heat exchange flow of the heat transfer fluid through the heat exchange chamber interior causes a heat exchange between the heat storage material and the heat transfer fluid. The heat exchange chamber is at least partly arranged in at least one soil excavation of a soil. The heat exchange chamber is at least partly buried in the soil. In a preferred embodiment, at least one of the heat exchange chamber boundaries is at least partly formed by at least one

[Continued on next page]

WO 2017/055475 A1

soil boundary. The respective heat ex-change chamber boundary comprises the soil boundary of the soil excavation. In a preferred embodiment, the soil boundary is formed by filled ground. The filled ground is preferably a result of digging into the soil for the providing of the soil excavation.

Description

Heat exchange system with a heat exchange chamber in a soil excavation, method for manufacturing the heat exchange system and method for exchanging heat by using the heat exchange system

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention refers to a heat exchange system with a heat exchange chamber, a method for manufacturing the heat exchange system and a method for exchanging heat by using the heat exchange system.

2. DESCRIPTION OF THE RELATED ART

Despite the integration of renewable energy into the public electric energy system (power grid) a large share of electricity is nowadays still generated by fossil energy sources. But the global climate change requires the further development of renewable energies.

The energy output of renewable energy sources like wind and solar is not constant throughout a day or throughout a year. Consequently, electricity which is generated by utilizing energy from renewable energy sources fluctuates.

In order to manage this fluctuating electricity, heat (thermal energy) storage systems are developed for storing and releasing thermal energy (heat exchange system). Such a heat exchange system comprises a heat exchange chamber with heat exchange chamber boundaries which surround a heat exchange chamber interior. The heat exchange chamber interior is filled with heat storage material like stones. The heat exchange chamber boundaries comprise a first opening for guiding an inflow of a heat transfer fluid, e.g. air, into the heat exchange chamber interior and a second opening for guiding out an outflow of the heat transfer fluid out of the heat exchange chamber interior.

For a charging mode, the heat exchange system additionally comprises a charging unit for heating the heat transfer fluid with the aid of excess electricity. The resulting hot heat transfer fluid is infused into the heat exchange chamber interior via one of the openings (e.g. first opening) of the heat exchange chamber boundaries. This opening defines a "hot" terminal of the heat exchange chamber. The hot heat transfer fluid is guided through the heat exchange chamber interior. By the guiding of the hot heat transfer fluid through the heat exchange chamber interior a heat transfer from the heat transfer fluid to the heat storage material is caused. Heat is stored by the heat storage material.

Via the other opening (second opening) of the heat exchange chamber the resulting "cold" heat transfer fluid is guided out of the heat exchange chamber interior. Thereby, this opening of the heat exchange chamber boundaries defines a "cold" terminal (end) of the heat exchange chamber. The charging mode is stopped when the temperature at the cold terminal of the heat exchange chamber begins to rise above a predetermined temperature.

In a discharging mode of the heat exchange chamber this stored heat can be recovered: "cold" heat transfer fluid is infused into the heat exchange chamber interior via one of the openings of the heat exchange chamber boundaries. In this case, this opening defines a "cold" terminal. The cold heat transfer fluid is guided through the hot heat exchange chamber interior. By the guiding of the cold heat transfer fluid through the heat exchange chamber interior a heat transfer from the heat storage material to the heat transfer fluid is caused. Heat is released from the heat storage material.

Via the second opening of the heat exchange chamber boundaries the resulting "hot" heat transfer fluid is guided out of the heat exchange chamber interior. Thereby, the second opening of the heat exchange chamber defines a "hot" terminal of the heat exchange chamber.

The resulting hot heat transfer fluid can be used for generating steam with which a steam turbine is driven. Result of the described discharging mode: Heat is transformed back to electricity.

The discharging mode is stopped when the temperature at the cold terminal of the heat exchange storage begins to drop below a certain temperature.

The heat exchange chamber of the heat exchange system can comprises extensions of more than 100 m which requires a respective space with a respective impact to the environment.

SUMMARY OF THE INVENTION

It is an objective of the invention to provide a heat exchange system with little impact to the environment in regard to its space requirements.

This objective is achieved by the invention specified in the claims.

A heat exchange system with at least one heat exchange chamber is provided. The heat exchange chamber comprises heat exchange chamber boundaries which surround at least one heat exchange chamber interior of the heat exchange chamber. The heat exchange chamber boundaries comprise at least one first opening for guiding in an inflow of at least one heat transfer fluid into the heat exchange chamber interior and at least one second opening for guiding out an outflow of the heat transfer fluid out of the heat exchange chamber interior. At least one heat storage material is arranged in the heat exchange chamber interior such that a heat exchange flow of the heat transfer fluid through the heat exchange chamber interior causes a heat exchange between the heat storage material and the heat transfer fluid. The heat exchange chamber is at least partly arranged in at least one soil excavation of a soil. The heat exchange chamber is at least partly buried in the soil. In a preferred embodiment, at least one of the heat exchange chamber boundaries is at least partly formed by at least one soil boundary. The respective heat exchange chamber boundary comprises the soil boundary of the soil excavation. In a preferred embodiment, the soil boundary is formed by filled ground. The filled ground is preferably a result of digging into the soil for the providing of the soil excavation.

In addition to the heat exchange system, a method for manufacturing a heat exchange system with following manufacturing steps is provided: a) providing of the soil excavation of a soil and b) arranging of the heat exchange chamber in the soil excavation of the soil. Preferably, for the arranging of the heat exchange chamber in the soil excavation different layers are arranged in the soil excavation of the soil. Result is a stacked heat exchange chamber which is arranged in the soil excavation. Thereby, the different layers comprise different functions, e.g. a support function for the heat storage material, a sealing function for avoiding a penetration of water into the heat exchange chamber interior or a thermal insulation function.

Moreover, a method for exchanging heat by using the heat exchange system is provided. In an operating mode of the heat exchange system the heat exchange flow of the heat transfer fluid is guided through the heat exchange chamber interior, wherein a heat exchange between the heat storage material and the heat transfer fluid is caused.

The heat exchange chamber is a space, cavity or a housing in which the heat storage material is located. Inside of the heat exchange chamber the heat exchange takes place. In order to provide an efficient heat exchange, the heat exchange chamber is preferably thermally insulated against the surroundings. The loss of heat is reduced by the thermal insulation.

The heat transfer fluid is guided (led) into the heat exchange chamber interior via the first opening and is guided out of the heat exchange chamber interior via the second opening. The first opening of the heat exchange chamber boundaries is an inlet opening. The second opening of the heat exchange chamber boundaries is an outlet opening. Thus, there are different areas of the heat exchange chamber boundaries, namely an inlet area of the heat exchange chamber boundaries with the first opening and an outlet area of the heat exchange chamber boundaries with the second opening.

The operating mode of the heat exchange system is selected from the group consisting of charging mode with a heat transfer from the heat transfer fluid to the heat storage material and discharging mode with a heat transfer from the heat storage material to the heat transfer fluid.

