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(54) **LOW LOSS SENSIBLE HEAT STORAGE**

(57) The present inventions is directed to a sensible heat storage apparatus and use thereof. The apparatus comprises an inner vessel (2) comprising an internal volume (3) adapted to comprise a fluid (4); an outer container (5) enclosing said inner vessel; a thermal insulation layer (6) between said inner vessel and said outer container; and at least one integrated connection (7) to connect the internal volume of said inner vessel to an outer environment through the thermal insulation layer. Said at least one integrated connection is adapted to integrate and accommodate at least two individual sub-connections such that every integrated connection forms a single thermal bridge (8) between the inner vessel and outer container and wherein all thermal bridges are located in the bottom 75% of the total height of said outer container.

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Description

[0001] The invention is in the field of energy storage. The invention is in particular directed to an apparatus for thermal storage and its use in hot water systems.

[0002] There is a general increase in the use of alternative energy sources such as solar, wind and hydro-powered as society is moving away from fossil-fuel based energy. However, these alternative energy sources generally depend on the amount of available sunlight, wind, water etc. Therefore, the supply of these energy from the alternative sources are typically fluctuating and a misbalance occurs between the supply and demand.

[0003] A challenge in the field is the prolonged energy storage with a minimal heat loss. This is particularly challenging for sensible heat storage apparatuses. In sensible heat storage, heat is stored in material using the intrinsic heat capacity (Cp) of the material. In contrast to latent heat storage and thermochemical storage, the material in sensible heat storage typically does not undergo a chemical and/or phase change. Sensible heat storage has the advantage over thermochemical heat storage and latent heat storage that it allows for relatively simple systems as no multiphase physics, complex kinetics etc. are involved. One method for storing sensible heat is in the form of hot water tanks.

[0004] Hot water tank technology may suffer from reduced stored energy as there are typically heat losses over time due to the temperature difference between the environment and the temperature of the internal volume of the tank. Conventional sensible heat storage vessels may suffer from heat losses of 30% to 80% per weak under ideal testing conditions. Long-term storage of heat for multiple days may therefore be challenging.

[0005] An example to minimize heat losses in a hot water tank is disclosed in US4286573 where a heat trap assembly is disclosed to prevent heat loss in the cold water inlet and hot water outlet piping systems.

[0006] Another example is disclosed in US9476599 where a hot water storage unit is disclosed comprising a relief device to improve on a pressure temperature relief valve which has been associated with heat loss.

[0007] Further methods to minimize heat losses include the addition of insulation layers around the vessels. However, there are typically still significant heat losses that reduce the storage time of the energy.

[0008] Another heat storage tank is described by Thomas Beikircher (Vacuum tank stores heat, BINE-Projectinfo 14/2014), which discloses a vacuum insulated tank that can store heat for a prolonged time. The space between an inner and outer vessel is filled with perlite and placed under vacuum. However, as perlite is a naturally occurring mineral of volcanic origin and typically produces gas over time. This gas may be damaging the vacuum resulting in an increased heat loss. Further, the tank accordingly may require regular maintenance.

[0009] It is desired to provide a sensible heat storage apparatus that does not suffer from one or more of the above-mentioned drawbacks of conventional heat storage apparatus.

[0010] The present inventors have surprisingly found that minimal heat loss may be achieved by providing a sensible heat storage apparatus that comprises an integrated connection that forms a single thermal bridge. More particularly, the present inventors found that the combination of an integrated connection and the location of this integrated connection forming a thermal bridge is particularly beneficial for reducing heat loss. Accordingly, the stored heat may be stored over a prolonged time with minimal heat loss. This may allow for reduced peak loads on the electrical grid, since the misbalance between energy supply and demand can be limited. The stored heat in the sensible heat storage apparatus may for instance be put to use in domestic applications and/or industrial applications for *i.a.* the provision of hot water.

Figure 1 illustrates a preferred embodiment of the sensible heat storage apparatus comprising a fluid and one integrated connection.

Figure 2 illustrates part of the sensible heat storage apparatus comprising a stratification device.

Figure 3 illustrates a preferred embodiment of the sensible heat storage apparatus comprising three integrated connections.

Figures 4A-4F illustrate top views of several configurations for the integrated connections.

Figure 5 illustrates a preferred embodiment of the sensible heat storage apparatus comprising a stratification device and two integrated connections.

Figure 6 illustrates the experimentally obtained temperature in the internal volume of the sensible heat storage apparatus and the ambient temperature over time.

[0011] Thus, in a first aspect, the present invention is directed to a sensible heat storage apparatus (1) comprising

- an inner vessel (2) comprising an internal volume (3) adapted to comprise a fluid (4);
- an outer container (5) enclosing said inner vessel;
- a thermal insulation layer (6) between said inner vessel and said outer container;
- at least one integrated connection (7) to connect the internal volume of said inner vessel to an outer environment through the thermal insulation layer;

wherein said at least one integrated connection is adapted to integrate and accommodate at least two individual sub-connections such that every integrated connection forms a single thermal bridge (8) between the inner vessel and outer container and wherein all thermal bridges are located in the bottom 75% of the total height of said outer container.

[0012] When the sensible heat storage apparatus is not installed and/or not operational, it may not contain the fluid. This is typically considered easier during storage, transportation and/or installation. When the sensible heat storage apparatus is operational or in use, it accordingly comprises the fluid in the internal volume. It is particularly preferred that the internal volume comprises glycol and/or water, more preferably water. Generally, water is a convenient heat storage medium for a sensible heat storage apparatus as it is non-toxic, low cost and readily available. Further, the stored water may be directly used for several applications, such as, but not limited to, domestic hot water, drinking water or as supply towards a fresh water station. Additionally, the heat storage apparatus may be combined with *i.a.* heat pump systems, gas boilers and other storage systems such as phase change material or thermochemical storage units. Figure 1 illustrates the sensible heat storage apparatus according to the present invention comprising a fluid.

