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(54) **Steam compression apparatus and method**

Dampfkompressionsvorrichtung

Appareil de compression de vapeur

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Description

[0001] The invention relates to a steam compression apparatus and a method of operating a steam compression apparatus.

[0002] It is known in the field of steam systems to compress a low-pressure steam flow to provide a high-pressure steam flow. Compression of steam results in a change of temperature and may result in the steam transitioning from one steam region to another (e.g. from wet steam to dry saturated steam or to superheated steam). A steam flow may be compressed to increase the pressure and temperature of the steam flow.

[0003] Where a high-pressure steam flow from a compressor is superheated, it may be desirable to subsequently de-superheat the steam to reduce the level of superheat or to provide substantially dry saturated steam. For example, saturated steam is preferred for heat transfer applications, whereas superheated steam is preferred for flow through turbines. Dry saturated steam is steam at saturation temperature and in the absence of saturated liquid water, and is typically represented in steam charts by the "dry saturated steam" or "saturated steam" line. Substantially dry saturated steam is steam close to or on the dry saturated steam line, i.e. with a dryness approaching 100% or a small level of superheat.

[0004] A steam flow is typically de-superheated by cooling in a heat exchanger or by a de-superheater.

[0005] Compressors for compressing a steam flow are typically driven by a motor that produces thermal energy in use. This thermal energy is typically exhausted to the ambient air, which can be considered to be an inefficient use of energy.

[0006] WO 2009/136967 discloses a valve element for a spray nozzle assembly of a steam desuperheating device that is configured to spray cooling water into a flow of superheated steam in a generally uniformly distributed spray pattern. US 3,210,943 discloses a valve controlling injection of water into a steam pipe which is operated by cam. The rate of flow of steam is measured by an orifice and a differential pressure gauge which rotates the cam. The steam temperature is measured by a beam provided with a pivoted knife-edge, which detects thermal expansion or contraction of the pipe, and which through a mechanical linkage moves the cam axially. The angular and axial position of the cam and hence the valve setting thus depend on steam flow and steam temperature.

[0007] WO 2011/022810 discloses a method and system of generating high pressure steam from a low pressure low energy steam which comprises providing a low pressure steam source; dividing the source into at least two streams. A first stream driving a turbine/expander is coupled to a steam compressor of a steam generator. The steam compressor is fed by the second stream of the low pressure steam source, and the mass flow rate of the first stream is sufficient to raise the pressure of the second stream to a desired pressure. At steady state operating conditions the first and the second stream respectively acts as the driving force for the steam compressor and the inlet feed to the steam compressor generating the high pressure steam.

[0008] US 2009/107156 discloses a heat pump system including a water purifier and an evaporator for evaporating feed-water to produce steam and in which water used for spray cooling is effectively used and productivity of purified water used for the spray cooling is increased. Discharged water from the water purifier is supplied to the evaporator when water used for spray cooling is produced by use of the water purifier. Otherwise, drain of the evaporator having higher temperature is supplied to the water purifier by using such a fact that in a reverse osmosis membrane type water purifier, the higher the temperature of feed-water is, the higher the purified water productivity becomes.

[0009] Whilst known steam compression apparatus may be satisfactory, it is desirable to provide improvements in efficiency.

[0010] In a broad aspect there is provided a method of operating a steam compression apparatus comprising a compressor and a drive unit, the method comprising: operating the drive unit to drive the compressor so as to provide a superheated steam flow; cooling the drive unit with a liquid cooling medium, so that the cooling medium recovers thermal energy from the drive unit; and de-superheating the steam flow by heat transfer between the steam flow and the cooling medium downstream of the drive. There is also provided a steam compression apparatus comprising: a compressor for providing a superheated steam flow; a drive unit for driving the compressor; a cooling apparatus arranged to provide a cooling medium to the drive unit so that in use the cooling medium recovers thermal energy from the drive unit; and a de-superheater arranged to receive the cooling medium downstream of the drive unit, the de-superheater being arranged to de-superheat the steam flow from the compressor by heat transfer between the steam flow and the cooling medium .