Depending on the operating mode, a specific opening can have the function of an inlet opening or the function of an outlet opening. The flow direction of the heat exchange flow depends on the operating mode. Preferably, during the charging mode the heat exchange flow is directed in a charging mode direction, during the discharging mode the heat exchange flow is directed in a discharging mode direction and the charging mode direction and the discharging mode direction are opposed to each other (countercurrent operation). But, a change of the directions of the heat exchange flow is not necessary. Charging mode direction and discharging mode direction comprise the same direction (co-current operation).

In countercurrent operation, switching from the charging mode to the discharging mode the direction of the heat exchange flow through the heat exchange chamber interior is reversed and consequently, the function of the openings (inlet opening, outlet opening) is reversed, too. With such a solution it is especially advantageous to use the same heat transfer fluid for the charging mode and for the discharging mode. But of course, different heat transfer fluids for the charging mode and the discharging mode can be used, too.

For the charging mode, the heat exchange system is equipped with at least one charging unit for heating the heat transfer fluid. In the charging mode with activated charging unit, the charging unit can be located upstream of the heat exchange chamber. In contrast to that, in the discharging mode with a deactivated charging unit, the charging unit can be located downstream of the heat exchange chamber.

Preferably, the charging unit comprises at least one electrical heating device which is selected from the group consisting of resistance heater, inductive heater, emitter of electromagnetic radiation and heat pump. The electromagnetic radiation is preferably infrared radiation. A combination of different electrical heating devices is possible. With the aid of the electrical heating devices electricity is transformed into heat. This heat is absorbed by the heat transfer fluid and transported to the heat storage material in the heat exchange chamber interior.

For instance, the electrical heating device comprises a resistance heater. This heater is located in the heat exchange inflow upstream of the heat exchange chamber. The heat transfer fluid is heated up before it’s entering of the heat exchange chamber interior. The resistance heater comprises a large heat exchange area for an efficient heat exchange from the resistance heater to the heat transfer fluid. For instance, the large heat exchange area is formed by a grid of the resistance heater. A meander shaped resistance heater is possible, too. With such a measure, the heat transfer to the heat transfer fluid is enhanced. In addition, the possibility of the (not desired) occurrence of hot spots within the resistance heater is reduced.

The heat exchange system is preferably equipped with at least one discharging unit for discharging the heat transfer fluid of the outflow from heat for production of electricity. Heat is removed from the heat transfer fluid. The removed heat is transformed into electricity. In a preferred embodiment, the transformation of heat into electricity is carried by a water/steam cycle for driving a turbine of a steam power plant.

The discharging mode can be realized when electricity prices and demand are high or when the production of renewable energies is low. For that and in order to limit the costs which are connected to the invention, it is advantageous to use existing power plants. So, the heat exchange system is a kind of retrofit system. For instance, well suited are CCPP (combined cycle power plant) since their heat recovery steam generator (HRSG) is similar to the application proposed here. Nevertheless, hard coal, oil, gas, waste incineration, wood or lignite fired power plants can be used since the charging unit can be designed for high temperatures to match the temperatures used in the steam generator. In a hybrid mode the fuel can be used to increase the temperature from the temperature level of the heat exchange system to the operating temperature of the original furnace or boiler design.

In a preferred embodiment, the heat exchange system is equipped with a flow adjusting element for adjusting the heat exchange flow through the heat exchange chamber interior, for adjusting the inflow into the heat exchange chamber interior and/or for adjusting the outflow out of the heat exchange chamber. The flow adjusting element comprises at least one active fluid motion device which is selected from the group consisting of blower, fan and pump and/or the flow adjusting element comprises at least one passive fluid control device which is selected from the group consisting of activatable bypass pipe, nozzle, flap, damper and valve. A multitude of these devices are possible as well as a combination of these devices. Preferably, driving units of the active fluid motion devices like electrical motors and electrical equipment are located outside of the heat exchange flow with the (possibly very hot) heat transfer fluid. A multitude of these devices are possible as well as a combination of these devices. In addition, flow adjusting elements can be arranged serially or in parallel. For instance, two flaps are arranged at two openings in order to adjust the inflows of the heat transfer fluid into the heat exchange chamber interior and consequently in order to adjust the temperature distribution in the heat exchange chamber interior.

The advantage of passive control devices is that they are cheap. In addition, passive control devices are very reliable. But preferably, active motion devices are used. By that, it is advantageous that driving units of the active fluid motion devices like electrical motors and electrical equipment are located outside of the heat exchange flow with the (possibly very hot) heat transfer fluid.

Just to be noted: There are different locations for the flow adjusting element possible. The flow adjusting element can be arranged directly in the heat exchange chamber interior, downstream of the heat exchange chamber interior and/or upstream of the heat exchange chamber interior. The location depends – inter alia - on the kind of flow adjusting element (active fluid motion device or passive fluid control device).

The heat storage material can be liquid and/or solid. For instance, a core of the heat storage material is solid and a coating of this solid core is liquid. Such a liquid coating can comprise ionic liquid.

The solid material comprises preferably bulk material. Mixtures of different liquid materials and different solid materials are possible as well as mixtures of liquid and solid materials.

It is possible that the heat storage material is a thermo-chemical energy storage material: Thermal energy can be stored via an endothermic reaction whereas thermal energy can be released via an exothermic reaction. Such a thermo chemical storage material is for instance the calcium oxide/calcium hydroxide system.

The heat storage materials can be arranged in one or more specific containers made of non-reactive container material. Non-reactive means that no chemical reaction between the heat storage material and the container material takes place during the heat exchange process.

In a preferred embodiment, the heat storage material comprises at least one chemically and/or physically stable material. In the range of the operational temperature of the heat exchange system the heat storage material does not change its physical and/or chemical properties. A physically stable material does not change its physical properties during the heat exchange. For instance, the heat storage material remains in a solid state in the operating temperature range. A chemically stable material does not change its chemical composition during the heat exchange. For instance, such a chemically stable material is a phase change material (PCM).

Moreover, a complex heat exchange system with different heat exchange chambers with different heat storage materials and/or different heat transfer fluids is possible, too. For instance, a heat exchange chamber with stones as heat storage material and a heat exchange chamber with a phase change material as a heat storage material are combined together (in parallel or in series).

In a preferred embodiment, the heat storage material comprises sand and/or stones. The stones can be natural stones or artificial stones. Mixtures thereof are possible, too. Artificial stones can consist of containers which are filled with heat storage material. This heat storage material is for instance a phase change material or a thermo-chemical storage material (see above).

Preferably, the stones comprise gravel (pebbles), rubbles and/or grit (splits). The artificial material comprises preferably clinkers or ceramics. Again, mixtures of the mentioned materials are possible, too.

In order to provide a cheap energy storage material it is advantageous to use waste material. Therefore, in a preferred embodiment, the artificial material comprises at least one by-product of an industrial process. For instance, the by-product is iron silicate. Iron silicate origins from a slag of copper production.

