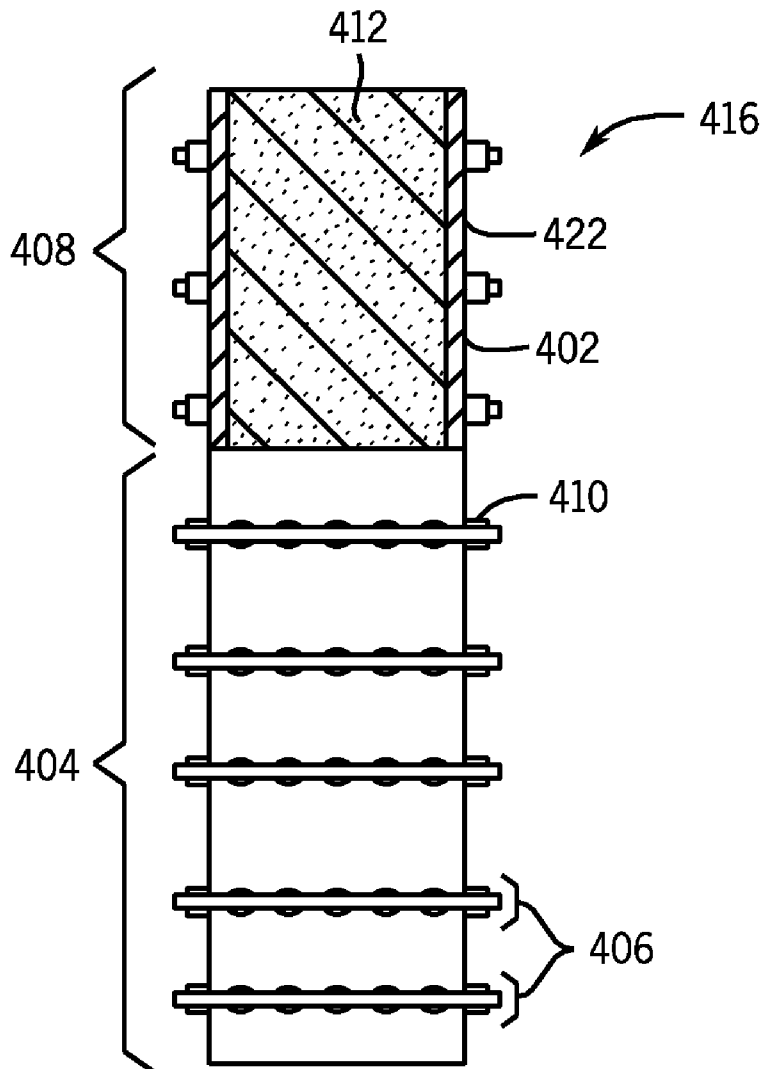




US 20110100583A1

(19) **United States**(12) **Patent Application Publication**
Freund et al.(10) **Pub. No.: US 2011/0100583 A1**(43) **Pub. Date: May 5, 2011**(54) **REINFORCED THERMAL ENERGY
STORAGE PRESSURE VESSEL FOR AN
ADIABATIC COMPRESSED AIR ENERGY
STORAGE SYSTEM****Publication Classification**(51) **Int. Cl.**
F28D 17/02 (2006.01)
B21D 53/02 (2006.01)
(52) **U.S. Cl.** **165/10**; 29/890.03; 29/890.034;
29/897.34(76) **Inventors:** **Sebastian W. Freund**, Unterföhring
(DE); **Matthias Finkenrath**,
Garching b. München (DE);
Cristina Botero, Cambridge, MA
(US); **Clarissa S.K. Belloni**,
Oxford (GB); **Miguel Angel**
Gonzalez Salazar, München (DE);
Stephanie Marie-Noelle
Hoffmann, München (DE)(57) **ABSTRACT**

A thermal energy storage system comprises a pressure vessel configured to withstand a first pressure, wherein the pressure vessel has a wall comprising an outer surface and an inner surface surrounding an interior volume of the pressure vessel. The interior volume of the pressure vessel has a first end in fluid communication with one or more compressors and one or more turbines, and a second end in fluid communication with at least one compressed air storage component. A thermal storage medium is positioned in the interior volume, and at least one reinforcement structure is affixed to the outer surface of the wall, wherein the at least one reinforcement structure configured to reinforce the wall to withstand a second pressure greater than the first pressure.