[0011] According to a first aspect of the invention there is provided a method of operating a steam compression apparatus comprising a compressor and a drive unit, the method comprising: operating the drive unit to drive the compressor so as to provide a superheated steam flow; cooling the drive unit with a liquid cooling medium, so that the cooling medium recovers thermal energy from the drive unit; and de-superheating the steam flow from the compressor by injecting the cooling medium into the steam flow downstream of the drive unit. The thermal energy recovered from the drive unit is therefore transferred to the steam flow. The method of operating the steam compression apparatus may be a heat recovery method for the steam compression apparatus.

[0012] The purpose of the de-superheater is to cool the superheated steam flow, and so it may seem that the use of a cooling medium that has recovered thermal energy from the drive unit is counterintuitive, since it will be

at a comparatively higher temperature than if it had not recovered said thermal energy. However, it will be appreciated that the increased thermal energy of the cooling medium means that an increased quantity of the cooling medium is required to de-superheat the steam flow. One benefit of this is that proportionally less of the steam flow downstream of the de-superheater originates upstream of the compressor, therefore reducing the demand on upstream steam generation, or conversely increasing the output overall.

[0013] The method may further comprise controlling the injection of the cooling medium into the steam flow.

[0014] The method may further comprise monitoring a thermodynamic property of the steam flow, and the injection of the cooling medium may be controlled at least partly based on the thermodynamic property. The thermodynamic property may be the temperature, pressure and/or dryness of the steam flow.

[0015] The thermodynamic property of the steam flow may be monitored upstream or downstream of the injection of the cooling medium. For example, the temperature, pressure and/or dryness of the steam flow may be monitored upstream of the compressor; downstream of the compressor and upstream of the injection of the cooling medium; or downstream of the injection of the cooling medium.

[0016] More than one thermodynamic property may be monitored, and the injection of the cooling medium may be controlled at least partly based on one or more of the monitored properties.

[0017] The method may further comprise monitoring the flow rate of the steam flow and controlling the injection of the cooling medium at least partly based on the flow rate.

[0018] Similarly, the method may further comprise monitoring a thermodynamic property of the cooling medium downstream of the drive unit and controlling the injection of the cooling medium at least partly based on the thermodynamic property of the cooling medium. The thermodynamic property may be the temperature and/or pressure of the cooling medium. More than one thermodynamic property may be monitored, and the injection of the cooling medium may be controlled at least partly based on one or more of the monitored thermodynamic properties of the cooling medium.

[0019] The injection of the cooling medium may be controlled so as to de-superheat the steam flow to provide substantially dry saturated steam. The steam flow may be determined to comprise substantially dry saturated steam when the temperature is at least the saturation temperature of the steam flow and no more than 10°C, no more than 5°C, no more than 2°C or no more than 1°C above the saturation temperature of the steam flow. The steam flow may be determined to comprise substantially dry saturated steam when the steam dryness is at least 90%, at least 95%, at least 98%, at least 99% or 100%.

[0020] The injection of the cooling medium may be controlled so as to de-superheat the steam flow to a predetermined level of superheat. The predetermined level of superheat may be at least 1°, at least 2°, at least 5° at least 10° or more above the saturation temperature of the steam flow.

[0021] The method may further comprise adjusting the shaft power provided to the compressor from the drive unit, so as to adjust the compression ratio of the steam, and thereby the level of superheat in the superheated steam flow.

[0022] According to a second aspect of the invention there is provided a method of operating a steam compression apparatus comprising a compressor and a drive unit, the method comprising: operating the drive unit to drive the compressor so as to provide a superheated steam flow; cooling the drive unit with a liquid cooling medium, so that the cooling medium recovers thermal energy from the drive unit; and de-superheating the steam flow from the compressor by indirect heat transfer between the steam flow and the cooling medium downstream of the drive unit, thereby vaporising a portion of the cooling medium to provide a vaporised flow which combines with the steam flow. The thermal energy recovered from the drive unit is therefore transferred to the steam flow. The method of operating the steam compression apparatus may be a heat recovery method for the steam compression apparatus.