In a preferred embodiment, heat exchange channels are embedded in the heat storage material for guiding of the heat exchange flow through the heat exchange chamber interior. The heat storage material forms a heat exchange bed. The heat exchange bed comprises the heat exchange channels. The heat exchange channels are embedded into the heat storage bed such that the heat exchange flow of the heat transfer fluid through the heat exchange channels causes the heat exchange between the heat storage material and the heat transfer fluid. The heat exchange channels can be formed by interspaces (gaps) of the heat storage material. For instance, the heat storage material comprises stones. The stones form the heat exchange bed with the heat exchange channels. In addition or alternatively, the heat storage material is porous. Open pores of the heat storage material form the heat exchange channels.

The heat transfer fluid is selected from the group consisting of a liquid and a gas. The gas is selected from the group consisting of inorganic gas and/or organic gas. The inorganic gas is preferably air. Mixtures of different liquids are possible as well as mixtures of different gases.

Preferably, the heat transfer fluid comprises a gas at ambient gas pressure. Preferably, the gas at the ambient pressure is air. The ambient pressure (900 hPa to 1.100 hPa) varies such that the heat exchange flow through the heat exchange chamber interior is caused.

For the guiding of the heat transfer fluid into the heat exchange chamber interior and for the guiding of the heat transfer fluid out of the heat exchange chamber interior a pipe system (or channel system, ducting system) is used. This pipe system can be closed (with a closed loop) or can be open (with an open loop).

For instance the heat transfer fluid is ambient air of the environment. The loop is an open loop. Air from the environment is introduced into the heat exchange system and air of the heat exchange system is released to the surroundings. There is an air exchange during the operation of the heat exchange system.

In contrast to that, there is no air exchange or a selectively adjustable air exchange during the operation in a closed loop. Air of the environment is not added or just added on a small scale to the air which is used as heat transfer fluid. This has following specific advantage: In a situation with almost completely charged heat storage material, heat transfer fluid with remaining heat would be released to the environment in an open loop. The remaining heat is lost. In contrast to that, in a closed loop this heat transfer fluid with remaining heat stays in heat exchange system. The remaining heat is not lost. Therefore, in a preferred embodiment, a closed loop is implemented and wherein the inflow comprises the outflow. The outflow is guided back into the heat exchange chamber interior.

In a preferred embodiment of the heat exchange system, the soil boundary which is formed by the filled ground is a ceiling of the heat exchange chamber. So, the heat exchange chamber interior with the heat storage material is covered by the filled ground.

Preferably, the soil boundary which is formed by the filled ground is designed such that a packing (settling) of the heat storage material within the heat exchange chamber interior can be compensated. For instance, the heat storage material comprises stones. During a couple of charging cycles and discharging cycles the stones crack. Hence, a packing of the heat storage material takes place. The packing of the heat storage material leads to a decreasing of a height of a filling height of the heat storage material. For the case that the ceiling of the heat exchange chamber is formed by the heat storage material, a height of the heat exchange chamber is decreased by the packing of the heat storage material. This packing is compensated. Additional measures for the compensation of the packing and hence for compensation of the change of the height of the heat exchange chamber are not necessary.

Additional layers can improve the above describe compensation function. For this, a ballast layer with ballast material is advantageous. In a preferred embodiment, the ceiling of the heat exchange chamber is covered by at least one ballast layer with sand or with soil. The ballast material is sand and/or soil. Other ballast materials are possible, too.

In a preferred embodiment, the heat exchange chamber is at least partly covered by at least one foil. Preferably, the foil is arranged at least partly on top (of the heat exchange chamber and/or at least partly on a side of the heat exchange chamber and/or at least partly below the heat exchange chamber. In the latter case, a bottom of the heat exchange chamber comprises the foil.

In a preferred embodiment, the foil is resistant against a permeation of air and/or water. Preferably, the heat exchange chamber is sealed by the foil. So, water from the outside cannot penetrate into the heat exchange chamber interior. Also air (heat transfer fluid) cannot leave the heat exchange chamber interior uncontrolled. Thereby, the openings for the inflow of the heat transfer fluid and the openings for the outflow of the heat transfer fluid are left out. These openings are not sealed.

As described above, the stacking of different layers with different functions is advantageous. This refers to the heat exchange chamber as a whole as well as specific parts of the heat exchange chamber, especially the top of the heat exchange chamber. In a preferred embodiment, the ceiling of the heat exchange chamber comprises a layer structure with following layers: Thermal insulation layer and soil layer with filled ground. With the aid of the thermal insulation heat cannot leave the heat exchange chamber uncontrolled. With the aid of the soil layer the above described packing of the heat storage material can be compensated. A similar layer structure can refer to a side of the heat exchange chamber as well as to a bottom of the heat exchange chamber.

In a preferred embodiment, the layer structure comprises at least one ballast layer with sand and/or at least one foil layer with at least one foil. With this measure the compensation of the packing is improved as well as the sealing of the heat chamber interior.

The different layer can be arranged in different ways. In a preferred embodiment, the foil layer is arranged between the thermal insulation layer and the soil layer.

The penetration of water into the heat exchange chamber interior is a crucial problem. In order to avoid this is meaningful to use a drainage system. In a preferred embodiment, the soil excavation is at least partly surrounded by at least one drainage system for avoiding penetration of water into the heat exchange chamber interior. Preferably, the soil excavation is completely surrounded by the drainage system. By this measure the probability of the penetration of water into the heat exchange chamber interior is reduced.

The heat exchange chamber is preferably a horizontal heat exchange chamber.

The term "horizontal heat exchange chamber" implies a horizontal main (average) flow of the heat transfer fluid through the heat exchange chamber interior. The flow direction of the horizontal main flow is essentially parallel to the average surface of the earth. The horizontal direction is essentially a perpendicular direction to the direction of the gravity force which affects the heat transfer fluid. Perpendicular means in this context that deviations from the perpendicularity of up to 20° and preferably deviations of up to 10° are possible.

A horizontally oriented direction of the heat exchange flow can be achieved by lateral first openings and/or lateral second openings. The horizontal heat exchange chamber comprises these openings in its side heat exchange chamber boundaries. In addition, with the aid of an active fluid motion device like a blower or a pump the heat exchange flow in the heat exchange chamber interior is caused. The heat transfer fluid is blown or pumped into the heat exchange chamber interior or is pumped or sucked out of the heat exchange chamber interior.

In a preferred embodiment, at least two first openings are arranged vertically to each other and/or at least two second openings are arranged vertically to each other. Openings are arranged above each other. By this measure it is possible to influence a vertical distribution of heat exchange flows in order to improve a temperature distribution (temperature front) in the heat storage material and heat exchange chamber interior respectively. Isothermal lines perpendicular to the flow direction are influenced.