[0013] For sake of conciseness and clarity, the apparatus is herein further described as if it were in use, *i.e.* with the fluid.

[0014] It is typically preferred that the inner vessel and outer vessel have a cylindrical shape as this shape may have an optimal surface to volume ratio. However, it may be appreciated that other shapes, such as square, rectangle, hexagonal, or other shapes are also feasible.

[0015] In general, temperature differences between the internal volume of the inner vessel and the temperature of the outer environment causes heat losses through *i.a.* radiation and/or convection. In order to minimize these heat losses, the sensible heat storage apparatus according to the present invention comprises a thermal insulation layer between the inner vessel and outer container. The term thermal insulation layer is herein used to describe a layer that has a lower thermal conductivity than the material of the inner vessel and outer container. It is preferred that the inner vessel and/or outer container comprise stainless steel.

[0016] In a preferred embodiment the thermal insulation layer comprises a vacuum insulation element. The vacuum between the inner vessel and outer container typically minimizes the heat losses through radiation and/or convection. A preferred vacuum insulation element and its preparation method is described in EP3225728 and has a thermal conductivity in the range of 0.001 W/mK and 0.004 W/mK at a residual gas pressure of 0.1 mbar and a mean temperature between 50 and 300 °C. This vacuum insulation element is preferred as it is considered low-maintenance or even maintenance-free as the material typically does not produce any gas over time. Further, the vacuum may be stable for approximately 20 years or more, which may also increase the life time of the sensible heat storage apparatus.

[0017] A measure to minimize heat losses is the at least one integrated connection. In general, sensible heat storage apparatus have several separate connections that allow for individual liquid inlets, liquid outlets, thermometers, etc. Typically, such connections from the outside to the inside of the apparatus are enabled by providing a metal-based pass-through through the insulation layer thereby creating a metal to metal contact between the inner and outer vessels. Each of these connections may thus thermally connect the outer container and inner vessel and thereby create a thermal bridge. A thermal bridge is herein thus considered as a direct thermal contact between the inner vessel and outer container that has a higher thermal conductivity than the material of the thermal insulation layer. Accordingly, a thermal bridge is a path of relatively low heat resistance. This can have serious consequences on the heat storing capability of the apparatus as in typical well-insulated heat storage apparatus, the majority of the heat is lost through thermal bridges. The present invention is directed at minimizing the amount of thermal bridges.

[0018] The present inventors surprisingly found that providing at least one integrated connection to connect the internal volume of the inner vessel to an outer environment through the thermal insulation layer is beneficial for a prolonged heat storage. The integrated connection is adapted to integrate and accommodate at least two individual sub-connections and forms a single thermal bridge. Thus, by integrating and accommodating a plurality of sub-connections in an integrated connection, the number of thermal bridges can be reduced. The reduced number of thermal bridges may accordingly allow for minimal heat loss. It may be appreciated that the reduced number or minimal number of thermal bridges can be advantageous for various applications as long as there is a thermal insulation layer in place with a lower heat conductivity than the material of the inner vessel and outer container.

[0019] The sub-connections that are integrated and accommodated in the integrated connection can be any type of connection that is required to operate the apparatus. Typical examples of sub-connections include those selected from the group consisting of liquid ports such as heat coil in- and outlets, liquid inlets and liquid outlets, gas ports such as gas inlets and gas outlets, entry points for an anti-scaling device, entry points for a sensor, such as a temperature sensor, a pressure sensor, a magnetic field sensor, entry points for an electric heater and electric feedthroughs such as electricity in- and outlets for electrical heaters.

[0020] For instance, an integrated connection can be adapted to integrate and accommodate a gas port and a liquid port. This liquid port can be used as an outlet for hot fluid from the internal volume. It may be appreciated that the liquid outlet may also be thermally insulated to allow for a minimal heat loss from the fluid during the transportation from the internal volume to the destination. Alternatively, the liquid port may be used as inlet of the fluid to fill the internal volume. The fluid that is provided through the liquid inlet may for instance be a cold fluid to replace hot fluid that has been obtained from the internal volume. Alternatively or additionally, the fluid provided through the liquid inlet may be at an elevated temperature (*i.e.* above 20°C) and previously heated by an external system.

[0021] One or more liquid ports may also be used to supply an internal heating coil that is positioned in the internal volume with a heat transfer fluid to provide heat energy to the fluid that is stored in the internal volume.

[0022] The gas port may for instance be used as an gas outlet. An gas outlet is typically provided as this allows for *i.a.* air to be removed and in this way more space for fluid to be stored in the internal volume may be created.

[0023] A further possibility for a sub-connection is an entry point for an anti-scaling device or an entry point for an electrical heater. The sub-connection may also be an entry point for a sensor. Examples of suitable sensors include, but are not limited to, a pressure sensor and a temperature sensor. It is particularly advantageous if the sub-connection is an entry point for a temperature sensor, as in conventional storage vessels several entry points are typically provided over the length of the vessel to measure the temperature of the fluid at several heights. In other words, in conventional storage vessels several thermal bridges are typically present over the length of the vessel and thus multiple paths for the heat to be lost are typically provided. In the present invention it is therefore preferred that the temperature sensor is a thermocouple, preferably with at least two measuring points. This allows for the measuring of the temperature at different heights within the internal volume without the need to provide multiple entry points over the length of the inner vessel. The thermocouple preferably has at least four measuring points, more preferably at least five measuring points, most preferably the thermocouple has at least six measuring points. The temperature sensor may be used to determine the state of charge of the sensible heat storage apparatus. The term "state of charge" is used to describe the amount of energy stored in the sensible heat storage apparatus. Nonetheless, it may be appreciated that any other means for measuring the temperature may also be feasible.

