

ENERGY STORAGE AND UTILISATION SYSTEM

Field of the Invention

[0001] The present invention relates to a system and a method for providing steam. In particular, the present invention relates to a steam delivery system comprising a thermal energy storage apparatus for heating a flow of feedwater to produce steam. However, it will be appreciated that the invention is not limited to these particular fields of use.

Background of the Invention

[0002] The following discussion of the prior art is provided to place the invention in an appropriate technical context and enable the advantages of it to be more fully understood. It should be appreciated, however, that any discussion of the prior art throughout the specification should not be considered as an express or implied admission that such prior art is widely known or forms part of the common general knowledge in the field.

[0003] Due to its many advantages including superior energy holding capacity, steam plays a vital role for various purposes in a huge number of processes across industries including pharmaceutical, food and beverage, textiles, pulp and paper, oil and petrochemicals, laundries, and public buildings. Particularly, steam has long been used to produce electrical power in thermal power stations.

[0004] Typically, steam is produced in steam boilers by heating water to and/or above its boiling point. Different energy sources may be used during this process, for example, combustible fuels (natural gas, coal, or oil) or electricity. The development of renewable energy technologies, for use in steam generation, has been of particular interest due to environmental concerns (such as reducing pollution and carbon dioxide emissions from coal and other fossil fuels). These renewable energy technologies include hydroelectric, wind, solar, tidal and geothermal heat.

[0005] A particular issue of energy production from renewable energy sources is that they are intermittent sources. For example, wind turbines require strong winds, solar power cannot be generated at night, hydro power generation is limited during drought, and wave power is limited according to weather and sea conditions. As such, renewable technologies ideally require a method of storing the energy for later use.

[0006] One such approach to storing energy is to use battery technology such as chemical batteries (e.g. lithium-ion batteries) so that when on-demand production of electricity from a renewable source is unavailable, the electricity demand can readily be met. However, battery

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technology can still be expensive for large-scale deployment and the energy capacity stored is limited and may not meet the energy demands when renewable energy production is delayed for long periods (such as when there are consecutive cloudy days for solar energy production, etc.). Further, batteries are not an ideal store of energy for thermal (e.g. steam generating) requirements.

[0007] As an alternative to battery technology, sensible heat storage mediums have been used to store thermal energy. For example, graphite energy storage mediums have been used to store electrical energy generated from sources such as renewables in the form of heat. A variant of the above approach is heating a body of graphite induced by eddy currents. The thermal energy stored in a block of graphite can then be recovered for later direct use and/or converted into electrical energy using a fluid such as water/steam.

[0008] The energy storage apparatus disclosed in PCT/AU2022/050031 describes a method of and an apparatus for reversibly storing and/or extracting heat energy in a body of graphite. The method comprises heating an inner region of a sensible heat storage body using a removable heating element to input the energy to be stored, and flowing a heat transfer medium having a temperature below that of said sensible heat storage body such that energy is transferred from the sensible heat storage body to the heat transfer medium to extract energy.

[0009] A thermal energy storage apparatus may be operating at different temperature reflecting different amount of energy stored therein. Furthermore, feedwater of different sources may have time-varying temperature and/or pressure and/or flowrate. These factors make it difficult to provide steam at a predetermined temperature and/or pressure, which is typically required in industry. Given the limitations, it may therefore be desirable to develop a steam delivery system and a method for providing steam at a predetermined temperature and/or pressure, which is capable of accommodating feedwater with time-varying temperature and/or pressure and/or flowrate and/or thermal energy storage apparatus operating with time-varying temperature.

[0010] It is an object of the present invention to overcome or ameliorate at least one of the disadvantages of the prior art, or to provide a useful alternative.

[0011] Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise”, “comprising”, and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in the sense of “including, but not limited to”.

[0012] Although the invention will be described with reference to specific examples it will be appreciated by those skilled in the art that the invention may be embodied in many other forms.

Summary of the Invention

[0013] According to a first aspect of the present invention there is provided a steam delivery system for providing industrial steam, the system comprising:

a feedwater control system for providing a flow of feedwater;

a thermal energy storage apparatus in fluid communication with the feedwater control system to heat the feedwater flowing through a conduit of the thermal energy storage apparatus to provide steam; and

a desuperheater in fluid communication with the thermal energy storage apparatus to receive the steam and regulate the steam temperature;

such that in use, the steam delivery system provides industrial steam having at least one of a predetermined temperature and a predetermined pressure.

[0014] Advantageously, the present inventors have developed a system and method as described herein for providing industrial steam at a predetermined temperature and/or a predetermined pressure, from a flow of feedwater having a variable temperature and/or a variable pressure and/or a variable flowrate. Furthermore, the system and method can advantageously accommodate a thermal energy storage apparatus operating at variable temperature (for example, the thermal energy storage apparatus may have a standby temperature and an operating temperature) and thereby producing steam of a variable temperature and/or a variable pressure. Yet further still, the system and method can advantageously adapt to a wide range of thermal energy storage apparatus.

Thermal energy storage apparatus

[0015] It will be appreciated by the skilled person that any thermal energy storage apparatus that is capable of transferring heat energy to a flow of feedwater will be suitable in the present invention. An example of the thermal energy storage apparatus is disclosed in PCT/AU2022/050031, which is incorporated by reference herein.

[0016] In preferred embodiments of the invention, the thermal energy storage apparatus comprises:

a sensible heat storage body having a heat exchanger channel and a heating element channel adapted to receive a removable heating element; and

a heat exchanger having an inlet and an outlet, wherein at least a portion of the heat exchanger is disposed along the channel.

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[0017] In a preferred embodiment of the invention, the sensible heat storage body is formed of graphite. In some embodiments of the invention, the graphite is crystalline, amorphous or a combination thereof. Graphite also has high thermal stability and electrical and thermal conductivity which makes it suitable for use as a refractory in high-temperature applications. In an embodiment of the invention, the graphite is used between ambient temperature up to 1000 °C and in preferred embodiments of the invention, the operational temperature is between about 120 to 800 °C.