The temperature front is defined by neighboring cold and hot areas of the heat storage material in the heat exchange chamber interior caused by the flow of the heat transfer fluid through the heat exchange chamber interior. The temperature front is aligned perpendicular to the respective flow direction of the heat exchange flow through the heat exchange chamber. During the charging mode the heat exchange flow is directed in a charging mode direction wherein the temperature front moves along this charging mode direction. In contrast to that, during the discharging mode the heat exchange flow is directed in the discharging mode direction (opposite to the charging mode direction) wherein the temperature front moves along the discharging mode direction. In both cases, the temperature front of the heat exchange chamber is migrating through the heat exchange chamber to the respective hot/cold ends of the heat exchange chamber. It is to be noted that in case of countercurrent operation, the hot (hot opening) end remains the hot end (hot opening), independently from the mode (charging mode or discharging mode).

The temperature front is a zone of strong temperature gradient in the heat storage material, i.e. high temperature difference between hot and cold areas. In this application it separates the hot (charged with heat) and the cold (not charged) zone in the heat exchange chamber with the heat storage material. The temperature front develops due to the transfer of heat from the heat transfer fluid to the heat storage material during the charging mode and due to the transfer of heat from the heat storage material to the heat transfer fluid during the discharging mode. Isothermal zones/lines develop ideally (e.g. without the influence of gravitation) perpendicular to the main flow direction, i.e. zones/lines of constant temperature.

In order to optimize the efficiency of the heat exchange system it is advantageous to ensure a uniform temperature front. There are just small variations concerning the temperature gradients perpendicular to the flow direction. In a vertical heat exchange chamber with a flow direction top down, the temperature front is nearly uniform due to natural convection. So, in this case additional measures are not necessary. In contrast to that, natural convection leads to a non-uniform temperature front in a horizontal heat exchange chamber. So, in this case additional measures could be meaningful (like usage of more openings or usage of more flow adjusting elements).

Preferably, the chamber boundary with one of the openings comprises a transition area with a tapering profile such that an opening diameter of the opening aligns to a first tapering profile diameter of the tapering profile and a chamber diameter of the heat exchange chamber aligns to a second tapering profile diameter of the tapering profile. The transition area comprises an increasing cross section from the respective opening towards the heat exchange chamber. This is especially advantageous for the first opening for guiding the heat transfer fluid into the heat exchange chamber. The diameter of the transition area expands from the opening diameter of the first opening to the diameter of the heat exchange chamber. With the aid of the tapering profile the inflow of the heat transfer fluid is guided into the heat exchange chamber interior. The guided inflow is distributed to a wide area with the heat storage material. By this measure a capacity of the heat exchange unit (heat storage material which is located in the heat exchange chamber) can be highly exploited. In addition, the efficiency of the heat exchange can be improved by adapting the heat exchange flow. Remark: For additionally adapting the heat exchange flow, a diffuser can be located at the first opening, especially in the transition area. By means of the diffuser an incident flow of the heat transfer fluid into the heat exchange chamber interior can be adjusted. For instance, such a diffuser is formed by stones which are located in the transition area with the tapering profile.

For the case that the heat exchange chamber comprises a number of first openings it is very advantageous to arrange a described transition area at that number of first openings. Thereby, the first openings can comprise a joint transition area or individual transition areas.

The transition area with the second opening for guiding the heat transfer fluid out of the heat exchange chamber interior can be tapered, too. By this measure the guiding of heat flow out of the heat exchange chamber interior of the heat exchange chamber is simplified.

In this context, the use of a short transition area is very advantageous. For instance, the short transition area comprises a dimension which is less than 50% of a length of the heat exchange chamber. For instance, the dimension is about 20% of the length of the heat exchange chamber. The length is the dimension of the heat exchange chamber that is parallel to the main flow direction of the heat transfer fluid through the heat exchange chamber interior. But of course, the dimension of the transition area is dependent on a number of features of the complete heat exchange system, e.g. temperature of the heat transfer fluid, mass flow of the heat exchange flow, speed of the heat exchange flow at the relevant opening temperatures, etc.

In order to save space and in order to reduce the surface-volume ratio for a reduced heat loss, it is advantageous to implement a transition area as short as possible. The result is a short transition channel for guiding the inflow into the heat exchange chamber interior. Besides an efficient usage of the capacity of the heat exchange chamber a low space requirement is connected to this solution.

Preferably, the heat exchange chamber comprises a cylindrically shaped chamber boundary. For instance, the chamber boundary which comprises the first opening is formed as a circular cylinder and/or the chamber boundary with the second opening is formed as a circular cylinder. Such shapes lead to best surface-volume ratios.

The dimensions of the heat exchange chamber can be different. But, the invention is especially advantageous for heat exchange systems with large heat exchange chambers. Therefore, in a preferred embodiment, the horizontal heat exchange chamber comprises a heat exchange chamber length which is at least twice of a heat exchange chamber width of the heat exchange chamber and/ or which is at least twice of a heat exchange chamber height of the heat exchange chamber. Preferably, the heat exchange chamber length is selected from the range between 20 m and 300 m. In addition, the heat exchange chamber width and/or the heat exchange chamber height are selected from the range of 1 m to 100 m.

The heat exchange system is especially adapted for operation at high temperatures of more than 300 °C. Therefore, in a preferred embodiment, an operating temperature of the operating mode is selected from the range between 300 °C and 1000 °C, preferably selected from the range between 500 °C and 1000 °C, more preferably selected from the range between 600 °C and 1000 °C, 650 °C to 1000 °C and most preferably between 700 °C and 1000 °C. A deviation of the temperature ranges is possible. In this context, very advantageous is an upper limit of the temperature range of 900 °C and most preferably an upper limit of the temperature range of 800 °C. The heat exchange system is a high temperature heat exchange system.

The proposed invention can be applied for renewable energy production as well as for conventional energy production. For instance, in order to increase the flexibility the steam cycle of fossil fired power plants (or nuclear power plants, etc.) it can be combined with the heat exchange system proposed here. In this case, the boiler of the steam cycle of the power plant can be operated with fuel when fuel costs are lower than electricity costs and the heat exchange system is charged in periods when electricity prices are low. Alternatively, the charging can take place during a period of excess production of energy.

With the invention following specific advantages has to be pointed out:

- The heat exchange system with the heat storage chamber in the soil excavation doesn't impact the environment such as comparable heat exchange systems. Space can be saved.

- The heat exchange chamber is cheap. It is inexpensive, flexible and simple to built.

- A compensation and a managing of expansion and retraction of storage material can easily be carried out.

- The heat exchange chamber is reliable. Temperature changes during the charging and discharging modes don't affect the structure of the heat exchange chamber seriously. Temperature variation doesn't lead to cracks of the heat exchange chamber boundaries and hence doesn`t lead to leakage of the heat exchange chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

Further features and advantages of the invention are produced from the description of exemplary embodiments with reference to the drawings. The drawings are schematic.

Figure 1 shows a heat exchange chamber of the heat exchange system.

Figure 2 shows a temperature distribution of the heat exchange chamber of figure 1 in a charging mode.

Figure 3 shows the heat exchange system in a charging mode.

Figure 4 shows the heat exchanges system in a discharging mode.

Figure 5 shows a specific layer structure of a ceiling of the heat exchange chamber.

Figure 6 shows the dimensions of the heat exchange chamber.