[0023] The cooling medium may be water when in liquid form. The cooling medium may be steam when vaporised (i.e. in gaseous form).

[0024] According to a third aspect of the invention there is provided a steam compression apparatus comprising: a compressor for providing a superheated steam flow; a drive unit for driving the compressor; a cooling apparatus arranged to provide a cooling medium to the drive unit so that in use the cooling medium recovers thermal energy from the drive unit; and a de-superheater arranged to receive the cooling medium downstream of the drive unit, the de-superheater being arranged to de-superheat the steam flow from the compressor by injecting the cooling medium into the steam flow. The cooling apparatus allows thermal energy recovered from the drive unit to be transferred to the steam flow.

[0025] The de-superheater may be arranged to receive the cooling medium directly from the drive unit. The cooling medium may be received at the de-superheater at substantially the same temperature that it left the drive unit (i.e. the steam compression apparatus may be configured so that the temperature of the cooling fluid is substantially constant between the drive unit and the de-superheater).

[0026] The de-superheater may comprise a valve and a valve controller for controlling the injection of the cooling medium into the steam flow. The steam compression apparatus may further comprise a steam sensor for monitoring a thermodynamic property of the steam flow, and the valve controller may control the injection of the cooling medium at least partly based on the thermodynamic

property of the steam flow.

[0027] The steam sensor may comprise a temperature, pressure and/or dryness sensor. The steam sensor may be disposed upstream of the compressor; downstream of the compressor and upstream of the de-superheater; or downstream of the de-superheater. The steam sensor may be disposed within the de-superheater. There may be more than one sensor for monitoring more than one thermodynamic property of the steam flow, and the injection of the cooling medium may be controlled at least partly based on one or more of the monitored properties.

[0028] The steam compression apparatus may further comprise a flow meter for monitoring the flow rate of the steam flow, and the valve controller may control the injection of the cooling medium at least partly based on the flow rate of the steam flow.

[0029] The steam compression apparatus may further comprise a cooling medium sensor for monitoring a thermodynamic property of the cooling medium downstream of the drive unit, and the valve controller may control the injection of the cooling medium at least partly based on the thermodynamic property of the cooling medium. The thermodynamic property may be the temperature and/or pressure of the cooling medium. The cooling medium sensor may be disposed upstream of the de-superheater and downstream of the drive unit. The cooling medium sensor may be disposed within the de-superheater. There may be more than one cooling medium sensor for monitoring more than one thermodynamic property of the cooling medium, and the injection of the cooling medium may be controlled at least partly based on one or more of the monitored thermodynamic properties of the cooling medium.

[0030] The valve controller may be configured to control the injection of the cooling medium so as to de-superheat the steam flow to provide substantially dry saturated steam.

[0031] The valve controller may be configured to control the injection of the cooling medium so as to de-superheat the steam flow to a predetermined level of superheat.

[0032] According to a fourth aspect of the invention there is provided a steam compression apparatus comprising: a compressor for providing a superheated steam flow; a drive unit for driving the compressor; a cooling apparatus arranged to provide a liquid cooling medium to the drive unit so that in use the cooling medium recovers thermal energy from the drive unit; a de-superheater arranged to receive the cooling medium downstream of the drive unit, the de-superheater being arranged to de-superheat the steam flow from the compressor by indirect heat transfer between the steam flow and the cooling medium so that in use a portion of the cooling medium is vaporised, wherein the de-superheater is arranged to combine the vaporised cooling medium with the steam flow.

[0033] The de-superheater may be arranged so that the cooling medium received from the drive unit is at substantially the same pressure as the steam flow, so that in use the cooling medium received therein tends to the saturation temperature of the steam flow.

[0034] The cooling medium received from the drive unit may be in fluid communication with the steam flow. The cooling medium received from the drive unit may be in fluid communication with the steam flow so that when vaporised it combines with the steam flow.

[0035] The invention will now be described, by way of example, with reference to the following Figures, in which:

Figure 1 schematically shows a steam compression apparatus according to a first embodiment of the invention;

Figure 2 schematically shows a steam compression apparatus according to a second embodiment of the invention; and

Figure 3 schematically shows a steam compression apparatus according to a third embodiment of the invention.