[0024] Another possibility is that the sub-connection is an electric feedthrough. An electric feedthrough can for instance be used to connect one or more electrical heaters and to provide electricity thereto. The electrical heater may accordingly be present in the internal volume and may be used to heat the fluid. Further, the electrical feedthrough may be used to connect and provide one or more heating coils with electricity. The heating coil may be at least partially present in the internal volume and may comprise a liquid inlet and liquid outlet, however this liquid does not enter the internal volume. Additionally, the liquid used for an optional heating coil may be different from the fluid present in the internal volume.

[0025] As detailed above, the use of an integrated connection may allow for a minimal number of thermal bridges and thus for reduced heat losses. The heat loss through thermal bridges is *i.a.* determined by the cross sectional area of the wall of the thermal bridge and the thermal conductivity of the material of the wall of the thermal bridge. Another factor that may play a role for the heat losses are the (local) temperature differences between the internal volume and the outer environment (*vide infra*). The thermal bridge is a direct thermal contact between the inner vessel and outer container, which is formed by an integrated connection. The material of the wall of the thermal bridge can thus be considered the material that is in direct contact with the inner vessel and the outer container, wherein the outside of the wall of the thermal bridge is in connection with the thermal insulation layer. In other words, if, for instance, the thermal bridge is a metal pipe between the inner vessel and outer container, the cross sectional area of the wall of this pipe is an important factor of the heat loss together with the thermal conductivity of the metal. Accordingly, it is preferred to minimize the cross sectional area of the wall. However, making the cross sectional area of the wall of the thermal bridge smaller typically results in several challenges. For instance, if the thermal bridge is provided for a liquid outlet and this is minimized, the flow rate for the liquid may not be sufficient. Another example is that when a thermal bridge is created to provide an entry for a temperature sensor, the size of this entry point cannot be reduced beyond the size of the temperature sensor. To reduce the size of the cross sectional area of the thermal bridge, the present inventors found that the total cross sectional area can be reduced by for instance a pipe-in-pipe configuration. The heat losses may then only be determined by the cross sectional area of the wall of the outer pipe, instead of the sum of the cross sectional areas of the walls of the individual pipes. In principle, the sum of the cross sectional area of the walls of the individual pipes is higher than the cross sectional area of the wall of an outer pipe in a pipe-in-pipe configuration, while keeping the internal area (*i.e.* the sum of the internal area of the individual pipes for e.g. liquid flow) constant.

[0026] The pipe-in-pipe configuration may be further beneficial for the manufacturability. More non-integrated connection are typically expensive and may lead to micro leakages to the thermal insulation layer. In other words, multiple connections through the insulation layer may present higher risks during manufacturing and thus increase the costs associated with the production. Using integrated connections and the preferred pipe-in-pipe configuration can improve on the manufacturability and may decrease any risks and costs.

[0027] Accordingly, it is preferred that at least two individual sub-connections are integrated and accommodated in the at least one integrated connection via a pipe-in-pipe configuration, preferably a co-axial pipe-in-pipe configuration. Figures 4A-4F illustrate top views of suitable pipe-in-pipe configurations, Figures 4A-4D show this top view for suitable configurations with an increasing number of integrated and accommodated sub-connections.

[0028] Figure 4A illustrates a top view of the basic pipe-in-pipe principle wherein an outer pipe (10) having an outer-pipe wall (100) and an inner pipe (11) having an inner-pipe wall (110) are represented. As mentioned above, the at least one integrated connection connects the internal volume of the inner vessel to an outer environment through the thermal layer thereby forming a single thermal bridge (8) as *i.a.* illustrated in Figure 1. The single thermal bridge forms the direct thermal contact between the inner vessel and outer container. The outer pipe (10), particularly the outer-pipe wall (100) allows for thermal contact between the inner vessel and outer vessel. The outer pipe may however be longer than the distance between the inner vessel and the outer container and, for instance, part of the outer pipe may extend further into the internal volume. Accordingly, at least part of the outer pipe (10) can be considered a thermal bridge. More specifically, the thermal bridge is the part of the outer-pipe wall (100) that forms the direct thermal contact between the inner vessel and outer container. The length of the thermal bridge and thus the length of the part of the outer pipe forming the thermal bridge is accordingly limited to the distance between the inner vessel and outer container.

[0029] As the thermal bridge is determined by the outer pipe, more specifically by the outer-pipe wall, several other configurations are feasible, wherein a single outer pipe remains, but several inner pipers are incorporated. For instance, Figure 4B illustrates a pipe-in-pipe configuration wherein two inner pipes are located in an outer pipe. Similarly, Figure 4C illustrates a pipe-in-pipe configuration wherein three inner pipes are located in an outer pipe and Figure 4D illustrates the configuration for four inner pipes in an outer pipe. Preferably, the circumference of the pipes are of circular, but other shapes may nonetheless be possible such as square, oval and/or rectangular as for instance illustrated in Figure 4E for an outer pipe. Further, configurations wherein consecutive pipe-in-pipe configurations are present may also be suitable, as for instance illustrated in Figure 4F for a pipe-in-pipe-in-pipe configuration.

[0030] To further reduce heat loss, all the thermal bridges in the apparatus are located in the bottom 75% of the total height of the outer container, preferably in the bottom 50%, more preferably in the bottom 25%, most preferably in the bottom 10% of the total height of the outer container. Herein the total height of the outer container is meant as the total height of the wall of the outer container that encloses the inner vessel. In other words, if the outer container for instance is placed on legs or on a platform, these legs and platform may be part of the apparatus but do not contribute to the total height of the outer container. Having the thermal bridges located in the bottom 75% of the total height of the outer container is particularly beneficial for embodiments of the invention comprising a temperature gradient within the internal volume. It is even more particularly beneficial for embodiments wherein a fluid is used for which the density alters with temperatures over the operating range. For instance, hot water tends to form a layer on top of cold water layer. This way, if the internal volume comprises water, a temperature gradient from bottom to top may be present in the internal volume from low to high temperatures. Having the thermal bridges at the bottom may thus minimize heat losses as the temperature difference at opposites ends of the thermal bridge (*i.e.* between the outer environment and the inner vessel) is typically less than the temperature difference between the outer environment and the inner vessel at a higher height.