[0018] In preferred embodiments of the invention, to provide the steam from the thermal energy storage apparatus, the feedwater flows through the heat exchanger to be heated by the sensible heat storage body having a higher temperature, when disposed along the heat exchanger channels. Heat exchangers of the present invention can take many shapes and sizes depending on the requirements for flowrate of the feedwater, the size, material and conductivity of the sensible heat storage body and the operational requirements at operating pressures and temperatures. For example, the heat exchanger can be in the shape of a serpentine coil or a helical coil. Heat transfer occurs primarily by conduction from the sensible energy storage body to feedwater via the heat exchanger. The temperature of provided steam at an outlet of the thermal energy storage apparatus depends on any number of factors, for example, relative temperature difference between the sensible storage energy body and the feedwater, the feedwater flow rate, and the feedwater initial temperature.

[0019] In certain embodiments of the invention, the heating element comprises an elongated heating portion at one end, a thermally insulated portion at an opposite end, and wherein the thermally insulated portion further comprises an electrical conductor adapted to be in electrical communication with an electrical terminal.

[0020] In certain embodiments of the invention, the heating portion of the heating element comprises a resistance wire selected from a material including but not limited to metallic alloys with high electrical resistivity and temperature resistance, surrounded by an electrical insulator and enclosed by a metal or alloy casing. In further embodiments of the invention, the heating element can be an electrical resistor. This is used to convert electrical energy to thermal energy to directly heat the sensible heat storage body, representing a direct conversion to and delivery of useful heat energy to the sensible heat storage body.

[0021] It will be appreciated by the skilled person that when the thermal energy storage apparatus experiences a “cold start” (e.g. from ambient temperature), the sensible heat storage

body needs to be heated using the heating element before sufficient energy is stored to convert the feedwater into steam. During this period of time, hot water may be produced instead of steam.

Sparge system

[0022] In preferred embodiments of the invention, the steam delivery system further comprises a sparge system in fluid communication with the desuperheater, such that the system operates in configurations comprising:

- a excess-steam configuration, wherein at least a portion of the steam provided by the desuperheater is redirected to the sparge system;

- a no-demand configuration, wherein all the steam provided by the desuperheater is redirected to the sparge system.

[0023] It would be appreciated by the skilled person that the steam demand can vary from time to time. Advantageously, the sparge system serves as a bypass system, such that when there is excess steam provided, the excess steam can be redirected to the sparge system, and when there is no steam demand, all the steam provided can bypass a steam user and be redirected to the sparge system. These preferred configurations ensure that the thermal energy storage apparatus does not need to be turned off to reduce the steam supply, as such, cold start can be avoided when the steam demand resumes. It will also be appreciated by a skilled addressee that in these embodiments, the thermal energy storage apparatus can have a standby temperature and an operating temperature.

[0024] In preferred embodiments of the invention, the sparge system comprises a sparger tank comprising:

- a volume of water;

- at least one nozzle for injecting the steam provided by the desuperheater into the water;

such that in use, the steam is condensed and the water is heated.

[0025] In an embodiment of the invention, at least a portion of water from the sparger tank is recycled to mix with the feedwater.

[0026] When the steam is injected into the water in the sparger tank, it puts the molecules of high-energy steam in direct contact with the water molecules. The energy is transferred from the hotter to the colder molecules and so the steam condenses, and the water warms up. Advantageously, the sparger tank functions as an energy sink and the warmed water can be recycled to mix with the feedwater to increase its initial temperature, such that less energy is required by the thermal energy storage apparatus to heat the feedwater.

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[0027] In an alternative embodiment of the invention, the water in the sparger tank is directed to a blowdown tank.

[0028] In an embodiment of the invention, at least a portion of the feedwater is directed to the sparger tank. Advantageously, when the water from the sparger tank is recycled, the feedwater is pre-heated.

Desuperheater

[0029] It will be appreciated by the skilled person that the steam provided may be superheated. For example, the saturated temperature for steam at a pressure of about 1500 kPaG is about 201°C, and the steam further heated to a higher temperature is superheated. This advantageously provides flexibility in the steam temperature provided to a user, because the steam may be superheated in a thermal energy storage apparatus to a higher temperature before being desuperheated in the desuperheater to a lower, predetermined temperature.

[0030] In an embodiment of the invention, the desuperheater comprises a section of uninsulated pipe, where heat is radiated to the environment and the temperature of the steam is reduced.

[0031] In preferred embodiments of the invention, an aerosol of cooling water is introduced into the desuperheater and mixed with the steam to reduce the temperature of the steam. Specifically, a flow of cooling water is injected into the desuperheater through at least one nozzle and is atomised into the steam, such that the steam temperature is reduced.

[0032] In an embodiment of the invention, the desuperheater comprises a heat exchanger. In a particular embodiment of the invention, the heat exchanger is a shell and tube type, tube-in-tube type or a plate type.

[0033] It will be appreciated by the skilled person that the shell and tube heat exchanger comprises a shell with a bundle of tubes therein. When steam runs through the tubes (or over the tubes through the shell), a cooling fluid with a lower temperature runs over the tubes through the shell (or through the tubes) to facilitate heat transfer between the steam and the cooling fluid. As such, the temperature of the superheated steam decreases, and the amount reduction depends on a number of factors including relative temperature difference between the steam and cooling fluid, heat exchanger design, the steam flowrate and the cooling liquid flowrate.

[0034] In an embodiment of the invention, the shell and tube heat exchanger has 1 pass. In other embodiments of the invention, the shell and tube heat exchanger has 2, 3, 4, 5 or 6 passes.

[0035] In an embodiment of the invention, a flow of cooling water is provided to the heat exchanger for reducing the temperature of the steam.

[0036] In an embodiment of the invention, the cooling water has a temperature of from about 5 °C to about 95 °C. For example, the temperature is between about 5 °C and about 10 °C, or about 10 °C and about 15 °C, or about 15 °C and about 20 °C, or about 20 °C and about 25 °C, or about 25 °C and about 30 °C, or about 30 °C and about 35 °C, or about 35 °C and about 40 °C, or about 40 °C and about 45 °C, or about 45 °C and about 50 °C, or about 50 °C and about 55 °C, or about 55 °C and about 60 °C, or about 60 °C and about 65 °C, or about 65 °C and about 70 °C, or about 70 °C and about 75 °C, or about 75 °C and about 80 °C, or about 80 °C and about 85 °C, or about 85 °C and about 95 °C, or about 85 °C and about 90 °C, or about 90 °C and about 95 °C. In some embodiments, the cooling water has a temperature of about 95 °C. Preferably, the cooling water has a temperature of about 85 °C.