[0036] **Figure 1** shows a steam compression apparatus 10 comprising a compressor 12, a compressor drive unit 14, a de-superheater 16 and a water cooling network 18. In use, water is used to cool the compressor drive unit 14 and is then supplied to the de-superheater to de-superheat superheated steam from the compressor 12.

[0037] An inlet steam line 20 extends from an upstream steam system (not shown) to the compressor 12, which in this embodiment is an axial flow compressor. An outlet steam line 22 extends from the compressor 12. The de-superheater 16 is coupled to the outlet steam line 22, as will be described in detail below.

[0038] The compressor 12 is driven by the drive unit 14, which comprises a motor 24 and associated drive electronics 26 including an inverter. The motor 24 is coupled to the compressor 12 by a drive shaft 28.

[0039] The drive unit 14 is thermally coupled to a cooling apparatus in the form of a water cooling network 18 connected to a supply of cooling water (not shown). The water cooling network 18 is thermally coupled to heat sinks of the drive unit 14. Supply pipes 32 convey water from the water supply to the drive unit 14, and transfer pipes 34 convey the water from the drive unit 14 to the de-superheater 16.

[0040] In this embodiment the de-superheater 16 is an injection-type de-superheater which is arranged to inject the cooling water received from the drive unit 14 into the steam flow. The de-superheater 16 comprises an injection nozzle that extends into the steam flow.

[0041] The de-superheater 16 is coupled to control apparatus comprising steam sensors 36, 38, 40; a steam flow meter 42; a control valve 44; a cooling medium sensor 46 and a controller 48. In other embodiments one or

more parts of the control apparatus may be integrated with the de-superheater 16.

[0042] The steam sensor 36 is a steam dryness sensor 36 arranged to determine the dryness of the steam. For example, steam that is determined to be 95% dry comprises 95% water vapour (saturated steam) and 5% water droplets (saturated water). The steam sensor 38 is a temperature sensor which projects into the steam flow and is arranged to generate a signal relating to the temperature of the steam flow. The steam sensor 40 is a pressure sensor which projects into the steam flow and is arranged to generate a signal relating to the pressure of the steam flow. In this embodiment the steam sensors 36, 38, 40 are disposed downstream of the de-superheater 16.

[0043] The steam flow meter 42 is arranged to generate a signal relating to the flow rate of the steam flow. In this embodiment the steam flow meter 42 is disposed downstream of the compressor 12 and upstream of the de-superheater 16.

[0044] The cooling medium sensor 46 is a temperature sensor which projects into the cooling water flow in the transfer pipes 34 and is arranged to generate a signal relating to the temperature of the cooling water in the transfer pipes 34.

[0045] The control valve 44 is configured to limit the injection flow rate at which the cooling water is injected into the steam flow. The controller 48 is configured to control the valve 44 so as to increase or decrease the injection flow rate. The controller 48 may be configured to set a particular injection flow rate or an injection flow rate range for the control valve 44.

[0046] Operation of the steam compression apparatus 10 will now be described. In the following description, example steam properties are given for illustrative purposes only.

[0047] The drive unit 14 is operated to drive the compressor 12. The supply pipes 32 of the cooling network 18 bring cooling water at a supply temperature of approximately 20°C to flow over heat sinks of the drive unit 14, so as to transfer thermal energy from the drive unit 14 to the cooling water. The transfer pipes 34 convey the cooling water from the drive unit 14 at an elevated temperature of approximately 80°C.

[0048] Relatively low-pressure steam flows to the compressor 12 at a pressure of 1 bar gauge, a temperature of approximately 120°C (the saturation temperature) and a steam dryness of 90%. Accordingly, this low-pressure steam is wet steam comprising 90% saturated steam and 10% saturated water, as opposed to being substantially dry saturated steam or superheated steam. The compressor 12 is driven to compress the low-pressure wet steam to provide a high-pressure superheated steam flow at a pressure of 5 bar gauge and a temperature of 175°C (i.e. approximately 16°C superheated).