[0031] To maintain the temperature gradient in the internal volume, the inner vessel may further comprise a stratification device (9), as illustrated in Figure 2. Stratification herein is used to describe the phenomenon that layers of fluid can be formed based on the temperature of the fluid. The stratification device may be placed in the internal volume to ensure that the temperature gradient remains and by limiting turbulence and concomitant mixing of the warmer and colder fluid typically occurs. The stratification device may be any device known in the art, such as one or more perforated plates. For instance, a first perforated plate may be placed at the top of the internal volume and a second perforated plate may be placed on the bottom of the internal volume (see Figure 2). Other stratification devices may include inlet stratification devices that allow the fluid to enter at the level in the internal volume where the temperature is similar to the incoming fluid.

[0032] Depending on the final use of the sensible heat storage apparatus, the internal volume may for instance be between 1 to 15000 liters, preferably between 10 and 1000 liters, more preferably between 50 and 500 liters, most preferably between 75 and 250 liters. It was found that the use of an integrated connection and the low location of thermal bridges is most beneficial for smaller internal volumes.

[0033] In a preferred embodiment as illustrated in Figure 5, the sensible heat storage apparatus comprises a stratification device (9) comprising two perforated plates, one close to the top of the internal volume, and one close to the bottom of the internal volume.

[0034] The preferred embodiment according to Figure 5, further comprises two integrated connections, being a first (71) and a second integrated connection (72). The first integrated connection (71) may be adapted to integrate and accommodate a liquid port and a gas port. It is preferred that the gas port and liquid port are integrated in the first integrated connection via a co-axial pipe-in-pipe configuration, such as a configuration as illustrated in Figure 4A. Herein, it is further preferred that the liquid port forms the outer pipe (10) and the gas port forms the inner pipe (11). For instance, the liquid port may be used as an liquid outlet to obtain the fluid present in the internal volume and the gas port may be used as a deaeration port to degas the internal volume.

[0035] The second integrated connection (72) is preferably adapted to integrate and accommodate a liquid port and an entry point for a temperature sensor. Preferably the liquid port and entry point for a temperature sensor are integrated in said second integrated connection via a co-axial pipe-in-pipe configuration, as illustrated in for instance Figure 4A. It is further preferred that the liquid port forms an outer pipe (10) and said entry point for a temperature sensor forms an inner pipe (11). For instance, the entry point for a temperature sensor is used for entry of a thermocouple with six measuring points and the liquid port is used as liquid inlet for the feeding of the fluid to the internal volume.

[0036] As can be seen in Figure 5, the first and/or second integrated connection may further have a means (711, 721) to configure the preferred pipe-in-pipe configuration and to allow for attachment to *e.g.* an external system.

[0037] It may be particularly preferred that length of the gas port which is integrated and accommodated in the first integrated connection is longer than the liquid port integrated and accommodated in the first integrated connection. This length is determined as the length of the sub-connection that is present in the internal volume, thus the length measured starting from the inner wall to the end of the sub-connection in the internal volume. In other words, the length of the sub-connections may be equal or different, but the length in the internal volume is typically different such that the top of the gas port lies above the top of the liquid port. This is also illustrated in Figure 5, as the gas port herein extends beyond the liquid port. This is preferred as the gas port may be used as a deaeration port, for which is it typically required that the sub-connection reaches the optional gas or air present in the internal volume, which is generally above the fluid level. The liquid port may be used as a liquid inlet or outlet, for which it may be beneficial if the connection is submerged in the fluid optionally present in the internal volume.

[0038] Additionally or alternatively, the length of the first integrated connection (71) is longer in the internal volume than the second integrated connection (72), as further illustrated in Figure 5. The length of an integrated connection is determined by the longest sub-connection (*i.e.* with the longest length in the internal volume) integrated and accommodated in the integrated connection. A short sub-connection between the internal volume and outer environment is typically sufficient as entry point for a temperature sensor and there may be no need to extend this sub-connection to the top of the internal volume. Nonetheless, the temperature sensor and preferably a thermocouple itself may reach into the internal volume, however this does not contribute to the length of the sub-connection. Similarly, as detailed above, a liquid port may be shorter of length than a gas port.

[0039] Another example of a sensible heat storage apparatus with integrated connections of different length is schematically illustrated in Figure 3 for three integrated connections.

[0040] The sensible heat storage apparatus according to the present invention may find its purpose in several applications such as in domestic and/or industrial hot water systems. The sensible heat storage may be used as a standalone apparatus or it may be combined with *i.a.* heat pump systems, gas boilers and other storage systems such as phase change material or thermochemical storage units. Accordingly, the present invention is further directed to a domestic and/or industrial hot water system comprising the sensible heat storage apparatus.

[0041] The method for operating the sensible heat storage apparatus may comprise a storage stage wherein the fluid maintains a storage temperature set by an optional charging stage or period during which heat to the fluid is provided and/or a pre-heated fluid is provided into the internal volume. Thus, in the optional charging stage, energy is provided to the internal volume. The method may further comprise an optional discharging stage wherein hot fluid is obtained from the internal volume of the inner vessel. The optional charging stage may comprise providing heat to the fluid, this may for instance be provided by an electrical heater that is present in the internal volume and connected to an electric feedthrough. Other means may include an internal heat exchanger such as a (non-electric) heating coil. Alternatively or additionally, the optional charging stage may comprise providing a hot fluid. This hot fluid may be previously heated by an external system. The optional charging stage typically sets a storage temperature for the fluid to maintain, preferably this storage temperature is between 0 and 200 °C, preferably between 40 and 130 °C, more preferably between 50 and 95 °C. This temperature may be sufficiently high to be obtained from the internal volume during the optional discharging stage to be used for applications such as, but not limited to, domestic hot water, drinking water or as supply towards a fresh water station. For the purpose of clarity and a concise description features are described herein as part of the same or separate embodiments, however, it will be appreciated that the scope of the invention may include embodiments having combinations of all or some of the features described.