(21) **Appl. No.:** **12/608,087**(22) **Filed:** **Oct. 29, 2009**

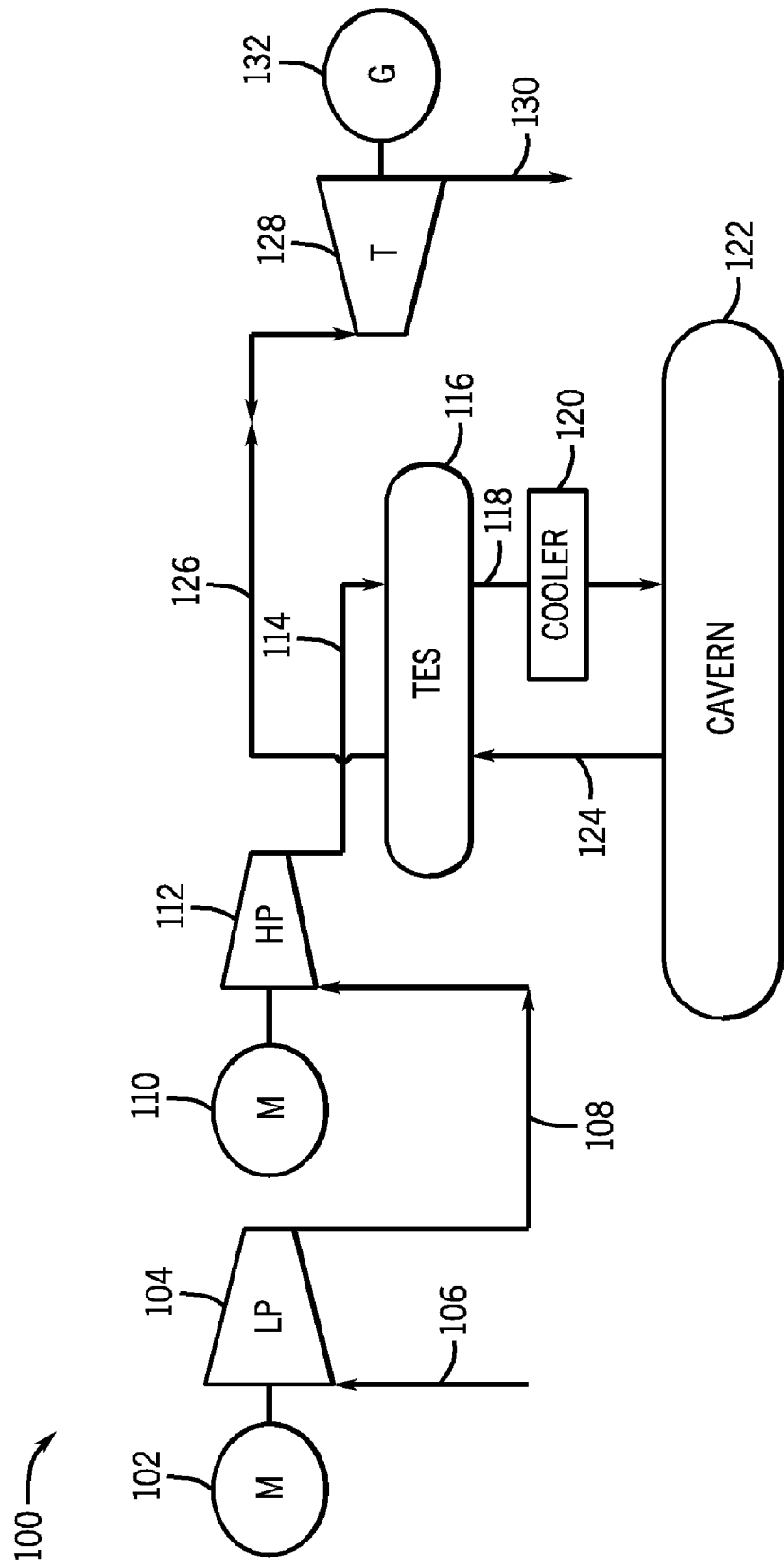
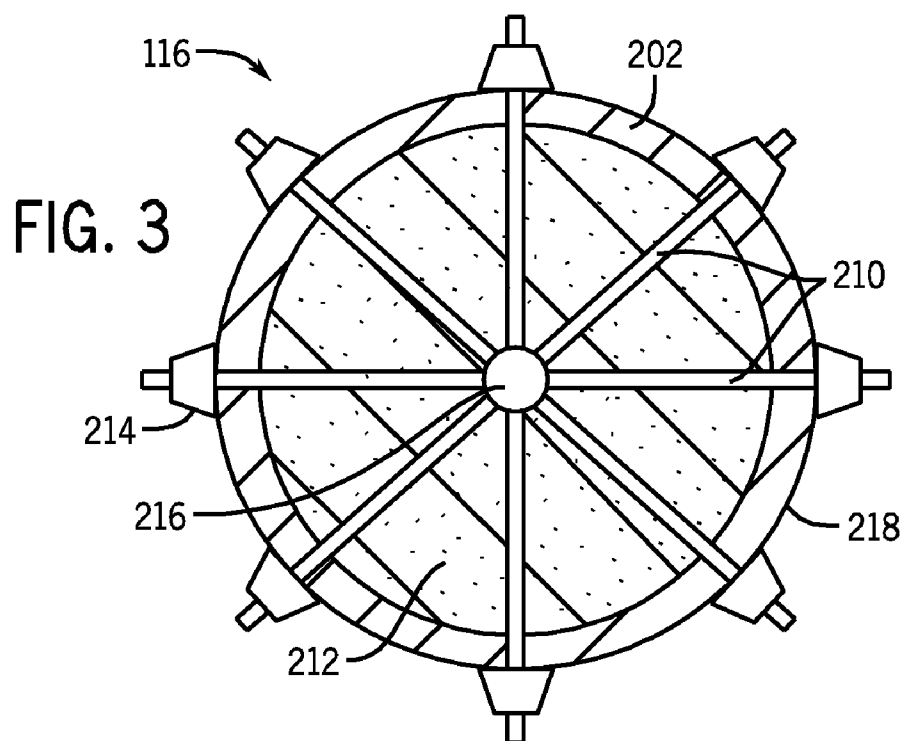