[0049] The de-superheater 16 receives the cooling water from the drive unit 14 via the transfer pipes 34 at the elevated temperature of approximately 80°C. The control valve 44 limits the injection flow rate at which cooling water received from the drive unit 14 is injected into the steam flow.

[0050] The control apparatus adjusts the injection flow rate according to the desired operation of the de-superheater 16. In one example mode of operation, the control apparatus is configured such that the steam flow downstream of the de-superheater 16 is substantially dry saturated steam, as will be described below.

[0051] In this embodiment, the steam sensors 36, 38, 40 are disposed downstream of the de-superheater, and the control apparatus operates a feedback loop. The signals from the steam sensors 36, 38, 40 are communicated to the controller 48 which determines whether the steam is superheated, substantially dry saturated steam, or wet steam. For example, the controller 48 looks up the saturation temperature associated with the monitored pressure of the steam flow, and determines from the temperature sensor 38 whether the temperature of the steam flow is higher than the saturation temperature, which would indicate that the steam flow is superheated.

[0052] A lower threshold and an upper threshold are set by the controller 48 according to the desired operation of the de-superheater 16. In this example mode of operation, the lower threshold is marginally below the saturation temperature at the monitored steam pressure (e.g. 1°C below) or 95% steam dryness, whereas the upper threshold is 2°C above the saturation temperature. In other embodiments the difference between the threshold values and the saturation temperature or the ideal steam dryness (100%) may be lesser or greater.

[0053] When the controller 48 determines that the steam flow is wet steam (i.e. below the lower threshold), it causes the control valve 44 to decrease the injection flow rate. When the controller determines that the steam flow is superheated (i.e. above the upper threshold), it causes the control valve 44 to increase the injection flow rate. When the controller determines that the steam flow is substantially dry saturated steam (i.e. between the thresholds), it causes the control valve 44 to maintain the present injection flow rate.

[0054] In an alternative example mode of operation the control apparatus is configured so that the steam flow downstream of the de-superheater 16 is superheated to a predetermined amount of 5°C. Accordingly, the lower threshold and upper threshold are set to 4°C and 6°C above saturation temperature. It will be appreciated that the thresholds may be set with wider or narrower tolerances.

[0055] In both examples, the amount of cooling water that is required to de-superheat the steam flow depends on the temperature of the cooling water injected by the de-superheater 16. Since the temperature of the cooling water at the de-superheater 16 is the elevated temperature of 80°C, significantly more cooling water is required to de-superheat the steam flow than would be required if the cooling water is received at the lower supply temperature of 20°C. Accordingly, providing the cooling water to the de-superheater 16 at the elevated temperature

has the effect of increasing the mass flow rate of the steam flow.

[0056] Using cooling water at the elevated temperature has the effect of transferring the thermal energy recovered from the drive unit 14 into the steam flow, despite the elevated temperature of the cooling water being less than the temperature of the resultant steam flow.

[0057] In a second embodiment shown in **Figure 2**, the steam sensors 36, 38, 40 and the flow meter 42 are disposed between the compressor 12 and the de-superheater 16. Accordingly, the steam conditions monitored by the steam sensors 36, 38, 40 correspond to the steam flow before injection of the cooling water. Consequently, the controller 48 is configured to calculate the injection flow rate required to reach the desired steam conditions.

[0058] In one example mode of operation, the control apparatus is configured so that the steam flow downstream of the de-superheater 16 is substantially dry saturated steam. The controller 48 periodically determines the pressure and temperature of the steam flow upstream of the de-superheater 16 and calculates the specific enthalpy of the superheated steam flow. Taking into account the temperature of the cooling water as monitored by the cooling medium sensor 46 and the flow rate of the steam flow as monitored by the flow meter 42, the controller 48 determines the injection flow rate of cooling water required to reduce the specific enthalpy of the steam flow to a value corresponding to substantially dry saturated steam. The controller 48 causes the control valve 44 to inject cooling water at this rate.

[0059] In other modes of operation, the control apparatus may be configured such that the steam flow downstream of the de-superheater 16 has a predetermined level of superheat, such as approximately 5°C.