[0042] The project leading to this application has received funding from the *European Unions' Horizon 2020 research and innovation programme* under grant agreement No 766464.

[0043] The invention may further be illustrated by the following nonlimiting examples.

Example 1

[0044] A prototype sensible heat storage apparatus was built with a height of approximately 1200 mm of the outer container and two perforated plates as stratification device. The prototype has two integrated connections, wherein a first integrated connection integrates and accommodates a liquid port and a gas port, and a second integrated connection integrates and accommodates a liquid port and an entry for a temperature sensor. A thermocouple with 6 measuring points was used.

[0045] The total thermal energy stored in the sensible heat storage apparatus was determined by using the average temperature for each of the measuring points. Based on the position of the measuring points a different weight factor corresponding to the thermal mass around each measuring point was estimated with a confidence interval per estimation as shown in Table 1. Wherein Tag is used to describe the individual temperature measuring points.

Table 1 - Estimated relative thermal mass around each measuring point in the sensible heat storage apparatus.

Tag	Estimated Relative Thermal Mass		
	Min	Mid	Max
TI-0.11	5	10	15
TI-0.12	15	23	30
TI-0.13	15	23	30
TI-0.14	15	23	30
TI-0.15	15	23	30
TI-0.16	5	10	15

[0046] The confidence interval for the resulting standing heat loss was calculated using Monte Carlo error analysis.

[0047] The results of the standing heat loss experiment are illustrated in Figure 6. In Figure 6, the T_boiler is the weighted mean temperature in the internal volume calculated using the mid estimation from Table 1. TI-0 1X.PV corresponds to the measuring points of the thermocouple in the internal volume and TISA-91.PV corresponds to the ambient temperature of the outer environment. The experiment was performed according to a norm as described in EU No. 812/2013, the energy labelling of water heaters, hot water storage tanks and packages of water heater and solar devices.. The test procedure was slightly altered and water was first run through an external heater and the internal volume of the sensible heat storage apparatus, once the water reached 70 °C the flow and heater were turned off.

[0048] From the data as shown in Figure 6, the average rate of temperature change was calculated from which the standing heat loss was calculated. The outcomes are presented in Table 2.

Table 2. List of measured and calculated variables.

Variable	Value	Unit
Average ambient temperature	20.1 ± 1.9	°C
Average rate of temperature change	-0.095 ± 0.002	°C hr^{-1}
Assumed water volume	106	dm^3
Standing heat loss	11.8 ± 0.2	W
Energy Class A+ (lower and upper limit)	(0, 25.9)	W

Example 2 - Comparative example

[0049] The obtained heat loss was compared to existing boilers on the marked as shown in Table 3.

Table 3. Short comparison of a sensible heat storage apparatus according to the present invention with boilers on the market.

Manufact urer	Model	Volume (dm3)	Electric heater	Energy label	Approximate heat losses [W]
Present applicant	According to Example 1	106	False	A+(+)	12
OEG	Art. 516008170	157	False	A+	28
Valliant	uniStOR VIH R120/6 H	117	False	A	27-37
ACV	Smart 130	99	True	B	40
Stiebel Eltron	Budget Line	100	True	C	50-70
Itho Daaldero p	Combiconnect boiler 210	130	True	D	80

[0050] The heat losses of the boilers on the market are tested under ideal lab conditions.

Claims

1. Sensible heat storage apparatus (1) comprising

   - an inner vessel (2) comprising an internal volume (3) adapted to comprise a fluid (4);
   - an outer container (5) enclosing said inner vessel;
   - a thermal insulation layer (6) between said inner vessel and said outer container;
   - at least one integrated connection (7) to connect the internal volume of said inner vessel to an outer environment through the thermal insulation layer;

   wherein said at least one integrated connection is adapted to integrate and accommodate at least two individual sub-connections such that every integrated connection forms a single thermal bridge (8) between the inner vessel and outer container and wherein all thermal bridges are located in the bottom 75% of the total height of said outer container.

2. Sensible heat storage apparatus according to the previous claim, wherein said internal volume comprises a fluid, preferably wherein said internal volume comprises water.

3. Sensible heat storage apparatus according to any of the previous claims, wherein all thermal bridges are located in the bottom 50%, more preferably in the bottom 25%, most preferably in the bottom 10% of the total height of said outer container.

4. Sensible heat storage apparatus according to any of the previous claims, wherein said inner vessel comprises a stratification device (9), preferably wherein said stratification device comprises one or more perforated plates.

5. Sensible heat storage apparatus according to any of the previous claims, wherein said at least two individual sub-connections are independently selected from the group consisting of liquid ports such as heat coil in- and outlets, liquid inlets and liquid outlets, gas ports such as gas inlets and gas outlets, entry points for an anti-scaling device, entry points for a sensor, such as a temperature sensor, pressure sensor, magnetic field sensor , entry points for an electric heater and electric feedthroughs such as electricity in- and outlets for electrical heaters.

6. Sensible heat storage apparatus according to the previous claim, wherein said temperature sensor is a thermocouple, preferably with at least two measuring points, more preferably at least four measuring points, even more preferably at least five measuring points, most preferably said temperature sensor is a thermocouple with at least six measuring points.

7. Sensible heat storage apparatus according to any of the previous claims, wherein said thermal insulation layer comprises a vacuum insulation element, preferably wherein said vacuum insulation element has a thermal conductivity in the range of 0.001 W/mK and 0.004 W/mK at a residual gas pressure of 0.1 mbar and a mean temperature between 50 and 300 °C.

8. Sensible heat storage apparatus according to any of the previous claims, wherein said at least two individual sub-connections are integrated and accommodated in said at least one integrated connection via a pipe-in-pipe configuration, preferably a co-axial pipe-in-pipe configuration.