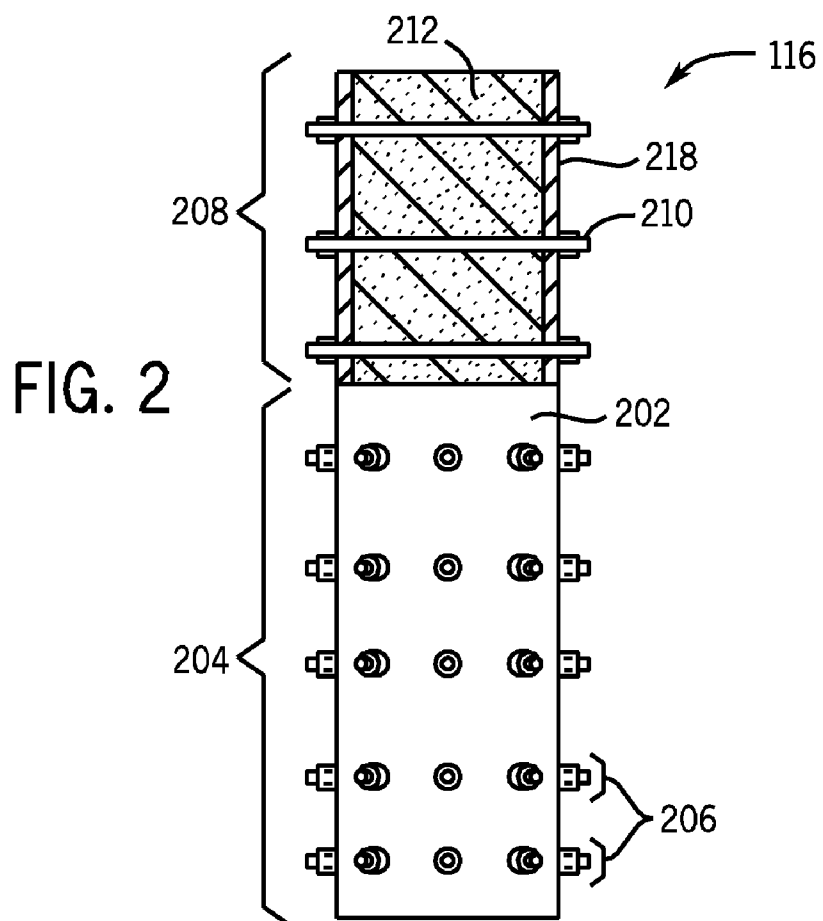
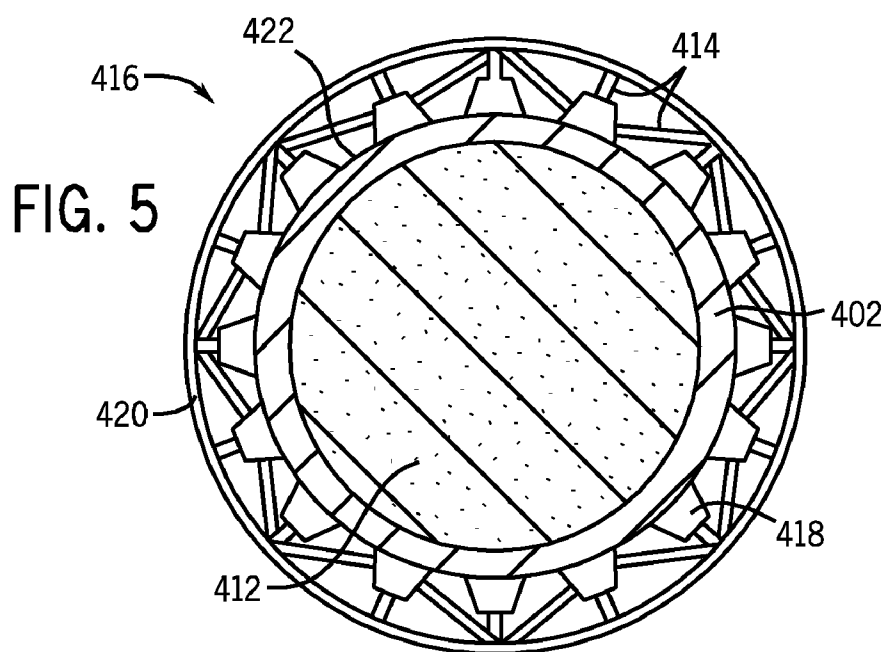
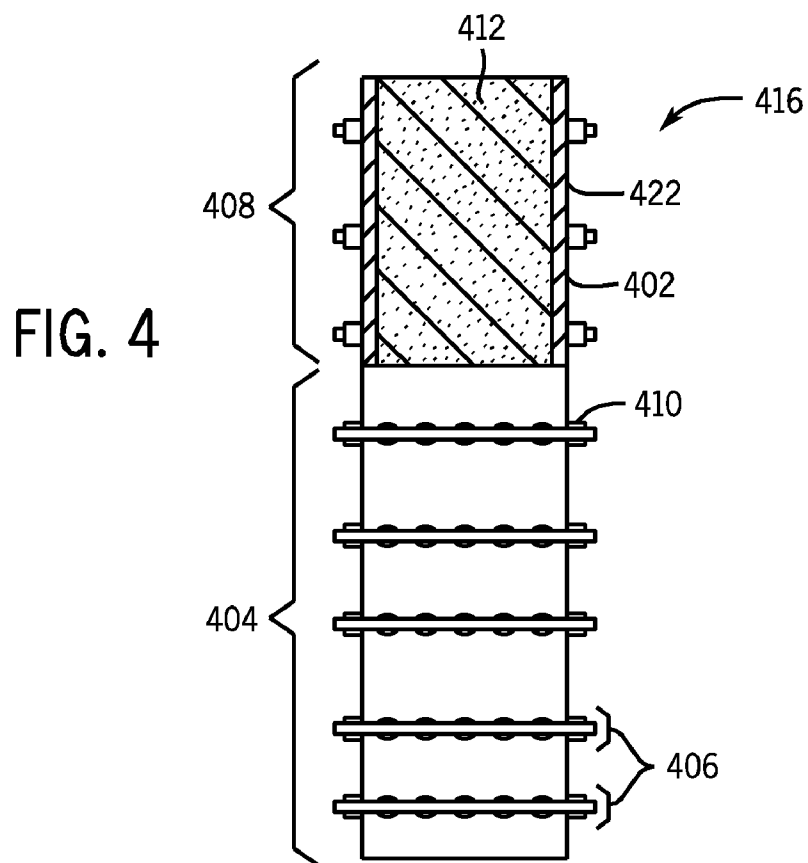