Figure 7 show the heat exchange chamber of figure 1 in a different view.

DESCRIPTION OF PREFERRED EMBODIMENTS

Core of this invention is a heat exchange system 1 with a heat exchange chamber 11 on a high temperature level. The heat exchange chamber 11 is at least partly arranged in at least one soil excavation 160 of a soil 161.

Heat storage material 121 (e.g. stones or sand) which is located in the heat exchange chamber interior 112 of the heat exchange chamber 11 can be charged and discharged with heat via the heat transfer fluid 13. Heat is stored by the heat storage material 121 and can be released from the storage material 121.

The temperature level of the stored heat is significantly higher compared to methods applied so far to increase the efficiency. The temperature level lies between 300 °C and 1000 °C, preferably between 500 °C and 1000 °C, more preferably between 650 °C and 1000 °C and most preferably between 700 °C and 1000 °C. The thermal capacity of the heat exchange system 1 lies in the range between 0.3 GWh and 100 GWh which causes a power output of 50 MW.

The heat exchange system 1 comprises at least one heat exchange chamber 11 with heat exchange chamber boundaries 111 which surround at least one heat exchange chamber interior 112 of the heat exchange chamber 11. The heat exchange chamber 11 is a horizontal heat exchange chamber 113.

The heat exchange chamber boundaries 111 comprise at least one first opening 1111 for guiding in an inflow 132 of at least one heat transfer fluid 131 into the heat exchange chamber interior 112 and at least one second opening 1112 for guiding an outflow 133 of the heat transfer fluid 131 out of the heat exchange chamber interior 112. At least one heat storage material 121 is arranged in the heat exchange chamber interior 112 such that a heat exchange flow 13 of the heat transfer fluid 131 through the heat exchange chamber interior 112 causes a heat exchange between the heat storage material 121 and the heat transfer fluid 131.

Exemplarily, the heat exchange chamber length of the horizontal heat exchange chamber 11 is about 200 m, the heat exchange chamber height of the heat exchange chamber 11 is about 10 m and the heat exchange chamber width of the heat exchange chamber is about 50 m.

With the embodiment, a stacking of different layers with different functions is described. The stacking refers to the ceiling 118 of the heat exchange chamber 11. The ceiling comprises at a layer structure 1181 with following layers above the heat storage material 121: Thermal insulation layer 1182 with mineral wool, foil layer 119 with an EPDM foil, ballast layer 1183 with sand and a soil layer 1184 with filled ground.

For the manufacturing of the heat exchange chamber of the heat exchange system following manufacturing steps are carried out: a) providing of the soil excavation of a soil (removing soil) and b) arranging of the heat exchange chamber in the soil excavation of the soil. Thereby, different layers of the heat exchange chamber are just filled up resulting in the described layer structure. For instance, after digging the excavation different layers are arranged on the bottom of the excavation. After that, storage material is arranged on the layers and on the storage material, the ceiling with different layers is arranged.

With the aid of the proposed heat exchange system 1, thermal energy can be stored on a high temperature level during the charging mode. This stored thermal energy can be used during the discharging mode for the production of steam in a water steam cycle for reconversion into electrical energy.

One or more heat exchange chambers 11 are filled with solid heat storage material 121. The solid heat storage material comprises stones. Alternatively, sand is used.

There is a transition area 116 of the heat exchange chamber 11 with a tapering profile 1161. Thereby an opening diameter 1113 of the opening 1111 or 1112 aligns to a first tapering profile diameter 1162 of the tapering profile 1161 and a chamber diameter 117 of the heat exchange chamber 11 aligns to a second tapering profile diameter 1163 of the tapering profile 1161.

The inflow 132 of the heat transfer fluid 13 is guided into the heat exchange chamber interior 112. The guided inflow 132 is distributed to a wide area of heat storage material 121. By this measure a capacity of the heat exchange unit (heat storage material 121 which is located in the heat exchange chamber interior 112) can be utilized in an advantageous manner.

The transition area 116 is short. The short transition area 116 projects into the heat exchange chamber 11. The result is a short transition channel for the guiding of the inflow 132 into the heat exchange chamber interior 112 of the heat exchange chamber 11.

The heat exchange system 1 is additionally equipped with at least one flow adjusting element 134 for adjusting a mass flow of the heat exchange flow 13 of the heat transfer fluid 131 through the heat exchange chamber interior 11. The flow adjusting element 134 is an active fluid motion device 1341 like a blower or a pump. Such a device enables a transportation of the heat transfer fluid 131 through the heat exchange chamber interior 112 of the heat exchange chamber 11. The blower or the pump can be installed upstream or downstream of to the heat exchange chamber 11.

In the charging mode, the heat transfer fluid 131 enters the heat exchange chamber 11 through a diffuser 1164. The diffuser 1164 comprises stones 1165 and is arranged at the transition area 116 of the heat exchange chamber 11.

The heat exchange flow 13 of the heat transfer fluid 131 is directed in the charging mode direction 135. The flow adjusting element 134, 1341 is advantageously installed upstream of the charging unit 200, 201 (figure 3): Relatively cold heat transfer fluid passes the flow adjusting element 134, 1341 before absorbing heat from the charging unit.

For the charging mode, the heat transfer fluid 131 is heated up from ambient conditions by the electrical heating device 201 (charging unit 200). This charged (heated) heat transfer fluid is guided into the heat exchange chamber interior 112 of the heat exchange chamber 11 for charging of the heat storage material. Thereby the heat exchange between the heat transfer fluid and the heat storage material takes place. With reference 2000 the temperature front at a certain time of this charging process is shown (figure 2). In addition, the temperature gradient 2001 which results in the temperature front is depicted.

For the discharging mode the heat exchange system 1 comprises one or several heat exchange chambers 11 mentioned above, an active fluid motion device 1341 to circulate the heat transfer fluid 131 and a thermal machine for re-electrification, which can be a water/steam cycle 1003. The working fluid of this cycle is water and steam. The water/steam cycle 1003 has the function of a discharging unit 400. Essential components of the steam turbine cycle 1003 are a steam turbine 1006 and a generator 1004.

In the discharging mode, the heat exchange flow of the heat transfer fluid is directed into the charging mode direction 136.

With the aid of the heat exchange system (heat exchanger) 1002 heat of the heat transfer fluid is transferred to the working fluid of the steam cycle 1003.

The heat exchange system 1 comprises a closed loop 1005. Heat exchange fluid which has passed the heat exchange chamber interior 112 is guided back into the heat exchange chamber interior 112.

Patent claims

1. Heat exchange system (1), with
- at least one heat exchange chamber (11) with heat exchange chamber boundaries (111) which surround at least one heat exchange chamber interior (112) of the heat exchange chamber (11), wherein
- the heat exchange chamber boundaries (111) comprise at least one first opening (1111) for guiding in an inflow (132) of at least one heat transfer fluid (131) into the heat exchange chamber interior (112) and at least one second opening (1112) for guiding out an outflow (133) of the heat transfer fluid (131) out of the heat exchange chamber interior (131);
- at least one heat storage material (121) is arranged in the heat exchange chamber interior (112) such that a heat exchange flow (13) of the heat transfer fluid (131) through the heat exchange chamber interior (112) causes a heat exchange between the heat storage material (121) and the heat transfer fluid (131); and wherein
- the heat exchange chamber (11) is at least partly arranged in at least one soil excavation (160) of a soil (161).