[0037] In certain embodiments of the invention, the cooling water has a flowrate of from about 0.1 kg/h to about 500 kg/h. For example, the flowrate is between about 0.1 kg/h and 1 kg/h, or about 1 kg/h and about 5 kg/h, or about 5 kg/h and about 10 kg/h, or about 10 kg/h and about 15 kg/h, or about 15 kg/h and about 20 kg/h, or about 20 kg/h and about 30 kg/h, or about 30 kg/h and about 40 kg/h, or about 40 kg/h and about 50 kg/h, or about 50 kg/h and about 60 kg/h, or about 60 kg/h and about 70 kg/h, or about 70 kg/h and about 80 kg/h, or about 80 kg/h and about 90 kg/h, or about 90 kg/h and about 100 kg/h, or about 100 kg/h and about 150 kg/h, or about 150 kg/h and about 200 kg/h, or about 200 kg/h and about 250 kg/h, or about 250 kg/h and about 300 kg/h, or about 300 kg/h and about 350 kg/h, or about 350 kg/h and about 400 kg/h, or about 400 kg/h and about 450 kg/h, or about 450 kg/h and about 500 kg/h.

[0038] In preferred embodiments of the invention, the steam temperature is reduced to the predetermined temperature of from about 210 °C to about 250 °C. For example, the predetermined temperature is between about 210 °C and about 215 °C, or about 215 °C and about 220 °C, or about 220 °C and about 225 °C, or about 225 °C and about 230 °C, or about 230 °C and about 235 °C, or about 235 °C and about 240 °C, or about 240 °C and about 245 °C, or about 245 °C and about 250 °C. In particular embodiments of the invention, the predetermined steam temperature is 230 °C.

[0039] In an alternative embodiment of the invention, at least a portion of the feedwater is used as the cooling water. In a further embodiment of the invention, the cooling water is recycled to mix with the feedwater such that the desuperheater effectively preheats at least a portion of the feedwater.

Pressure regulation

[0040] It will be appreciated by the skilled person that the steam may be required at a predetermined pressure. As such, one or more pressure regulator may be installed to regulate the steam pressure.

[0041] In preferred embodiments of the invention, the steam delivery system further comprises a pressure regulator in fluid communication with the desuperheater to receive the steam from the desuperheater and regulate the steam pressure. In further embodiments of the invention, the system may comprise 1, 2, 3, 4 or 5 of pressure regulators.

[0042] In certain embodiments of the invention, the desuperheater comprises a pressure regulator for regulating the steam pressure at an outlet of the desuperheater. In further embodiments of the invention, the desuperheater may comprise 1, 2, 3, 4 or 5 of pressure regulators.

[0043] In preferred embodiments of the invention, the pressure regulator a pressure control valve. For example, the pressure control valve is a pressure reducing valve or a pressure sustaining valve.

[0044] In preferred embodiments of the invention, the predetermined steam pressure is from about 100 kPaG to about 4000 kPaG. For example, the pressure is between about 100 kPaG to 500 kPaG, or about 500 kPaG and about 600 kPaG, or about 600 kPaG and about 700 kPaG, or about 700 kPaG and about 800 kPaG, or about 800 kPaG and about 900 kPaG, or about 900 kPaG and about 1000 kPaG, or about 1000 kPaG and about 1500 kPaG, or about 1500 kPaG and about 2000 kPaG, or about 2000 kPaG and about 2500 kPaG, or about 2500 kPaG and about 3000 kPaG, or about 3000 kPaG and about 3500 kPaG, or about 3500 kPaG and about 4000 kPaG. Preferably, the predetermined steam pressure is about 1550 kPaG.

Feedwater control system

[0045] The feedwater can be of different sources. For example, the feedwater may be rainwater, town water, recycled cooling water from a different process, or condensed water from a different steam process. As such, the feedwater can have different and varying temperature, pressure and flowrate.

[0046] In an embodiment of the invention, the feedwater has a temperature of from about 5 °C to about 95 °C. For example, the temperature may be between about 5 °C and 10 °C, or about 10 °C and 15 °C, or about 15 °C and about 20 °C, or about 20 °C and about 25 °C, or about 25 °C and 30 °C, or about 30 °C and 35 °C, or about 35 °C and 40 °C, or about 40 °C and 45 °C, or about

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45 °C and 50 °C, or about 50 °C and 55 °C, or about 55 °C and 60 °C, or about 60 °C and 65 °C, or about 65 °C and 70 °C, or about 70 °C and 75 °C, or about 75 °C and 80 °C, or about 80 °C and 85 °C, or about 85 °C and 95 °C, or about 85 °C and 90 °C, or about 90 °C and 95 °C. In some embodiments, the feedwater has a temperature of about 95 °C. Preferably, the feedwater has a temperature of about 85 °C.

[0047] The feedwater is preferably pressurised before being heated by the thermal energy storage apparatus to provide high pressure steam. Advantageously, the high pressure steam is of higher enthalpy and is required by a steam user in need of high energy steam, and can provide more flexibility in how the steam can be used depending on the industrial application.

[0048] In preferred embodiments of the invention, the feedwater control system comprises a pump.

[0049] In an embodiment of the invention, the feedwater has an initial pressure of between about 0 kPaG to about 500 kPaG. For example, the pressure may be between about 0 kPaG and about 50 kPaG, or about 50 kPaG and about 100 kPaG, or about 100 kPaG and about 150 kPaG, or about 150 kPaG and about 200 kPaG, or about 200 kPaG and about 250 kPaG, or about 250 kPaG and about 300 kPaG, or about 300 kPaG and about 350 kPaG, or about 350 kPaG and about 400 kPaG, or about 400 kPaG and about 450 kPaG, or about 450 kPaG and about 500 kPaG. Preferably, the feedwater has an initial pressure of about 350 kPaG.