9. Sensible heat storage apparatus according to any of the previous claims, wherein said internal volume is between 1 to 15000 liters, preferably between 10 and 1000 liters, more preferably between 50 and 500 liters, most preferably between 75 and 250 liters.

10. Sensible heat storage apparatus according to any of the previous claims, wherein said inner vessel and/or outer container comprise stainless steel.

11. Sensible heat storage apparatus according to any of the previous claims comprising a first and a second integrated connection, wherein said first integrated connection is adapted to integrate and accommodate a liquid port and a gas port, preferably wherein said gas port and liquid port are integrated in said first integrated connection via a co-

axial pipe-in-pipe configuration, preferably wherein said liquid port forms an outer pipe and said gas port forms an inner pipe;
and/or wherein said second integrated connection is adapted to integrate and accommodate a liquid port and an entry point for a temperature sensor, preferably wherein said liquid port and entry point for a temperature sensor are integrated in said second integrated connection via a co-axial pipe-in-pipe configuration, preferably wherein said liquid port forms an outer pipe and said entry point for a temperature sensor forms an inner pipe.

12. Sensible heat storage apparatus according to the previous claim, wherein the length of said gas port integrated and accommodated in said first integrated connection is longer than said liquid port integrated and accommodated in said first integrated connection in said internal volume and/or wherein the length of said first integrated connection is longer in said internal volume than said second integrated connection.

13. Domestic and/or industrial hot water system comprising the sensible heat storage apparatus according to any of the previous claims.

14. Method for operating the sensible heat storage apparatus according to any of the claims 1-12 for storing heat, said method comprising a storage stage wherein the fluid maintains a storage temperature set by an optional charging stage comprising providing heat to the fluid and/or providing hot fluid, said method further comprising an optional discharging stage wherein hot fluid is obtained from said internal volume.

15. Method according to the previous claim, wherein the storage temperature is between 0 and 200 °C, preferably between 40 and 130 °C, more preferably between 50 and 95 °C.