2. Heat exchange system according to claim 1, wherein at least one the heat exchange chamber boundaries (111) is at least partly formed by at least one soil boundary (1601).

3. Heat exchange system according to claim 2, wherein the soil boundary (1601) which is formed by the soil boundary is designed such that a packing (122) of the heat storage material (121) within the heat exchange chamber interior (112) can be compensated.

4. Heat exchange system according to one of the claims 1 to 3, wherein a ceiling (118) of the heat exchange chamber (11) is covered by at least one ballast layer (1181) with sand and/or with soil.

5. Heat exchange system according to one of the claims 7 to 9, wherein the heat exchange chamber (11) is sealed by a foil (119).

6. Heat exchange system according to one of the claims 1 to 5, wherein the soil excavation (160) is at least partly surrounded by at least one drainage system (1603) for avoiding penetration of water into the heat exchange chamber interior (112).

7. Heat exchange system according to one of the claims 1 to 6, wherein the heat storage material 121) comprises sand and/or stones.

8. Heat exchange system according to one of the claims 1 to 7, wherein the heat transfer fluid (131) comprises a gas at ambient gas pressure.

9. Heat exchange system according to claim 8, wherein the gas at the ambient pressure is air.

10. Method for manufacturing a heat exchange system (1) according to one of the claims 1 to 9, with following manufacturing steps:
a) Providing of the soil excavation (160) of a soil (161) and
b) Arranging of the heat exchange chamber (11) in the soil excavation (160) of the soil (161).

11. Method for exchanging heat by using the heat exchange system according to one of the claims 1 to 9, wherein in an operating mode of the heat exchange system (1) the heat exchange flow (13) of the heat transfer fluid (131) is guided through the heat exchange chamber interior (112), wherein a heat exchange between the heat storage material (121) and the heat transfer fluid (131) is caused.

FIG 1

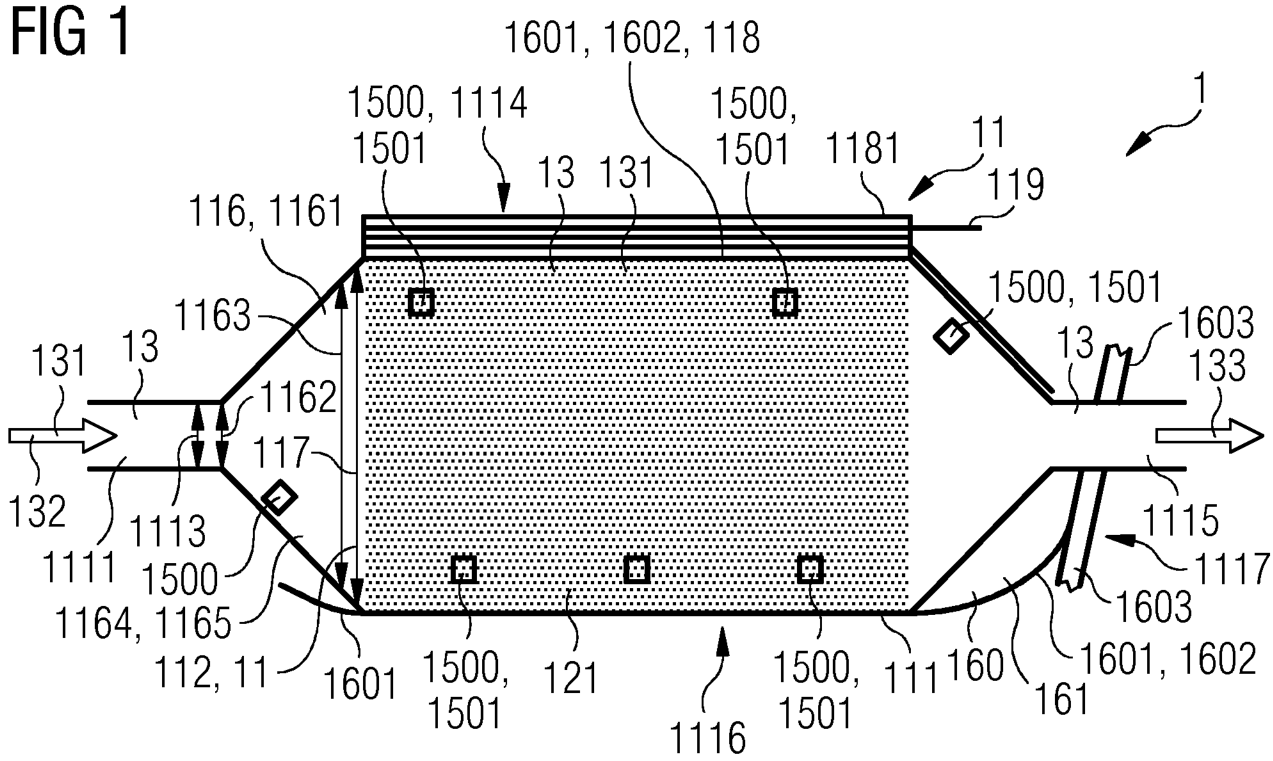

1601, 1602, 118
1500, 1114
1501
1500,
1501
1181
11
1
119
13
131
116, 1161
1500, 1501
1603
1163
131
13
13
133
1162
117
132
1111
1113
1500
1115
1117
1164, 1165
112, 11
1601
1500,
1501
121
1116
1500,
1501
111
160
161
1603
1601, 1602