[0060] In a third embodiment shown in **Figure 3**, the de-superheater 16' is a shell-and-tube de-superheater which is arranged to de-superheat the steam flow by indirect contact. The de-superheater 16' comprises a U-shaped shell 50 having two vertically upstanding parts 54, 55 and a curved lower part 56. A plurality of steam tubes 52, 53 extend longitudinally in each of the upstanding parts 54, 55 and are connected by a steam conduit 56 forming the curved part. In each of the upstanding parts 54, 55 the space between the steam tubes 52, 53 forms a cooling volume 58 for cooling water, bounded by a lower sealing plate 59 at the base of each upstanding part 54, 55. The two cooling volumes are connected by a lower channel 62 and are open at their upper ends so that they are in fluid communication with the open upper ends of the steam tubes 52, 53 respectively. The de-superheater 16' has a steam inlet 64 at the upper end of the first upstanding part 54 and a steam outlet 66 at the upper end of the second upstanding part 55.

[0061] A water-level control valve 68 is arranged to detect the water level of the cooling volumes in the upstanding parts 54, 55 and to control the flow of cooling water from the transfer pipes 34 into the cooling volume to maintain the water level within a predetermined range. A drain 70 is provided for draining cooling water from the cooling volumes. The water-level control valve 68 and the drain 70 are controllable by the controller 48.

[0062] The steam sensors 36, 38, 40 are disposed downstream of the de-superheater 16' for monitoring the steam dryness, temperature and pressure of the steam flow from the outlet 66.

[0063] In use, steam from the compressor 12 enters the de-superheater 16' via the steam inlet 64 and passes down through the first set of steam tubes 52, through the curved steam conduit 56 and up through the second set of steam tubes 53 to exit via the steam outlet 66. As the steam passes through the first and second sets of steam tubes 52, 53 it is cooled by heat transfer from the steam through the tubes 52, 53 to the surrounding cooling water. The cooling volumes of the upstanding parts 54, 55 of the de-superheater 16' are open to the steam flow, and so the cooling water is at the same pressure as the steam flow. Accordingly, the cooling water tends to the saturation temperature, and a portion of the cooling water vaporises as heat is transferred. Vaporised cooling water (i.e. steam) travels up through the respective upstanding parts 54, 55 and combines with the steam flow received from the compressor.

[0064] Accordingly, as with the injection-type de-superheater 16 of the above described embodiments, the thermal energy recovered from the drive unit 14 by the cooling water is transferred to the steam flow, although in this embodiment the cooling water first vaporises and then combines with the steam flow.

[0065] The amount by which the steam flow is de-superheated depends on the temperature of the steam flow, the temperature of the cooling water, and the length of the steam tubes 52, 53 that is immersed in the cooling water. The controller 46 determines the properties of the steam flow outlet from the steam outlet 66 (i.e. downstream of the de-superheater 16') based on monitoring by the steam sensors 36, 38, 40.

[0066] In one example mode of operation, the length of the steam tubes 52, 53 immersed in the cooling water is sufficient that the steam flow is fully de-superheated to the saturation temperature as it passes through the de-superheater 16', and a portion of the cooling water vaporises to combine with the steam flow.

[0067] However, in other example modes of operation the length of the steam tubes 52, 53 immersed in the cooling water is insufficient, or conversely the level of superheat in the steam flow is high, such that the steam flow is not fully de-superheated to the saturation temperature.

[0068] In one such mode of operation, a predetermined level of superheat in the outlet steam flow is desirable and the length of the steam tubes 52, 53 immersed in the cooling water is controlled by the water-level control 68 as part of a feedback loop with the controller 72 and steam sensors 36, 38, 40 so that steam outlet from the de-superheater 16' has the predetermined level of superheat.