FIG. 1





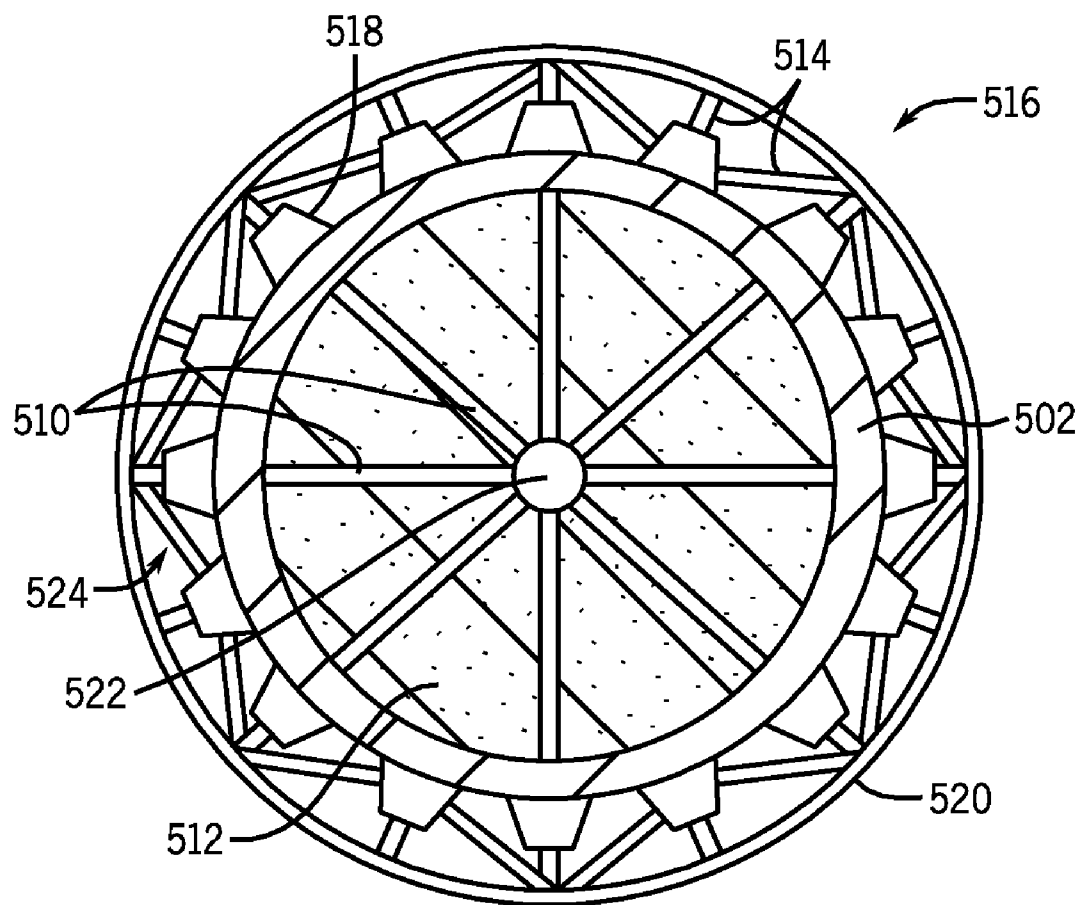


FIG. 6

**REINFORCED THERMAL ENERGY
STORAGE PRESSURE VESSEL FOR AN
ADIABATIC COMPRESSED AIR ENERGY
STORAGE SYSTEM**

BACKGROUND OF THE INVENTION

[0001] Embodiments of the invention relate generally to compressed air energy storage (CAES) systems and, more particularly, to thermal energy storage (TES) pressure vessels in an adiabatic CAES system.

[0002] CAES systems allow the generation of electricity without producing substantial emissions and/or consuming vast quantities of natural resources. CAES systems typically include a compression train having one or more compressors. The one or more compressors compress intake air in a compression stage for storage in a cavern, porous rock formation, depleted natural gas/oil field, or other compressed air storage component. The compressed air is then later used to drive turbines to produce electrical energy in an energy generation stage, which can in turn be provided to the utility grid. Often, if utility energy is used to power the compression train during the compression stage, the compression train operates during the off-peak hours of utility plants. The energy generation stage of the CAES in turn typically operates during high energy demand times. Alternatively, energy from renewable sources, such as energy from wind mills or solar panel arrays, may be used to power the compression train during the compression stage to compress and deliver air to the compressed air storage location (e.g., a cavern). In this way, the compression train may be operated during times other than off-peak hours, and existing utility energy may be preserved.

[0003] One type of CAES system is known as a diabatic-CAES system. In a diabatic-CAES system, heat generated by the compression train is typically lost to the ambient environment. That is, the heat of compression may be largely present when entering the cavern or other compressed air storage component, but its energetic value and availability is diminished as the compressed air mixes with the cavern air and further cools to ambient temperature during storage. Thus, when the compressed air stored in the cavern or compressed air storage component is to be used to drive one or more turbines to produce electrical energy, the compressed air is typically reheated prior to entering the turbines. This reheating step is typically performed using a natural gas-fired recuperator positioned between the compressed air storage component and the one or more turbines. Due to this reheating step, the overall efficiency of the diabatic-CAES system is reduced, and the use of natural gas to fuel the recuperator leads to carbon emissions and natural resource consumption.