[0050] In preferred embodiments of the invention, the feedwater is pressurised to between about 100 kPaG to about 4000 kPaG using the pump. For example, the feedwater is pressurised to a pressure of between about 100 kPaG to about 500kPaG, or about 500 kPaG and 1000 kPaG, or about 1000 kPaG and about 1200 kPaG, or about 1200 kPaG and about 1400 kPaG, or about 1400 kPaG and about 1600 kPaG, or about 1600 kPaG and about 1800 kPaG, or about 1800 kPaG and about 2000 kPaG, or about 2000 kPaG and about 2200 kPaG, or about 2200 kPaG and about 2400 kPaG, or about 2400 kPaG and about 2600 kPaG, or about 2600 kPaG and about 2800 kPaG, or about 2800 kPaG and about 3000 kPaG, or about 3000 kPaG and about 3200 kPaG, or about 3200 kPaG and about 3400 kPaG, or about 3400 kPaG and about 3600 kPaG, or about 3600 kPaG and about 3800 kPaG, or about 3800 kPaG and about 4000 kPaG. Preferably, the feedwater is pressurised to about 1700 kPaG.

[0051] In a particular embodiment of the invention, the feedwater is pressurised from about 350 kPaG to about 1700 kPaG.

[0052] In an embodiment of the invention, the feedwater has a variable flowrate. In preferred embodiments of the invention, the flowrate is from about 50 kg/h to about 2000 kg/h. For example,

the flowrate is between about 50 kg/h and about 100 kg/h, or about 100 kg/h and about 150 kg/h, or about 150 kg/h and about 200 kg/h, or about 200 kg/h and about 250 kg/h, or about 250 kg/h and about 300 kg/h, or about 300 kg/h and about 350 kg/h, or about 350 kg/h and about 400 kg/h, or about 400 kg/h and about 450 kg/h, or about 450 kg/h and about 500 kg/h, or about 500 kg/h and about 550 kg/h, or about 550 kg/h and about 600 kg/h, or about 600 kg/h and about 650 kg/h, or about 650 kg/h and about 700 kg/h, or about 700 kg/h and about 750 kg/h, or about 750 kg/h and about 800 kg/h, or about 800 kg/h and about 850 kg/h, or about 850 kg/h and about 900 kg/h, or about 900 kg/h and about 950 kg/h, or about 950 kg/h and about 1000 kg/h, or about 1000 kg/h and about 1200 kg/h, or about 1200 kg/h and about 1400 kg/h, or about 1400 kg/h and about 1600 kg/h, or about 1600 kg/h and about 1800 kg/h, or about 1800 kg/h and about 2000 kg/h.

[0053] In preferred embodiments of the invention, the pump is a positive-displacement pump, a centrifugal pump, an axial-flow pump, or a combination thereof. In an embodiment of the invention, the system comprises a plurality of pumps connected in series, or parallel, or arranged in series-parallel combination.

Pre-treatment of feedwater

[0054] It will be appreciated by the skilled person that the feedwater may contain contaminants that can corrode, erode or otherwise cause damage to the thermal energy storage apparatus and/or will decrease the energy transfer efficiency during the heating process and/or are not permitted in the steam due to purity requirement. As such, pre-treatment of the feedwater to remove its solid contents may be required.

[0055] In an embodiment of the invention, the feedwater control system comprises a filter to remove contaminants from the feedwater. The filter may be a mechanical filter, an absorption filter, a sequestration filter, an ion exchange filter, a reverse osmosis filter, or a combination thereof. In preferred embodiments of the invention, the filter is a reverse osmosis filter.

[0056] In an embodiment of the invention, filtered waste from the filter is directed to the sparger tank for storage. In an alternative embodiment of the invention, the filtered waste is recycled to mix with the feedwater. In yet another embodiment of the invention, the filtered waste is disposed of.

[0057] In an embodiment of the invention, the feedwater control system comprises a demineraliser to demineralise the feedwater. In certain embodiments of the invention, the feedwater is demineralised by an ion exchange process to remove mineral contaminants. In preferred embodiments of the invention, the demineraliser is a demineralisation tank.

[0058] It will be appreciated by the skilled person that an ion exchange process preferably uses ion exchange resins. As water passes through the resins, ion exchange occurs, removing targeted ions from the water and replacing them with more desirable ions. Ion exchange resins structure includes acidic radicals or basic radicals, where mobile ions are located. Those mobile ions are exchanged with cations and anions present in water coming from dissolved mineral salts. Then, cation resin exchanges desirable cations to the water, while anion resin exchanges desirable anions to the water. Furthermore, in order to prevent corrosion, an inert or noble gas is introduced into the demineralisation tank and maintains a protective layer, which prevents or minimises the water from being exposed to oxygen and/or carbon dioxide. In some embodiments, the inert gas is selected from the group consisting of nitrogen, argon, helium, krypton, xenon, neon and combinations thereof. In preferred embodiments of the invention, the inert gas is nitrogen.

[0059] In an embodiment of the invention, the feedwater control system comprises a heated water tank for pre-heating the feedwater. In preferred embodiments of the invention, the feedwater is pre-heated using at least one electrical heater disposed in the heated water tank. In other preferred embodiments of the invention, the feedwater is pre-heated by heat recovered from the steam using heat recovery means. It will be appreciated by the skilled person that heat recovery means may be installed in the steam delivery system or at the user's end to recover heat from the steam. Examples of the heat recovery means include rotary thermal wheels, heat pipes, heat exchangers, or a combination thereof.

Steam

[0060] As discussed, the feedwater can be heated above its saturated temperature to become superheated steam. In preferred embodiments of the invention, the steam provided by the thermal energy storage apparatus has a temperature of from about 120 °C to about 700 °C. For example, the temperature is between about 120 °C and 150 °C, or about 150 °C and 200 °C, or about 200 °C and 250 °C, or about 250 °C and 300 °C, or about 300 °C and 350 °C, or about 350 °C and 400 °C, or about 400 °C and 450 °C, or about 450 °C and 500 °C, or about 500 °C and 550 °C, or about 550 °C and 600 °C, or about 600 °C and 650 °C, or about 650 °C and 700 °C.

[0061] In an embodiment of the invention, the steam provided by the thermal energy storage apparatus has a pressure of from about 100 kPaG to about 4000 kPaG. For example, the pressure is between about 500 kPaG and about 1000 kPaG, or about 1000 kPaG and about 1500 kPaG, or about 1500 kPaG and about 2000 kPaG, or about 2000 kPaG and about 2500 kPaG, or about 2500

kPaG and about 3000 kPaG, or about 3000 kPaG and about 3500 kPaG, or about 3500 kPaG to 4000 kPaG.