[0069] In a further mode of operation, such a degree of superheat is undesirable and so the temperature of the cooling water is controlled to be lower than the saturation temperature, if required. The drain 70 is opened so as to allow cooling water to flow into and out of the cooling volume without reaching the saturation temperature. This effectively reduces the temperature of the cooling water in the cooling volume when compared with the first example of use, so that the heat transfer rate between the steam flow and the cooling water is increased to the extent that the steam flow can be fully de-superheated. In this example, the drain 70 can be opened to control a drainage flow rate and forms part of a feedback loop with the controller 72 and steam sensors 36, 38 and 40. The feedback loop alters the drainage flow rate to reach or maintain the desired outlet steam properties. However, since the cooling water is below the saturation temperature, the cooling water may not vaporise and combine with the steam flow. This example of use may correspond to a temporary mode of use, for example, if the level of superheat in the steam flow is temporarily too high.

[0070] As described above, the invention allows thermal energy recovered from the drive unit by cooling water to be transferred to the steam flow. Further, it will be appreciated that raising the temperature of the cooling water to the elevated temperature means that comparatively more cooling water is required to de-superheat the same quantity of steam flow. Since the cooling water is combined with the steam flow (either by injection or by vaporisation and subsequent joining of flows), the elevated temperature of the cooling water also results in an increased proportion of the steam flow downstream of the de-superheater originating from the cooling water (or, as a corollary, a reduced proportion originating from the steam flow upstream of the compressor). Consequently, less upstream low-pressure steam is required in order to provide the same quantity of downstream high-pressure steam.

Claims

1. A method of operating a steam compression apparatus (10) comprising a compressor (12) and a drive unit (14), the method comprising:

   operating the drive unit (14) to drive the compressor (12) so as to provide a superheated steam flow;
   characterized by
   cooling the drive unit (14) with a liquid cooling medium, so that the cooling medium recovers thermal energy from the drive unit (14); and
   de-superheating the steam flow from the compressor (12) by injecting the cooling medium into the steam flow downstream of the drive unit (14).

2. A method according to claim 1, further comprising controlling the injection of the cooling medium into the steam flow.

3. A method according to claim 2, further comprising monitoring a thermodynamic property of the steam flow such as the temperature, pressure and/or dryness of the steam flow, and wherein the injection of the cooling medium is controlled at least partly based on the thermodynamic property.

4. A method according to claim 2 or 3, further comprising monitoring the flow rate of the steam flow and controlling the injection of the cooling medium at least partly based on the flow rate of the steam flow.

5. A method according to any one of claims 2 to 4, further comprising monitoring a thermodynamic property of the cooling medium downstream of the drive unit (14), such as the temperature and/or pressure of the cooling medium, and controlling the injection of the cooling medium at least partly based on the thermodynamic property of the cooling medium.

6. A method according to any one of claims 2 to 5, wherein the injection of the cooling medium is controlled based on monitoring a thermodynamic property of the steam flow using a steam sensor so as to de-superheat the steam flow to provide substantially dry saturated steam or to de-superheat the steam flow to a predetermined level of superheat.

7. A method of operating a steam compression apparatus (10) comprising a compressor (12) and a drive unit (14), the method comprising:

   operating the drive unit (14) to drive the compressor (12) so as to provide a superheated steam flow;
   characterized by
   cooling the drive unit (14) with a liquid cooling medium, so that the cooling medium recovers thermal energy from the drive unit (14); and
   de-superheating the steam flow from the compressor (12) by indirect heat transfer between the steam flow and the cooling medium downstream of the drive unit (14), thereby vaporising a portion of the cooling medium to provide a vaporised flow which combines with the steam flow.

8. A steam compression apparatus (10) comprising:

   a compressor for providing a superheated steam flow;
   a drive unit for driving the compressor; and **characterized by**:

a cooling apparatus arranged to provide a cooling medium to the drive unit (14) so that in use the cooling medium recovers thermal energy from the drive unit (14); and
a de-superheater (16) arranged to receive the cooling medium downstream of the drive unit (14), the de-superheater (16)being arranged to de-superheat the steam flow from the compressor by injecting the cooling medium into the steam flow.

9. A steam compression apparatus (10) according to claim 8, wherein the de-superheater (16) comprises a valve and a valve controller (48) for controlling the injection of the cooling medium into the steam flow.