[0004] Adiabatic-CAES, or ACAES, systems are capable of improving system efficiency by capturing and storing the heat of compression for later use. In such a system, one or more thermal energy storage (TES) units are positioned between the compressor and the cavern. Typically, a TES unit contains therein a medium for heat storage, such as concrete, stone, a fluid (e.g., oil), a molten salt, or a phase-change material. Hot air from the compression stage is passed through the TES unit, thereby transferring its heat of compression to the medium in the process. Thus, unlike diabatic-CAES systems, ACAES systems do not lose all of the heat generated by the compression train, but instead store some of the heat within the TES unit or units. The compressed air then enters the cavern at or near ambient temperature.

[0005] When the compressed air stored within the cavern or other compressed air storage unit is to be withdrawn to drive the one or more turbines to produce electrical energy, the compressed air passes back through the TES unit, thereby reheating the compressed air prior to entry into the turbine or turbines. In this way, ACAES systems do not necessitate additional natural gas-fired recuperation to reheat the compressed air exiting the cavern or other compressed air storage component. Thus, ACAES systems provide improved efficiency over diabatic-CAES systems, with fewer (if any) carbon emissions and little to no natural resource consumption.

[0006] TES units built to effectively store heat generated during the compression cycle of the compression train are constructed to withstand the high heat fluctuations and high pressure associated with ACAES systems. For example, the compressed air temperature exiting the compression train may vary from 250° C. to 750° C., while the temperature of the compressed air entering the TES unit from the cavern is at or near ambient temperature. Likewise, the TES units are designed to withstand pressures of 65-85 bar. To withstand such high temperatures and pressures, current proposals for TES units involve the construction of large concrete cylinders filled with a medium for heat storage. Due to their large diameter, these TES units are formed having thick, pre-stressed and steel-reinforced concrete walls, which enable the TES unit to withstand the high tension forces in the wall created by the pressure therein. However, construction of such thick concrete walls leads to substantial engineering difficulties and high costs, thereby reducing the feasibility of implementing an ACAES system as opposed to a less efficient diabatic-CAES system. Furthermore, high operating temperatures and temperature cycles induce damaging thermal stresses into the concrete walls, and these stresses are amplified as the concrete walls grow thicker.

[0007] Therefore, it would be desirable to design an apparatus and method that overcomes the aforementioned drawbacks related to TES unit construction.

BRIEF DESCRIPTION OF THE INVENTION

[0008] Aspects of the invention provide a system and method for a TES unit having at least one reinforced structure affixed thereto to allow the TES unit to withstand both high pressures and high temperatures. The at least one reinforced structure enables the wall of the TES unit to have a minimal thickness.

[0009] In accordance with one aspect of the invention, a thermal energy storage system is disclosed, the thermal energy storage system comprising a pressure vessel configured to withstand a first pressure, wherein the pressure vessel has a wall comprising an outer surface and an inner surface surrounding an interior volume of the pressure vessel. The interior volume of the pressure vessel has a first end in fluid communication with one or more compressors and one or more turbines, and a second end in fluid communication with at least one compressed air storage component. A thermal storage medium is positioned in the interior volume, and at least one reinforcement structure is affixed to the outer surface of the wall, wherein the at least one reinforcement structure configured to reinforce the wall to withstand a second pressure greater than the first pressure.

[0010] In accordance with another aspect of the invention, a method of forming a thermal energy storage pressure vessel is described. The method comprises forming a wall having a predetermined height and thickness, wherein an inner surface

of the wall bounds an interior volume therein. The method further comprises affixing a reinforcement structure to a surface of the wall at a first location, affixing at least one additional reinforcement structure to a surface of the wall at another location along the height of the wall, and disposing a porous thermal storage medium within the interior volume.

[0011] In accordance with yet another aspect of the invention, a thermal energy storage pressure vessel is disclosed, the thermal energy storage pressure vessel comprising a concrete cylindrical wall bounding an interior volume, wherein the interior volume is configured to allow air passage there-through, and at least one reinforcing structure affixed to an outer surface of the concrete cylindrical wall. The thermal energy storage pressure vessel further comprises a porous thermal matrix material disposed within the interior volume of the concrete cylindrical wall, wherein the porous thermal matrix material is configured to allow air passage there-through.

[0012] Various other features and advantages will be made apparent from the following detailed description and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The drawings illustrate preferred embodiments presently contemplated for carrying out the invention.

[0014] In the drawings:

[0015] FIG. 1 is a schematic arrangement of an ACAES system according to an embodiment of the present invention.

[0016] FIG. 2 is a side view of a TES unit in accordance with an embodiment of the present invention.

[0017] FIG. 3 is a cross-sectional view of the TES unit of FIG. 2 in accordance with an embodiment of the present invention.

[0018] FIG. 4 is a side view of a TES unit in accordance with another embodiment of the present invention.

[0019] FIG. 5 is a cross-sectional view of the TES unit of FIG. 4 in accordance with another embodiment of the present invention.

[0020] FIG. 6 is a cross-sectional view of a TES unit in accordance with yet another embodiment of the present invention.

DETAILED DESCRIPTION

[0021] According to embodiments of the invention, a system is provided that comprises a TES unit having at least one reinforced structure affixed thereto to allow the TES unit to withstand high pressure and temperature fluctuations.

[0022] First, referring to FIG. 1, a schematic arrangement of the primary elements of a conventional ACAES system is shown. ACAES system 100 comprises an electric motor 102 coupled to a low-pressure compressor 104. Electric motor 102 may be electrically powered via conventional means, i.e., the utility grid, during off-peak utility hours. Alternatively, electric motor 102 may be powered by electricity provided via wind farms, solar arrays, or other renewable sources. Electric motor 102 powers low-pressure compressor 104 such that low-pressure compressor 104 pressurizes intake air 106. Pressurized air 108 from low-pressure compressor 104 is then provided to a high-pressure compressor 112 to enable the air to undergo further compression. Similar to low-pressure compressor 104, high-pressure compressor 112 is powered by an electric motor 110. Electric motor 110 may also be powered by the utility grid or by renewable sources such as

wind farms and solar arrays. While ACAES system 100 shows the use of two compressors in a "compression train", it is to be understood that more or fewer compressors could be used.