[0062] In an embodiment of the invention, the steam provided by the thermal energy storage apparatus has a variable flowrate. In preferred embodiments of the invention, the flowrate is from about 50 kg/h to about 2000 kg/h. For example, the flowrate is between about 50 kg/h and about 100 kg/h, or about 100 kg/h and about 150 kg/h, or about 150 kg/h and about 200 kg/h, or about 200 kg/h and about 250 kg/h, or about 250 kg/h and about 300 kg/h, or about 300 kg/h and about 350 kg/h, or about 350 kg/h and about 400 kg/h, or about 400 kg/h and about 450 kg/h, or about 450 kg/h and about 500 kg/h, or about 500 kg/h and about 550 kg/h, or about 550 kg/h and about 600 kg/h, or about 600 kg/h and about 650 kg/h, or about 650 kg/h and about 700 kg/h, or about 700 kg/h and about 750 kg/h, or about 750 kg/h and about 800 kg/h, or about 800 kg/h and about 850 kg/h, or about 850 kg/h and about 900 kg/h, or about 900 kg/h and about 950 kg/h, or about 950 kg/h and about 1000 kg/h, or about 1000 kg/h and about 1200 kg/h, or about 1200 kg/h and about 1400 kg/h, or about 1400 kg/h and about 1600 kg/h, or about 1600 kg/h and about 1800 kg/h, or about 1800 kg/h and about 2000 kg/h.

Steam storage unit

[0063] In an embodiment of the invention, the steam delivery system further comprises a storage unit in fluid communication with the desuperheater, such that the storage unit stores excess steam. In preferred embodiments of the invention, the stored steam is released to meet variable steam demand.

[0064] As discussed, the steam demand may vary from time to time. Advantageously, the steam storage unit can act as a buffer and provides a faster response than the thermal energy storage apparatus. For example, when the steam demand changes, it may take about 20 to 30 seconds for the thermal energy storage apparatus to respond to this change, while the steam storage unit can accommodate this change with a shorter response time. Furthermore, the peak steam demand may be higher than the maximum steam flowrate. Advantageously, the stored steam can then be released to meet the peak demand.

[0065] In preferred embodiments of the invention, the storage unit is a steam accumulator or a steam drum.

[0066] According to a second aspect of the invention there is provided a steam delivery system for providing industrial steam, the system comprising:

a feedwater control system for providing a flow of feedwater;

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a thermal energy storage apparatus in fluid communication with the feed water control system to heat the feedwater flowing through a conduit of the thermal energy storage apparatus to provide steam;

a desuperheater in fluid communication with the thermal energy storage apparatus to receive the steam and regulate the steam temperature;

a sparge system in fluid communication with the desuperheater;

such that in use,

the steam delivery system provides industrial steam having at least one of a predetermined temperature and a predetermined pressure, and

the steam delivery system operates in configurations comprising:

an excess-steam configuration, wherein at least a portion of the steam provided by the desuperheater is redirected to the sparge system;

a no-demand configuration, wherein all the steam provided by the desuperheater is redirected to the sparge system.

[0067] According to a third aspect of the invention there is provided a method of providing industrial steam, the method comprising the steps of:

- a) providing feedwater through a feedwater control system;
- b) flowing the feedwater from the feedwater control system to a thermal energy storage apparatus to heat the feedwater to provide steam; and
- c) desuperheating the steam to regulate the steam temperature;

to thereby provide industrial steam having at least one of a predetermined temperature and a predetermined pressure.

[0068] According to a fourth aspect of the invention there is provided a method of providing industrial steam, the method comprising the steps of:

- a) providing feedwater through a feedwater control system;
- b) flowing the feedwater from the feedwater control system to a thermal energy storage apparatus to heat the feedwater to provide steam; and
- c) desuperheating the steam to regulate the steam temperature;
- d) sparging the steam provided by the desuperheater to a sparge system in configurations comprising:

an excess-steam configuration, wherein at least a portion of the steam provided by the desuperheater is redirected to the sparge system;

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a no-demand configuration, wherein all the steam provided by the desuperheater is redirected to the sparge system.

to thereby provide industrial steam having at least one of a predetermined temperature and a predetermined pressure.

Process control system

[0069] In preferred embodiments of invention, the steam delivery system comprises at least one process control system. Examples of the system include, but are not limited to a process control system that controls the flowrate of the cooling water in the desuperheater through a flow valve, based on the predetermined steam temperature, cooling water temperature, steam temperature provided by the thermal storage apparatus and steam flowrate, measured by at least one temperature and flowrate transducer. Preferably, the process control system employs a feedback control algorithm. For example, the algorithm can be proportional integral derivative control or model predictive control.

Scaling up the system

[0070] The steam delivery system described above is scalable to accommodate different steam demand. In an embodiment of the invention, the system comprises a plurality of thermal energy storage apparatus. For example, the system may comprise 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 thermal energy storage apparatus. In an embodiment of the invention, the plurality of thermal storage apparatus is connected in series. In another embodiment of the invention, the plurality of thermal storage apparatus is connected in parallel. In yet another embodiment of the invention, the plurality of thermal storage apparatus is configured in series-parallel combination.

[0071] It will be appreciated by the skilled person that flowrate ranges of the feedwater and cooling water are also scalable in accordance with the number and/or configuration of thermal energy storage apparatus in the system. In some embodiments of the invention, the feedwater of the system has a flowrate between about 50 kg/h and 2000 kg/h. In some embodiments of the invention, the cooling water of the system has a flowrate between about 0.1 kg/h and 500 kg/h. In some embodiments of the invention, the feedwater of the system has a flowrate between about 50 kg/h and 40000 kg/h. In some embodiments of the invention, the cooling water of the system has a flowrate between about 0.1 kg/h and 10000 kg/h.

[0072] In a non-limiting example, for a steam delivery system comprising 15 thermal energy storage apparatus connected in series, the feedwater has a flowrate between about 50 kg/h and 2000 kg/h and the cooling water has a flowrate of between about 0.1 kg/h and about 500 kg/h. In another non-limiting example, for a steam delivery system comprising 20 thermal storage apparatus connected in parallel, the feedwater has a flowrate between about 1000 kg/h and 40000 kg/h and the cooling water has a flowrate of between about 2 kg/h and about 1000 kg/h. In yet another non-limiting example, for a steam delivery system comprising 18 thermal energy storage apparatus arranged in series-parallel combination, the feedwater has a flowrate between about 50 kg/h and 36000 kg/h and the cooling water has a flowrate of between about 0.1 kg/h and about 9000 kg/h.