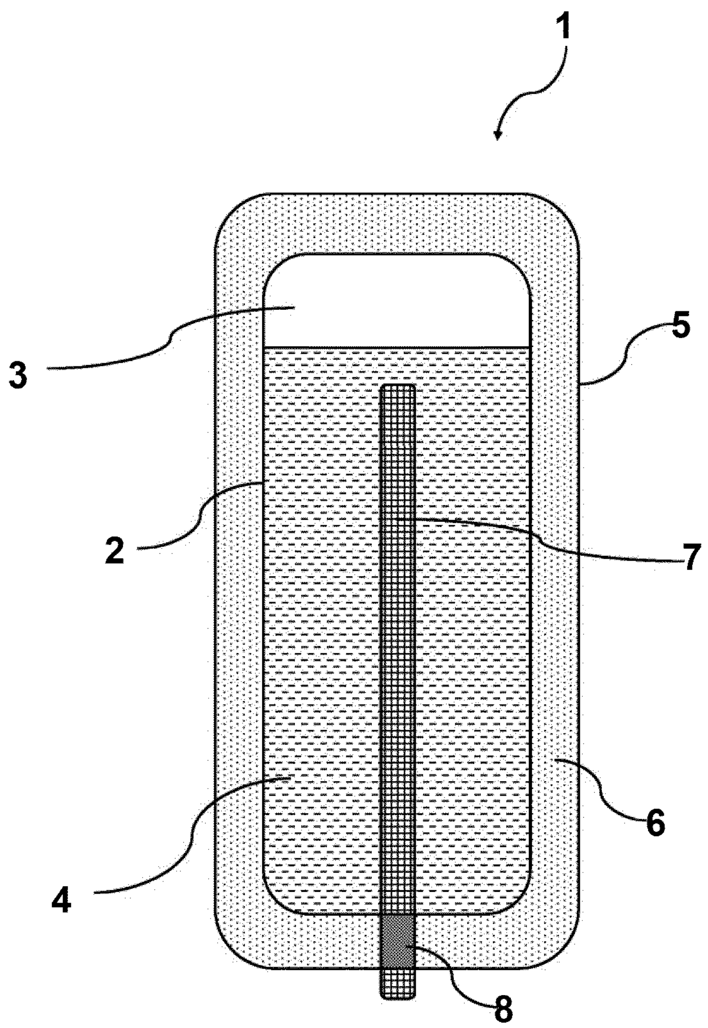


FIG. 1

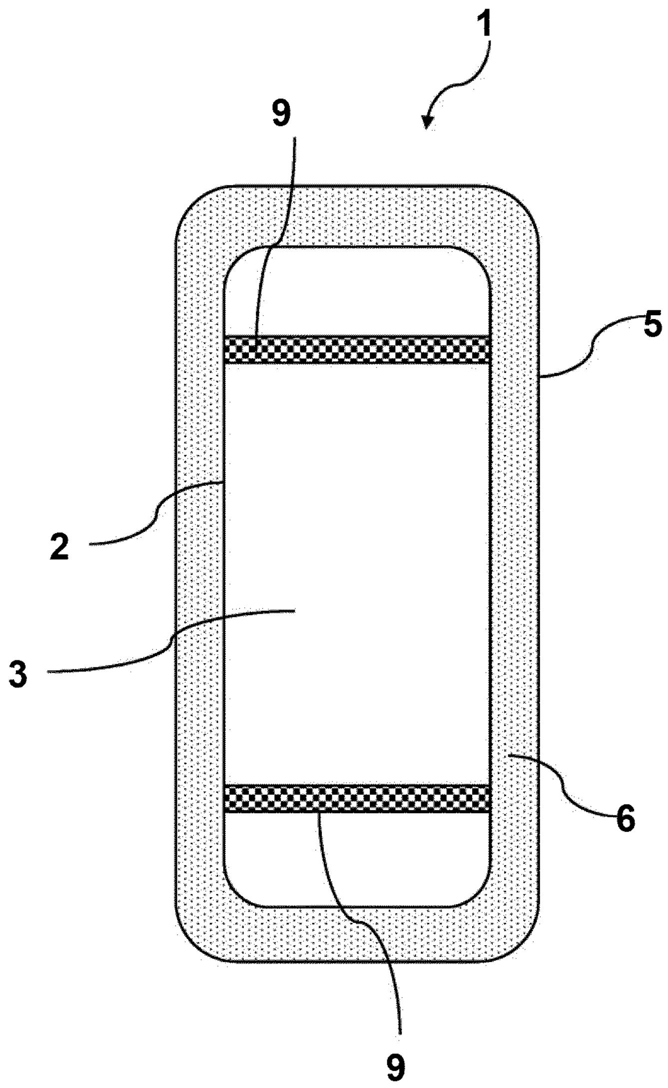


FIG. 2

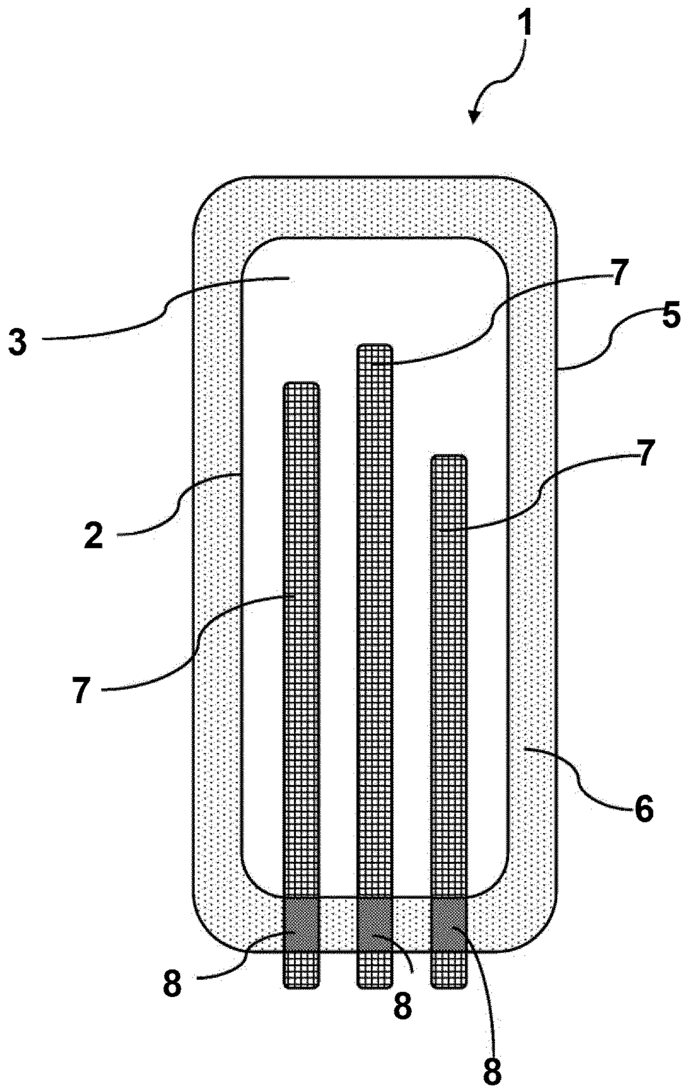


FIG. 3

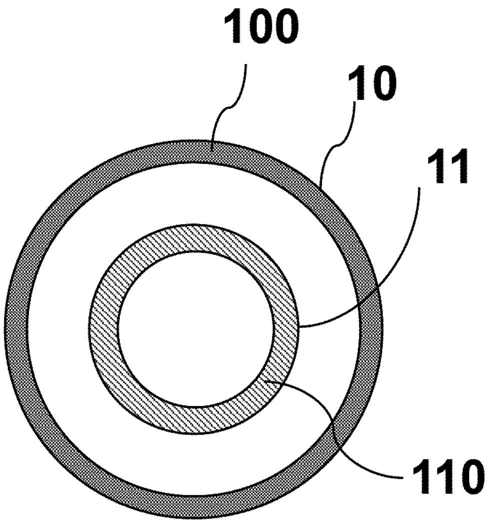


FIG. 4A

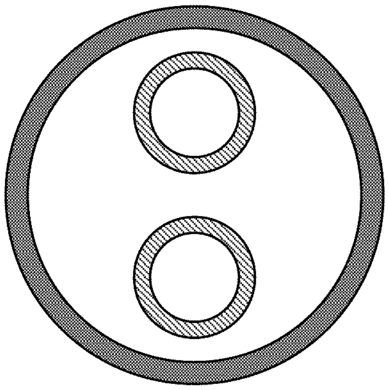


FIG. 4B

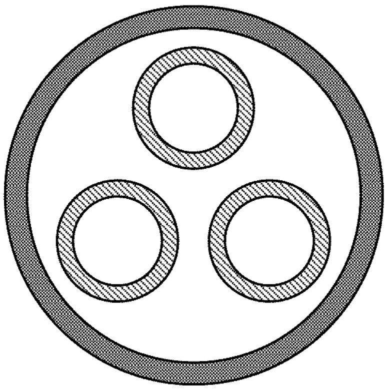


FIG. 4C

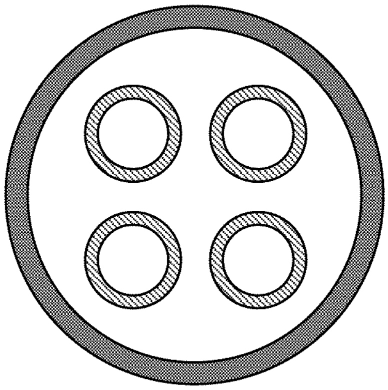


FIG. 4D

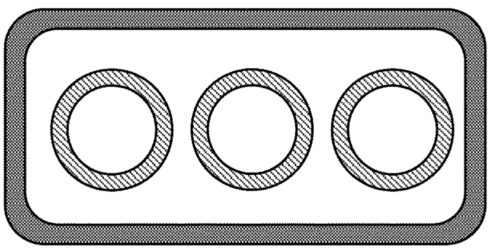


FIG. 4E

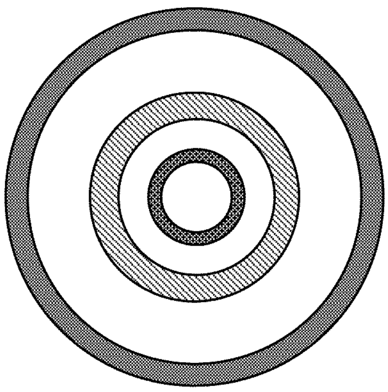


FIG. 4F

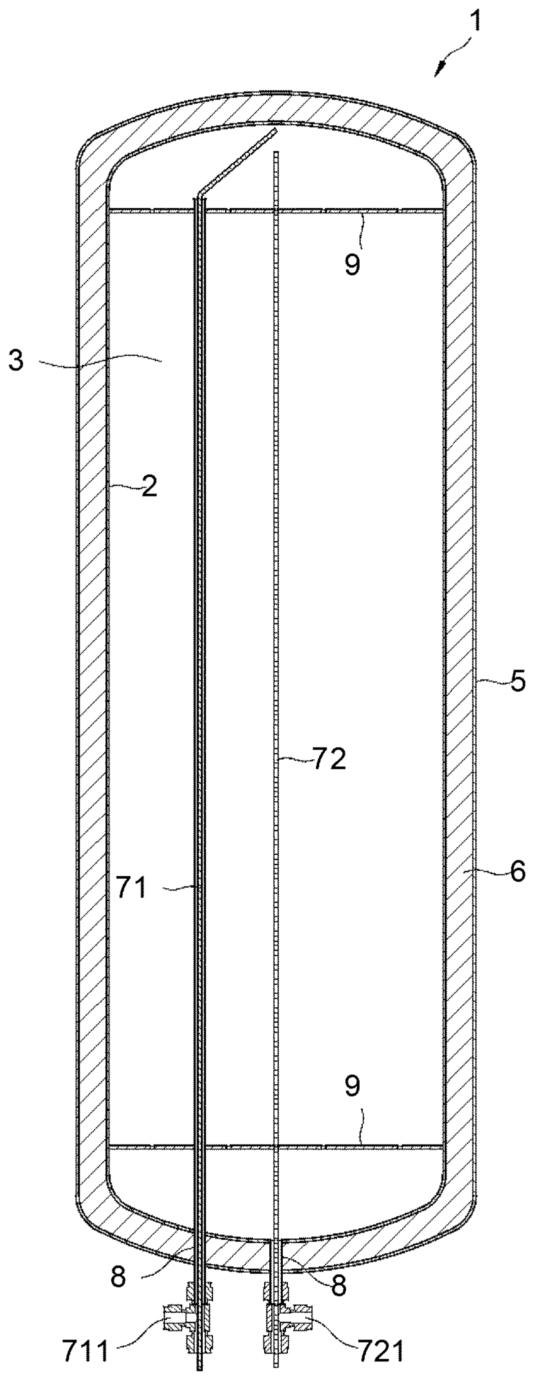