[0023] As the air passes through respective low-pressure compressor 104 and high-pressure compressor 112, the air is pressurized to a level of 65-85 bar and subsequently heated to a temperature of up to 650° C. This pressurized, heated air 114 then enters a thermal energy storage (TES) unit 116. TES unit 116 typically includes a porous thermal storage medium disposed therein, the porous thermal storage medium capable of retaining a substantial amount of the heat emitted by air 114 as it passes through TES unit 116. The porous thermal storage medium may be a variety of solid materials, such as natural stone, ceramics, concrete, cast iron, or a combination of ceramics and salt. Alternatively, the porous thermal storage medium may be a liquid material, such as a combination of nitrate salt and mineral oil.

[0024] After heated air 114 passes through TES unit 116, compressed air 118 exits TES unit 116 at a lowered temperature to enable compressed air 118 to be stored in a cavern 122 or other compressed air storage component. Prior to entering cavern 122, though, compressed air 118 may need to be further cooled by an optional intercooler 120 such that compressed air 118 enters cavern 122 at a maximum temperature of approximately 50° C., for example. Cavern 122 enables air pressurized to a level of about 60-80 bar to be stored for an extended period of time without significant compression losses.

[0025] Referring still to FIG. 1, compressed air 124 may be discharged from cavern 122 when use of the stored air is desired for the generation of electricity. Compressed air 124 exits cavern 122 and re-enters TES unit 116 at a temperature of approximately 20-50° C. As the compressed air passes through the porous thermal storage medium of TES unit 116, it is reheated to a temperature of up to 600° C., a temperature near that of heated air 114 previously discharged from high-pressure compressor 112. This reheated compressed air 126, which at this stage is pressurized to a level of about 55-75 bars, then enters a steam turbine 128, which is powered by reheated compressed air 126. Unlike diabatic-CAES systems, compressed air 126 has been reheated within TES unit 116, and thus there is no need for additional heat recuperation or gas firing at the steam turbine to reheat the compressed air. As steam turbine 128 operates, exhaust air 130 is discharged therefrom, and steam turbine 128 powers an electrical generator 132. Electrical energy generated by generator 132 may then be provided to the utility grid for consumption. As can readily be appreciated, ACAES system 100 represents a method of generating electricity that can greatly reduce, if not eliminate, natural resource consumption and/or carbon emissions in the production of electrical energy.

[0026] As discussed above with respect to FIG. 1, TES unit 116 may be subjected to significant pressures (65-85 bar) and temperatures (up to 650° C.) during operation of ACAES system 100. As a result, TES unit 116 is constructed to withstand such high pressure and temperature levels. Referring to FIGS. 2 and 3, TES unit 116 according to an embodiment of the invention is shown. FIG. 2 illustrates a side view of TES unit 116. TES unit 116 is illustrated as a cylindrical pressure vessel having a wall 202 of a predetermined length and thickness. TES unit 116, however, is not limited to cylindrical shapes, and may be of any suitable shape. Wall 202 is generally formed of concrete, but may be constructed using any

material of suitable strength and rigidity, such as steel. Cross section 204 of TES unit 116 further shows that a plurality of reinforcement structures 206 are affixed to an outer surface 218 of wall 202 along a length of TES unit 116. While a plurality of reinforcement structures 206 is shown, it is to be understood that embodiments of the invention are not limited to the number and placement of the reinforcement structures 206 shown.

[0027] FIG. 2 further shows a cut-away cross section 208 of TES unit 116. As can be seen by cut-away cross section 208, each reinforcement structure 206 comprises at least one rod 210 passing entirely through an interior volume 212 and wall 202. Interior volume 212 contains therein a porous thermal storage medium, such as natural stone or a ceramic material, which is designed to absorb and retain heat from the compressed air passing through TES unit 116, as described above. Each rod 210 is affixed to an outer surface of wall 202, thereby providing structural reinforcement within TES unit 116.

[0028] Referring now to FIG. 3, a cross-sectional view of TES unit 116 according to an embodiment of the invention is shown. As can be seen in FIG. 3, a plurality of rods 210 are configured to pass through both wall 202 and interior volume 212, forming a spoke-shaped framework within interior volume 212. Rods 210 are preferably made of steel, but may be made of any suitable material capable of withstanding high pressures and temperatures. Rods 210 are fixedly attached to the outer surface 218 of wall 202 by anchors 214. Anchors 214 may be affixed to the outer surface 218 of wall 202 by any appropriate means, e.g., through bolting or welding. Rods 210 are also coupled at a common centerpoint hub 216 located within interior volume 212. Preferably, rods 210 are of a sufficient length to pass entirely through wall 202 on opposite sides thereof and through interior volume 212 and centerpoint hub 216 to be affixed to two opposing anchors 214. For example, as shown in FIG. 3, a reinforcement structure 206 has four rods 210 interconnected by centerpoint hub 216. Each rod 210 is attached to outer surface 218 of wall 202 via a pair of respective anchors 214 attached to opposite sides of wall 202.

[0029] According to another embodiment, rather than extending entirely through wall 202 and interior volume 212 as a single rod, rods 210 may be configured to pass through wall 202 and extend toward centerpoint hub 216. In this manner, one end of each rod 210 is retained by a respective anchor 214, while the other end is retained by or coupled to centerpoint hub 216.

[0030] It is to be understood that the configuration shown in FIG. 3 is merely exemplary and that while four or eight rods 210 are shown as described above, embodiments of the invention include using more or fewer rods 210 and anchors 214 in each reinforcement structure 206.