[0073] Other aspects of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention.

Definitions

[0074] In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set out below. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments of the invention only and is not intended to be limiting. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one having ordinary skill in the art to which the invention pertains.

[0075] Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise”, “comprising”, and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in the sense of “including, but not limited to”.

[0076] As used herein, the phrase “consisting of” excludes any element, step, or ingredient not specified in the claim. When the phrase “consists of” (or variations thereof) appears in a clause of the body of a claim, rather than immediately following the preamble, it limits only the element set forth in that clause; other elements are not excluded from the claim as a whole. As used herein, the phrase “consisting essentially of” limits the scope of a claim to the specified elements or method steps, plus those that do not materially affect the basis and novel characteristic(s) of the claimed subject matter.

[0077] With respect to the terms “comprising”, “consisting of”, and “consisting essentially of”, where one of these three terms is used herein, the presently disclosed and claimed subject matter

may include the use of either of the other two terms. Thus, in some embodiments not otherwise explicitly recited, any instance of “comprising” may be replaced by “consisting of” or, alternatively, by “consisting essentially of”.

[0078] Other than in the operating examples, or where otherwise indicated, all numbers expressing quantities of ingredients or reaction conditions used herein are to be understood as modified in all instances by the term “about”. The examples are not intended to limit the scope of the invention. In what follows, or where otherwise indicated, “%” will mean “weight %”, “ratio” will mean “weight ratio” and “parts” will mean “weight parts”.

[0079] The term ‘substantially’ as used herein shall mean comprising more than 50% by weight, where relevant, unless otherwise indicated.

[0080] The recitation of a numerical range using endpoints includes all numbers subsumed within that range (e.g., 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, 5, etc.).

[0081] Further, unless expressly stated to the contrary, “or” refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[0082] The terms “preferred” and “preferably” refer to embodiments of the invention that may afford certain benefits, under certain circumstances. However, other embodiments may also be preferred, under the same or other circumstances. Furthermore, the recitation of one or more preferred embodiments does not imply that other embodiments are not useful and is not intended to exclude other embodiments from the scope of the invention.

[0083] It must also be noted that, as used in the specification and the appended claims, the singular forms “a”, “an” and “the” include plural referents unless the context clearly dictates otherwise.

[0084] As used herein, with reference to numbers in a range of numerals, the terms “about,” “approximately” and “substantially” are understood to refer to the range of -10% to +10% of the referenced number, preferably -5% to +5% of the referenced number, more preferably -1 % to +1 % of the referenced number, most preferably -0.1 % to +0.1 % of the referenced number. Moreover, with reference to numerical ranges, these terms should be construed as providing support for a claim directed to any number or subset of numbers in that range. For example, a disclosure of from 1 to 10 should be construed as supporting a range of from 1 to 8, from 3 to 7, from 1 to 9, from 3.6 to 4.6, from 3.5 to 9.9, from 8 to 10, and so forth.

[0085] The prior art referred to herein is fully incorporated herein by reference.

[0086] The term “steam” refers to water in the gas phase due to evaporation or due to boiling, where heat applied reaches and/or exceeds the enthalpy of vaporisation.

[0087] The term “superheated steam” refers to steam at a temperature higher than its vaporisation point at the absolute pressure where the temperature is measured. The vaporisation point of water is dependent on the pressure.

[0088] The term “industrial steam” refers to steam used in industry for a wide range of purposes. Examples of the purposes include, but are not limited to process heating, drying or concentrating, steam cracking, and distillation. Typically the steam is superheated at a pressure higher than the atmospheric pressure.

[0089] The term “desuperheater” refers to any unit or a number of units that is capable of reducing the temperature of superheated steam.

[0090] The term “predetermined” refers to a value that is determined or decided in advance. The value may be time-varying. For example, a pre-determine value may be a series of values at different time points, or a trajectory of values.

[0091] The term “cold start” refers to a scenario where a thermal energy storage apparatus is initially started and does not have enough energy to provide steam or steam at required temperature. In other words, it may take some time for the thermal energy storage apparatus to be heated and when it is started it may not be hot enough to heat feedwater to provide steam or provide steam at a hot enough temperature. During the cold start, hot water, instead of steam, may be provided. It will be appreciated by the skilled person that cold start should be minimised or avoided as steam cannot be provided during this period of time.

[0092] The term “excess-steam configuration” refers to a configuration that a steam delivery system operates when there is excess steam provided. In other words, the steam demand is lowered than the steam provided by the system.

[0093] The term “no-demand configuration” refers to a configuration that a steam delivery system operates in when there is zero or minimal steam demand.

[0094] The term “flowrate” refers to volumetric flowrate.

[0095] The term “steam demand” refers to a flowrate demand of the steam.

[0096] The term “saturated temperature” refers to the vaporisation point or boiling point.

[0097] The term “peak steam demand” refers to the steam demand that is typically higher than the maximum flowrate of the steam that can be provided by the steam delivery system.

[0098] The present specification uses the following abbreviations:

RO	Reverse osmosis
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Demin	Demineralisation
TES	Thermal energy storage apparatus
DS	Desuperheater

[0099] Although exemplary embodiments of the disclosed technology are explained in detail herein, it is to be understood that other embodiments are contemplated. Accordingly, it is not intended that the disclosed technology be limited in its scope to the details of construction and arrangement of components set forth in the following description or illustrated in the drawings. The disclosed technology is capable of other embodiments and of being practiced or carried out in various ways.

Brief Description of the Drawings

[00100] Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

[00101] Figure 1 shows a side perspective view of an embodiment of the energy storage apparatus of the present invention.

[00102] Figure 2 shows an embodiment of the steam delivery system.

[00103] Figure 3 shows a further embodiment of the system as shown in Figure 2, wherein a steam drum is installed after the desuperheater.

[00104] Figure 4 shows a further embodiment of the system as shown in Figure 3, wherein a heated water tank is installed for pre-heating the feedwater.

[00105] Figure 5 shows a further embodiment of the system as shown in Figure 4, wherein heat recovery means is used to pre-heat feedwater.