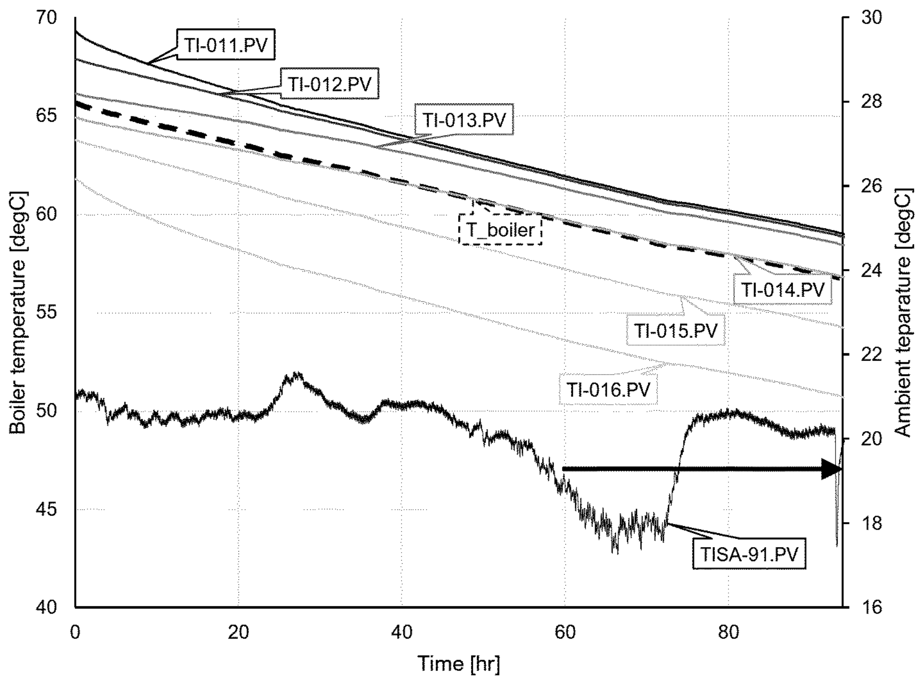


FIG. 5



70
65
60
55
50
45
40
30
28
26
24
22
20
18
16
0
20
40
60
80
Time [hr]
Boiler temperature [degC]
Ambient teparature [degC]
TI-011.PV
TI-012.PV
TI-013.PV
T_boiler
TI-014.PV
TI-015.PV
TI-016.PV
TISA-91.PV

FIG. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 21 16 8624

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	28 September 2021	Jessen, Flemming

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