[0031] By reinforcing TES unit 116 in the fashion shown by FIGS. 2 and 3, wall stresses caused by high air pressure within wall 202 can be substantially relieved. As a result, wall 202 can be constructed with a reduced overall thickness, as reinforcement structures 206 act to relieve stress on wall 202 that was previously addressed through increased wall thickness. With such reduced wall thickness, TES unit 116 will also not be subject to the substantial thermal stresses present in pressure vessels having thick walls. Furthermore, TES unit 116 is easier and less expensive to both construct and transport over conventional TES units. As such, embodiments of the invention allow for construction and adoption of ACAES systems as viable alternatives for producing electrical energy.

[0032] Referring now to FIGS. 4 and 5, another embodiment of the present invention is shown. FIG. 4 illustrates a side view of a TES unit 416 comprising a wall 402 having a predetermined length and thickness. While TES unit 416 is shown to be cylindrical, it is not limited as such, and may be of any suitable shape. Wall 402 is generally formed of concrete, but may be constructed using any material of suitable strength and rigidity, such as steel. Cross section 404 of TES unit 416 shows a plurality of reinforcement structures 406 affixed about an outer surface of wall 402 along a length of TES unit 416. While FIG. 4 shows a plurality of reinforcement structures 406 affixed along TES unit 416, the number and placement of reinforcement structures 406 is not limited to that shown, as it is possible one or more reinforcement structures 406 affixed to wall 402 according to embodiments of the present invention.

[0033] FIG. 4 further shows a cut-away cross section 408 of TES unit 416. Unlike reinforcement structures 206 described above with respect to FIG. 2, reinforcement structures 406 do not pass through an interior volume 412 of TES unit 416. Instead, reinforcement structures 406 comprise a trussed framework 410 that is affixed along an exterior surface 422 of wall 402. As such, each trussed framework 410 provides structural reinforcement along exterior surface 422 of wall 402 of TES unit 416. Interior volume 412, like interior volume 212 described above with respect to FIGS. 2 and 3, contains a porous thermal storage medium therein, which is designed to retain heat from the compressed air passing through TES unit 416.

[0034] FIG. 5 illustrates a cross-sectional view of TES unit 416. As can be seen in FIG. 5, trussed framework 410 comprises a plurality of rods 414 affixed to a plurality of anchors 418, the plurality of rods 414 being further affixed to and bounded by a rim 420. Anchors 418 may be affixed to wall 402 through any known means, such as by bolt or by weld. Rods 414 and rim 420 may be made of steel, but are not limited as such, and may be made of any suitable material. Rods 414 are arranged between anchors 418 and rim 420 to form the trussed framework about the external surface of wall 402. It is to be appreciated that the precise number of rods 414 and anchors 418 used is not imperative to the invention, but the number of rods 414 and anchors 418 utilized should be of an amount sufficient to allow the trussed framework to pressurize wall 402.

[0035] Using the trussed framework 410 as described above with respect to the embodiment shown in FIGS. 4 and 5, wall stresses caused by high air pressure within wall 402 can be substantially relieved, thereby allowing wall 402 to have a thickness substantially less than that of conventional TES units. Reduced wall thickness acts to mitigate the substantial thermal stresses present in pressure vessels, thermal stresses that become more prevalent as the walls become thicker. As an additional benefit, TES unit 416 may be both easier and less expensive to construct and transport than conventional TES units.

[0036] Next, FIG. 6 illustrates yet another embodiment of the present invention. FIG. 6 is a cross-sectional view of TES unit 516, which combines the concepts of the spoke-shaped reinforcement structure of TES unit 116 shown in FIGS. 2, 3 with the external trussed framework of TES unit 416 shown in FIGS. 4, 5. In particular, TES unit 516 comprises a plurality of rods 510 configured to pass through both a wall 502 and an interior volume 512, forming a spoke-shaped framework within interior volume 512. Rods 510 are fixedly attached to

the outer surface of wall **502** by anchors **518** and are coupled at a common centerpoint hub **522** located within interior volume **512**. TES unit **516** further includes a trussed framework **524** disposed about an outside surface of wall **502**. The trussed framework **524** comprises a plurality of rods **514** affixed to the anchors **518**, the plurality of rods **414** being further affixed to and bounded by a rim **520**. Rods **514** are arranged between anchors **518** and rim **520** to form the trussed framework about the outside surface of wall **502**.

[0037] As can be readily appreciated, the combination of the spoke-shaped reinforcement structure and the external trussed framework shown in FIG. 6 provides wall **502** with substantial protection from pressure-related stresses using walls that are thinner than walls of conventional TES units. Accordingly, TES unit **516**, like TES unit **116** and TES unit **416** described above, can be constructed to have thinner walls than conventional TES units, thereby reducing the cost and complexity of constructing the TES unit, and further reducing the likelihood of thermal stresses being suffered throughout regular operation of the ACAES system.

[0038] Therefore, according to one embodiment of the invention, a thermal energy storage system is disclosed, the thermal energy storage system comprising a pressure vessel configured to withstand a first pressure, wherein the pressure vessel has a wall comprising an outer surface and an inner surface surrounding an interior volume of the pressure vessel. The interior volume of the pressure vessel has a first end in fluid communication with one or more compressors and one or more turbines, and a second end in fluid communication with at least one compressed air storage component. A thermal storage medium is positioned in the interior volume, and at least one reinforcement structure is affixed to the outer surface of the wall, wherein the at least one reinforcement structure configured to reinforce the wall to withstand a second pressure greater than the first pressure.