[00106] Figure 6 shows an embodiment of the system, wherein excess steam is directed to a sparge system.

[00107] Figure 7 shows a further embodiment of the system as shown in Figure 6, wherein the water in the sparge system is recycled to mix with the feedwater in the heated water tank.

[00108] Figure 8 shows a further embodiment of the system as shown in Figure 7, wherein a steam drum is installed in parallel with the sparge system.

[00109] Figure 9 shows a further embodiment of the system as shown in Figure 8, wherein heat recovery means is used to pre-heat feedwater.

[00110] Figure 10 shows a particularly preferred embodiment of the system.

Detailed Description of the Invention

[00111] The skilled addressee will understand that the invention comprises the embodiments and features disclosed herein as well as all combinations and/or permutations of the disclosed embodiments and features.

[00112] The steam delivery system can have different configurations to suit different operating requirements.

[00113] Figure 2 shows an embodiment of invention, wherein a flow of feedwater 209 is flowed through a pump 201 to be pressurised. The pressurised feedwater 210 is then flowed through a conduit in a thermal energy storage apparatus 202, where it is heated to become superheated steam 211. After that, the superheated steam is introduced to a desuperheater 203 to reduce its temperature. The desuperheater preferably has a pressure regulator (not shown) that regulates the steam pressure at an outlet. The steam 212, having at least one of a predetermined temperature and a predetermined pressure is then provided to a steam user 204.

[00114] Figure 3 shows a steam drum 205 installed after the desuperheater 204. The steam drum advantageously stores excess steam that can be released to meet peak steam demand.

[00115] Figure 4 shows a heated water tank 206 installed before the pump 201, such that the feedwater can be pre-heated before being introduced to the thermal energy storage apparatus 202.

[00116] Figure 5 shows that the feedwater is preheated in the heated water tank 206 using heat recovered from heat recovery means 207 installed at the user's side.

[00117] Figure 6 and Figure 7 show that instead of a steam drum, a sparge system 208 can be installed after the desuperheater. Excess steam provided can be directed to the sparge system when the steam demand is lower than the supply or zero. Furthermore, the water in the sparge system, after being heated by the sparged steam, can be recycled to use as pre-heated feedwater. Advantageously, the thermal energy storage apparatus does not need to be turned down or turned off when the steam demand is low or zero, therefore cold start may be avoided.

[00118] Figure 8 shows that the steam drum 205 can be installed in parallel with the sparge system 208 after the desuperheater 204. In this configuration, when there is excess steam provided, a portion of the excess steam is stored while the other portion is directed to the sparge system 208 for pre-heating the feedwater.

[00119] Figure 9 shows another embodiment that heat recovered from the heat recovery means 207 is also used for pre-heating the feedwater.

EXAMPLES

Example 1 – Energy storage apparatus

[00120] Referring to Figure 1, there is shown a sensible heat storage body 102 for use as an energy apparatus 100. The sensible heat storage body 102 has a heating element channel 104 for receiving a removable heating element 106 (not shown). The sensible heat storage body 102 also has a heat exchanger channel 108 for receiving the heat exchanger 110. The sensible heat storage body 102 is assembled by component parts and can be milled, machined or the like to provide the heating element channel 104 and heat exchanger channel 108 having at least two open ends within the sensible heat storage body. The sensible heat storage body 102 is in the form of a graphite panel comprised of component ‘slabs’ of graphite machined to snugly receive a heat exchanger 110 as well as a heating element 106.

[00121] In use, the removable heating element 106 heats the inner region of the sensible heat storage body 102 and the heat exchanger 110 is encased within the heat exchanger channel 108 of the sensible heat storage body 102 such that a heat transfer medium can flow from the inlet to the outlet of the heat exchanger 110 through the body 102.

Example 2 – Steam delivery system

A particular example of the steam delivery system is shown in Figure 10. Feedwater 209 is filtered by an RO filter 213, followed by demineralisation in a demineralisation tank 214. The demineralised feedwater 216 is then pressurised using a pump 201 before being introduced to a thermal energy storage apparatus 202 to produce superheated steam 211. The steam is desuperheated in a desuperheater 203 with a flow of cooling water 215. The desuperheater preferably has a pressure regulator (not shown) that regulates the steam pressure at an outlet. Part of the steam 212, having at least one of a predetermined temperature and a predetermined pressure, is directed to a sparge system 208, while the rest is provided to a steam user 204. At least a portion the water in the sparge system is recycled to mix with the feedwater.

[00122] Table 1 shows exemplary properties of different flows in Figure 10.

Flow no.	Type of fluid	Temperature °C	Pressure kPaG	Flowrate kg/h
209	Feedwater	20	350	100-750
210	Pressurised demineralised feedwater	20	1700	100-750
211	Superheated steam	230-700	1650	100-750
212	Desuperheated steam	230	1500	100-1000

- 21 -

215	Cooling water	85	1650	0.1-500
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[00123] Although the invention will be described with reference to specific examples it will be appreciated by those skilled in the art that the invention may be embodied in many other forms.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:-

1. A steam delivery system for providing industrial steam, the system comprising:
 - a feedwater control system for providing a flow of feedwater;
 - 5 a thermal energy storage apparatus in fluid communication with the feedwater control system to heat the feedwater flowing through a conduit of the thermal energy storage apparatus to provide steam; and
 - a desuperheater in fluid communication with the thermal energy storage apparatus to receive the steam and regulate the steam temperature;
 - 10 such that in use, the steam delivery system provides industrial steam having at least one of a predetermined temperature and a predetermined pressure.
2. The steam delivery system according to claim 1, further comprising a sparge system in fluid communication with the desuperheater, such that the steam delivery system
15 operates in configurations comprising:
 - an excess-steam configuration, wherein at least a portion of the steam provided by the desuperheater is redirected to the sparge system;
 - a no-demand configuration, wherein the steam provided by the desuperheater is redirected to the sparge system.
20
3. The steam delivery system according to claim 2, wherein the sparge system comprises a sparger tank comprising:
 - a volume of water;
 - at least one nozzle for injecting the steam provided by the desuperheater into
25 the water;

such that in use, the steam is condensed and the water is heated.
4. The steam delivery system according to claim 3, wherein at least a portion the water is recycled to mix with the feedwater.
30
5. The steam delivery system according to any one of claims 1 to 4, wherein an aerosol of cooling water is introduced into the desuperheater and mixed with the steam for reducing the temperature of the steam.