FIG 2

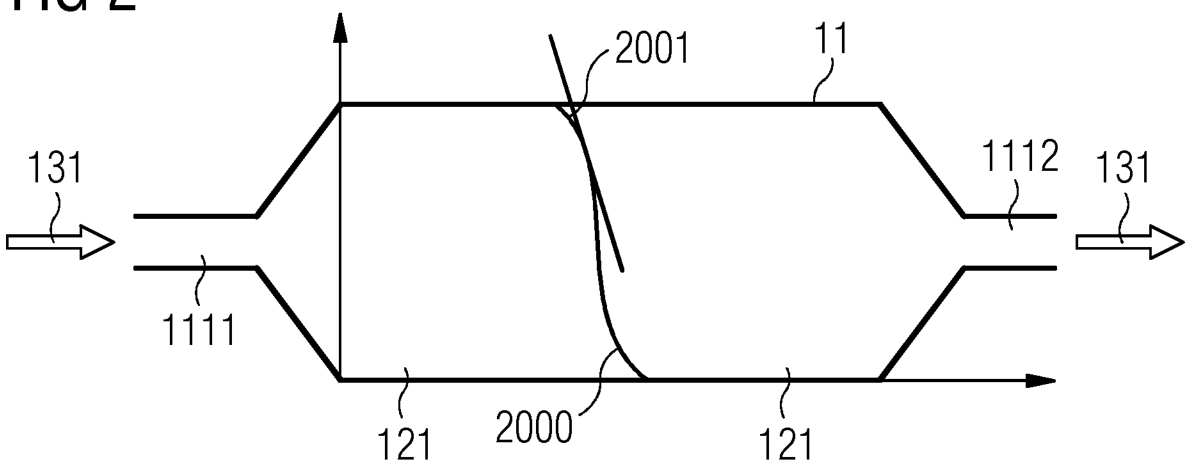

2001
11
131
1112
131
1111
121
2000
121

FIG 3

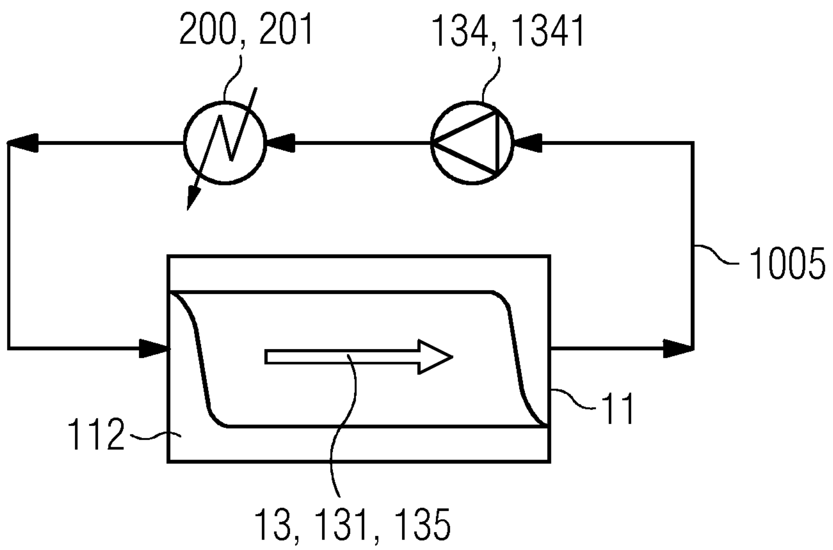

200, 201
134, 1341
1005
11
112
13, 131, 135

FIG 4

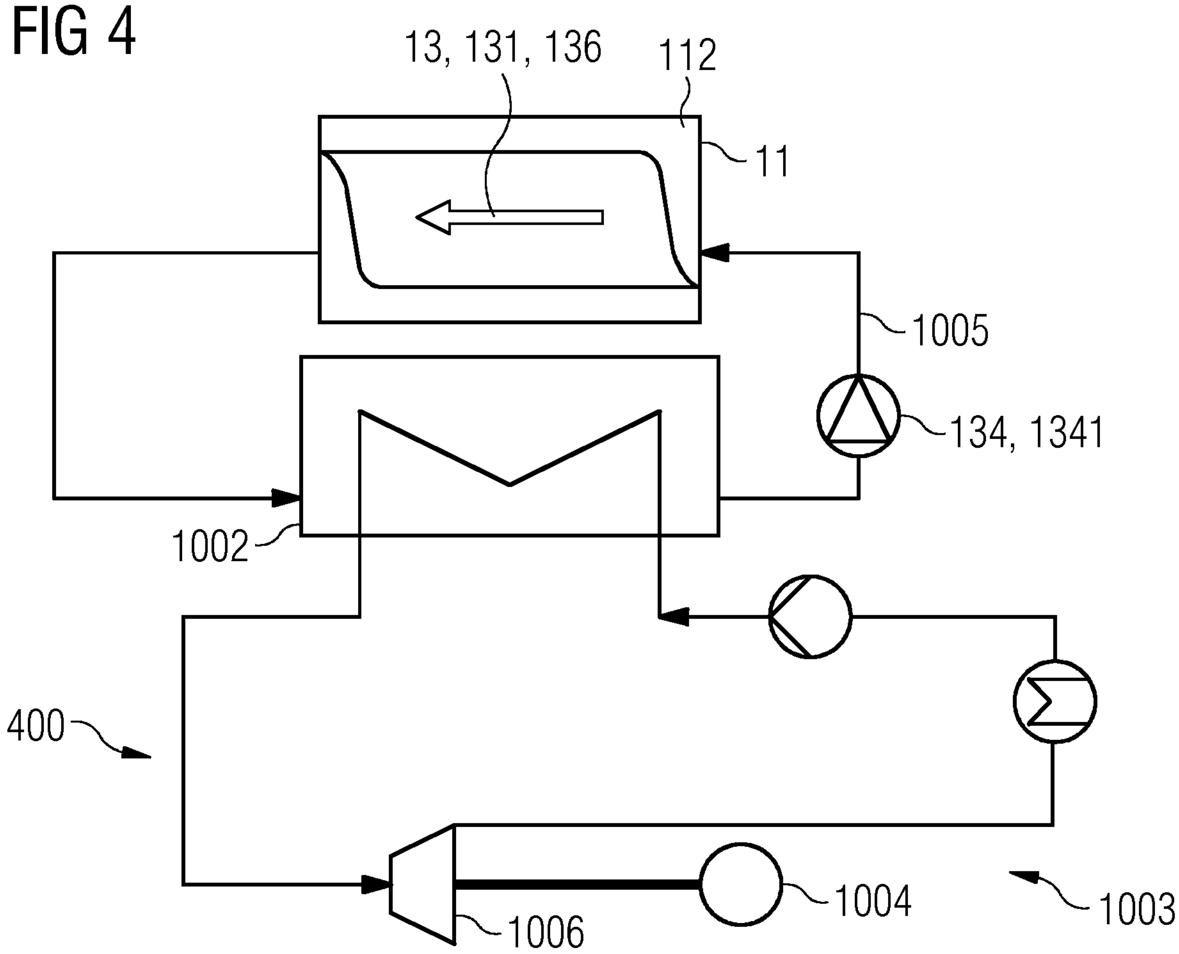

13, 131, 136
112
11
1005
134, 1341
1002
400
1004
1003
1006

FIG 5

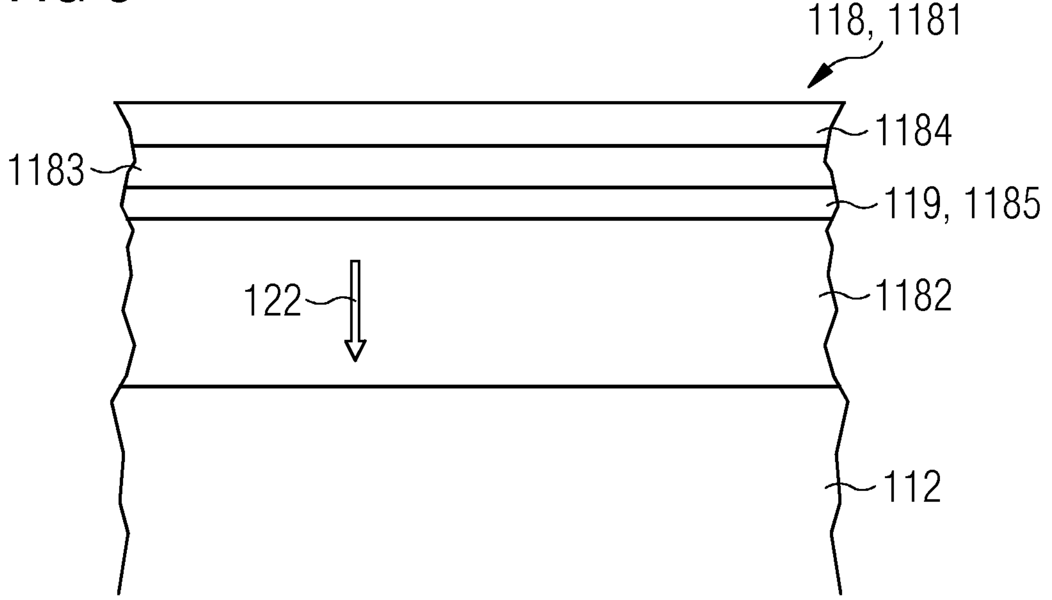


FIG 6

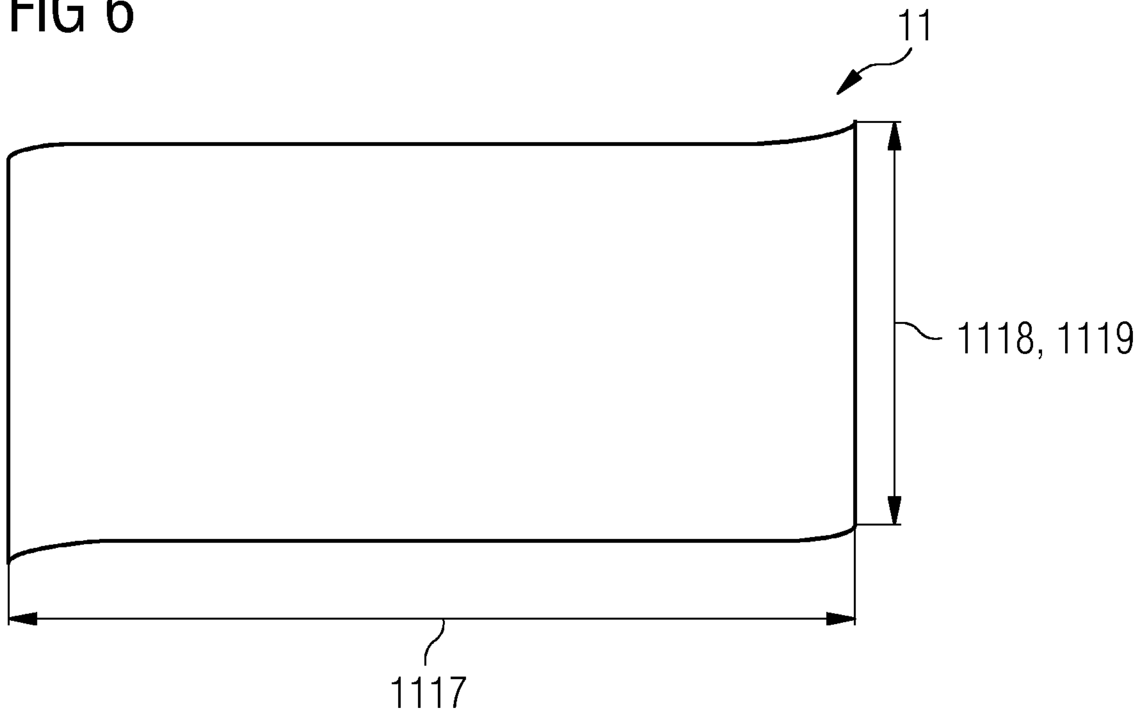
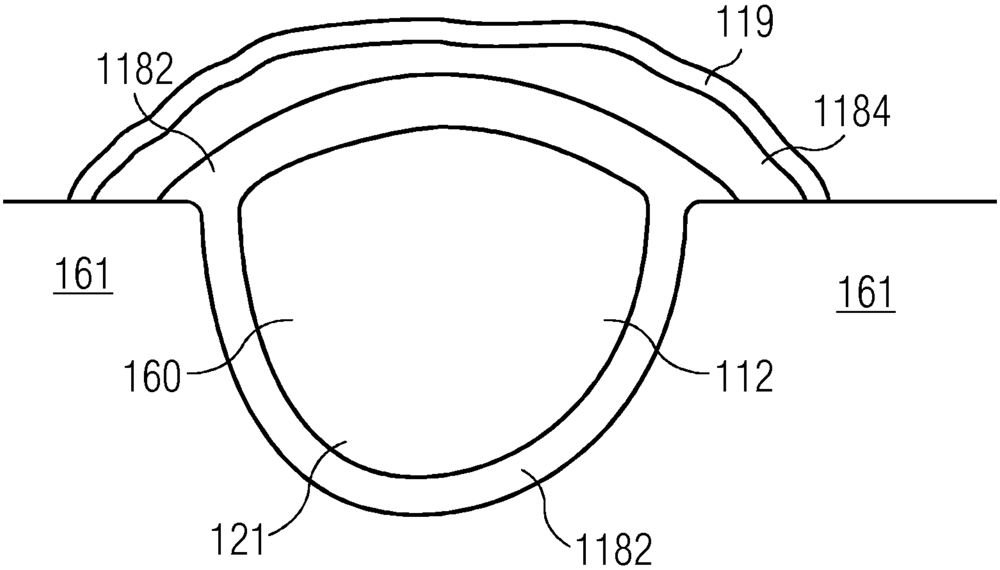


FIG 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/073299

A. CLASSIFICATION OF SUBJECT MATTER
INV. F28D20/00
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)
F28D

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	DE 27 21 173 A1 (KERNER FRANZ) 16 November 1978 (1978-11-16) page 7, line 4 - page 12, line 9; figure 1	1-11
X	DE 10 2011 107315 A1 (BARTH HEINZ [DE]) 17 January 2013 (2013-01-17) paragraphs [0044] - [0045]; figure 2	1-11
X	DE 29 49 584 A1 (KANIUT HERBERT ING GRAD) 11 June 1981 (1981-06-11) page 7, line 14 - page 8, line 9; figure 1	1-11
X	DE 199 29 692 A1 (SCHEUERMANN BERND [DE]) 4 January 2001 (2001-01-04) column 1, lines 3-23; figure 1	1-11

☐ 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	Date of mailing of the international search report
13 December 2016	09/01/2017

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	Axters, Michael

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/073299

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
DE 2721173	A1	16-11-1978	NONE	
DE 102011107315	A1	17-01-2013	NONE	
DE 2949584	A1	11-06-1981	NONE	
DE 19929692	A1	04-01-2001	NONE	