[0039] According to another embodiment of the invention, a method of forming a thermal energy storage pressure vessel is described. The method comprises forming a wall having a predetermined height and thickness, wherein an inner surface of the wall bounds an interior volume therein. The method further comprises affixing a reinforcement structure to a surface of the wall at a first location, affixing at least one additional reinforcement structure to a surface of the wall at another location along the height of the wall, and disposing a porous thermal storage medium within the interior volume.

[0040] According to yet another embodiment of the invention, a thermal energy storage pressure vessel is disclosed, the thermal energy storage pressure vessel comprising a concrete cylindrical wall bounding an interior volume, wherein the interior volume is configured to allow air passage there-through, and at least one reinforcing structure affixed to an outer surface of the concrete cylindrical wall. The thermal energy storage pressure vessel further comprises a porous thermal matrix material disposed within the interior volume of the concrete cylindrical wall, wherein the porous thermal matrix material is configured to allow air passage there-through.

[0041] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are

intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. A thermal energy storage system comprising:
 - a pressure vessel configured to withstand a first pressure, the pressure vessel having a wall comprising:
 - an outer surface; and
 - an inner surface surrounding an interior volume of the pressure vessel, the interior volume having:
 - a first end in fluid communication with one or more compressors and one or more turbines; and
 - a second end in fluid communication with at least one compressed air storage component;
 - a thermal storage medium positioned in the interior volume; and
 - at least one reinforcement structure affixed to the outer surface of the wall; the at least one reinforcement structure configured to reinforce the wall to withstand a second pressure greater than the first pressure.
2. The thermal energy storage system of claim 1 wherein the at least one reinforcement structure comprises a plurality of steel rods interconnected to form a trussed framework about the outer surface of the wall.
3. The thermal energy storage system of claim 2 further comprising a steel rim disposed about an outer circumference of the trussed framework.
4. The thermal energy storage system of claim 1 wherein the at least one reinforcement structure extends into the interior volume of the pressure vessel.
5. The thermal energy storage system of claim 4 wherein the at least one reinforcement structure comprises a plurality of steel rods forming a spoke-shaped framework within the interior volume of the pressure vessel.
6. The thermal energy storage system of claim 1 wherein the at least one reinforcement structure comprises:
 - a plurality of first rods interconnected between a plurality of wall-mounted anchors and a circumferential rim to form a trussed framework about the outer surface of the wall; and
 - a plurality of second rods forming a spoke-shaped framework within the interior volume of the pressure vessel.
7. The thermal energy storage system of claim 1 wherein the at least one reinforcement structure comprises a plurality of reinforcement structures disposed along a length of the pressure vessel.
8. The thermal energy storage system of claim 1 wherein the wall of the pressure vessel is formed of concrete.
9. The thermal energy storage system of claim 1 wherein the thermal storage medium is a porous thermal storage medium disposed within the interior volume of the pressure vessel.
10. The thermal energy storage system of claim 9 wherein the porous thermal storage medium comprises at least one of natural stone, ceramic, concrete, cast iron, nitrate salt, and mineral oil.
11. The thermal energy storage system of claim 1 wherein the pressure vessel is cylindrical in shape.
12. A method of forming a thermal energy storage pressure vessel, the method comprising:

forming a wall having a predetermined height and thickness, wherein an inner surface of the wall bounds an interior volume therein;

affixing a reinforcement structure to a surface of the wall at a first location;

affixing at least one additional reinforcement structure to a surface of the wall at another location along the height of the wall; and

disposing a porous thermal storage medium within the interior volume.

13. The method of claim **12** wherein the affixing of a reinforcement structure to the surface of the wall comprises: affixing a plurality of anchors to an outside surface of the wall; attaching a plurality of rods to the anchors at a first end of the rods; and attaching the plurality of rods to a rim at a second end of the rods such that the plurality of anchors, the plurality of rods, and the rim form a trussed framework about an outside surface of the wall.

14. The method of claim **12** wherein affixing the reinforcement structure to the surface of the wall comprises: affixing a plurality of anchors to an outside surface of the wall; and affixing a plurality of rods to the plurality of anchors, the plurality of rods passing through the wall to form a spoke-shaped framework within the interior volume of the wall.

15. The method of claim **12** wherein affixing the reinforcement structure to the surface of the wall comprises: affixing a plurality of anchors to an outside surface of the wall; attaching a plurality of first rods to the anchors at a first end of the first rods; attaching the plurality of first rods to a rim at a second end of the first rods such that the plurality of anchors, plu-

rality of first rods, and the rim form a trussed framework about an outside surface of the wall; and

affixing a plurality of second rods to the plurality of anchors, the plurality of second rods passing through the wall to form a spoke-shaped framework within the interior volume of the wall.

16. A thermal energy storage pressure vessel comprising: a concrete cylindrical wall bounding an interior volume, wherein the interior volume is configured to allow air passage therethrough; at least one reinforcing structure affixed to an outer surface of the concrete cylindrical wall; and a porous thermal matrix material disposed within the interior volume of the concrete cylindrical wall, wherein the porous thermal matrix material is configured to allow air passage therethrough.

17. The thermal energy storage pressure vessel of claim **16** wherein the at least one reinforcing structure comprises a steel ring and a plurality of trusses interconnected to form a framework about the outer surface of the concrete cylindrical wall.

18. The thermal energy storage pressure vessel of claim **16** wherein the at least one reinforcing structure extends into the inner volume of the concrete cylindrical wall.

19. The thermal energy storage pressure vessel of claim **18** wherein the at least one reinforcing structure comprises a plurality of interconnected steel rods affixed at a common centerpoint within the inner volume of the concrete cylindrical wall.

20. The thermal energy storage pressure vessel of claim **16** wherein the at least one reinforcing structure is secured to the outer surface of the concrete cylindrical wall by a plurality of anchors.

* * * * *