6. The steam delivery system according to any one of claims 1 to 4, wherein the desuperheater comprises a heat exchanger, preferably the heat exchanger is a shell and tube type, a tube-in-tube type, or a plate type.
- 5 7. The steam delivery system according to any one of claims 1 to 6, wherein the desuperheater comprises a pressure regulator for regulating the steam pressure at an outlet of the desuperheater.
- 10 8. The steam delivery system according to any one of claims 1 to 7, further comprising a pressure regulator in fluid communication with the desuperheater to receive the steam from the desuperheater and regulate the steam pressure, preferably the pressure regulator is a pressure control valve, more preferably a pressure reducing valve or a pressure sustaining valve.
- 15 9. The steam delivery system according to any one of claims 1 to 8, wherein the feedwater control system comprises a pump, preferably a positive-displacement pump, a centrifugal pump, an axial-flow pump, or a combination thereof connected in series or parallel.
- 20 10. The steam delivery system according to any one of claims 1 to 9, wherein the feedwater control system comprises a filter to remove contaminants from the feedwater, preferably the filter is a reverse osmosis filter.
- 25 11. The steam delivery system according to any one of claims 1 to 10, wherein the feedwater control system comprises a demineraliser to demineralise the feedwater.
- 30 12. The steam delivery system according to any one of claims 1 to 11, wherein the feedwater control system comprises a heated water tank for pre-heating the feedwater, preferably the feedwater is pre-heated by heat recovered from the steam using heat recovery means.
- 35 13. The steam delivery system according to any one of claims 1 to 12, further comprising a storage unit in fluid communication with the desuperheater, such that the storage unit stores excess steam, preferably the storage unit is a steam accumulator or a steam drum.

14. The steam delivery system according to claim 13, wherein the stored steam is released to meet peak steam demand.

- 5 15. A steam delivery system for providing industrial steam, the system comprising:
- a feedwater control system for providing a flow of feedwater;
 - a thermal energy storage apparatus in fluid communication with the feed water control system to heat the feedwater flowing through a conduit of the thermal energy storage apparatus to provide steam;
 - 10 a desuperheater in fluid communication with the thermal energy storage apparatus to receive the steam and regulate the steam temperature;
 - a sparge system in fluid communication with the desuperheater;
- such that in use,
- the steam delivery system provides industrial steam having at least one of a
 - 15 predetermined temperature and a predetermined pressure, and
 - the steam delivery system operates in configurations comprising:
 - an excess-steam configuration, wherein at least a portion of the steam provided by the desuperheater is redirected to the sparge system;
 - a no-demand configuration, wherein the steam provided by the desuperheater
 - 20 is redirected to the sparge system.

16. A method of providing industrial steam, the method comprising the steps of:
- a) providing feedwater through a feedwater control system;
 - b) flowing the feedwater from the feedwater control system to a thermal
 - 25 energy storage apparatus to heat the feedwater to provide steam; and
 - c) desuperheating the steam to regulate the steam temperature;
- to thereby provide industrial steam having at least one of a predetermined temperature and a predetermined pressure.

- 30 17. The method according to claim 16, further comprising a step of sparging the steam provided by the desuperheater to a sparge system in configurations comprising:
- an excess-steam configuration, wherein at least a portion of the steam provided by the desuperheater is redirected to the sparge system;

a no-demand configuration, wherein the steam provided by the desuperheater is redirected to the sparge system.

18. The method according to claim 17, wherein the sparge system comprises a sparger
5 tank comprising:

a volume of water;

at least one nozzle for injecting the steam provided by the desuperheater into
the water;

to thereby condense the steam and heat the water.

10

19. The method according to claim 18, wherein at least a portion the water is recycled to
mix with the feedwater.

20. The method according to any one of claims 16 to 19, wherein an aerosol of cooling
15 water is introduced into the desuperheater and mixed with the steam for reducing the
temperature of the steam.

21. The method according to any one of claims 16 to 20, wherein the desuperheater
comprises a heat exchanger, preferably the heat exchanger is a shell and tube type, a
20 tube-in-tube type, or a plate type

22. The method according to any one of claims 16 to 21, wherein the desuperheater
comprises a pressure regulator for regulating the steam pressure at an outlet of the
desuperheater.

25

23. The method according to any one of claims 16 to 22, further comprising a step of
regulating the steam pressure using a pressure regulator, preferably the pressure
regulator is a pressure control valve, more preferably a pressure reducing valve or a
pressure sustaining valve.

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24. The method according to any one of claims 16 to 23, wherein the feedwater control
system comprises a pump, preferably a positive-displacement pump, a centrifugal
pump, an axial-flow pump, or a combination thereof connected in series or parallel.

25. The method according to any one of claims 16 to 24, wherein the feedwater control system comprises a filter that removes contaminants from the feedwater, preferably the filter is a reverse osmosis filter.
- 5 26. The method according to any one of claims 16 to 25, wherein the feedwater control system comprises a demineraliser to demineralise the feedwater.
27. The method according to any one of claims 16 to 26, wherein the feedwater control system comprises a heated water tank for pre-heating the feedwater, preferably the
10 feedwater is pre-heated by heat recovered from the steam using heat recovery means.
28. The method according to any one of claims 16 to 27, further comprising a step of storing excess steam provided by the desuperheater in a storage unit, preferably the storage unit is a steam accumulator or a steam drum.
15
29. The method according to claim 28, wherein the stored steam is released to meet peak steam demand.
30. A method of providing industrial steam, the method comprising the steps of:
20 a) providing feedwater through a feedwater control system;
b) flowing the feedwater from the feedwater control system to a thermal energy storage apparatus to heat the feedwater to provide steam;
c) desuperheating the steam to regulate the steam temperature; and
d) sparging the steam provided by the desuperheater to a sparge system in
25 configurations comprising:
an excess-steam configuration, wherein at least a portion of the steam provided by the desuperheater is redirected to the sparge system;
a no-demand configuration, wherein the steam provided by the desuperheater is redirected to the sparge system.
30 to thereby provide industrial steam having at least one of a predetermined temperature and a predetermined pressure.