10. A steam compression apparatus (10) according to claim 9, further comprising a steam sensor (36, 38, 40) for monitoring a thermodynamic property of the steam flow, such as a temperature, pressure and/or dryness sensor, and wherein the valve controller (48) controls the injection of the cooling medium at least partly based on the thermodynamic property of the steam flow.

11. A steam compression apparatus (10) according to claim 9 or 10, further comprising a flow meter (42) for monitoring the flow rate of the steam flow, wherein the valve controller (48) controls the injection of the cooling medium at least partly based on the flow rate of the steam flow.

12. A steam compression apparatus (10) according to any one of claims 9 to 11, further comprising a cooling medium sensor (46) for monitoring a thermodynamic property of the cooling medium downstream of the drive unit (14), such as the temperature and/or pressure of the cooling medium, wherein the valve controller (48) controls the injection of the cooling medium at least partly based on the thermodynamic property of the cooling medium.

13. A steam compression apparatus (10) according to any one of claims 9 to 12, wherein the valve controller (48) is configured to control the injection of the cooling medium based on monitoring a thermodynamic property of the steam flow so as to de-superheat the steam flow to provide substantially dry saturated steam or to de-superheat the steam flow to a predetermined level of superheat.

14. A steam compression apparatus (10) comprising:

a compressor (12) for providing a superheated steam flow;
a drive unit (14) for driving the compressor; and
characterized by
a cooling apparatus (18) arranged to provide a liquid cooling medium to the drive unit (14) so that in use the cooling medium recovers thermal energy from the drive unit (14); and
a de-superheater (16') arranged to receive the cooling medium downstream of the drive unit (14), the de-superheater comprising:

a cooling volume (58) for receiving the cooling medium; and
a steam tube (52, 53) extending through the cooling volume (58) for conveying the superheated steam flow therethrough to de-superheate the steam flow by indirect heat transfer to the cooling medium so that in use a portion of the cooling medium is vaporised;
wherein the de-superheater (16') is arranged so that the vaporised cooling medium in the cooling volume (58) is in fluid communication with the steam tube (52, 53) to combine with the steam flow.

15. A steam compression apparatus (10) according to claim 14, wherein the steam tube (52, 53) has an open upper end in fluid communication with the cooling volume (58) so that the cooling medium received from the drive unit is at substantially the same pressure as the steam flow, and so that in use the cooling medium received therein tends to the saturation temperature of the steam flow.

Patentansprüche

1. Verfahren zum Betreiben einer Dampfkompressionsvorrichtung (10), die einen Kompressor (12) und eine Antriebseinheit (14) umfasst, wobei das Verfahren Folgendes umfasst:

Betreiben der Antriebseinheit (14), um den Kompressor (12) anzutreiben, um einen Heißdampfstrom vorzusehen;
gekennzeichnet durch
Kühlen der Antriebseinheit (14) mit einem flüssigen Kühlmedium, sodass das Kühlmedium Wärmeenergie von der Antriebseinheit (14) zurückgewinnt; und
Abkühlen des Dampfstroms vom Kompressor (12) durch Einspritzen des Kühlmediums in den Dampfstrom nach der Antriebseinheit (14).

2. Verfahren nach Anspruch 1, ferner das Steuern des Einspritzens des Kühlmediums in den Dampfstrom umfassend.

3. Verfahren nach Anspruch 2, ferner das Überwachen einer thermodynamischen Eigenschaft des Dampfstroms, zum Beispiel der Temperatur, des Drucks

und/oder der Trockenheit des Dampfstroms, umfassend, und wobei das Einspritzen des Kühlmediums zumindest teilweise auf Grundlage der thermodynamischen Eigenschaft gesteuert wird.

4. Verfahren nach Anspruch 2 oder 3, ferner das Überwachen der Strömungsgeschwindigkeit des Dampfstroms und das Steuern des Einspritzens des Kühlmediums zumindest teilweise auf Grundlage der Strömungsgeschwindigkeit des Dampfstroms umfassend.

5. Verfahren nach einem der Ansprüche 2 bis 4, ferner das Überwachen einer thermodynamischen Eigenschaft des Kühlmediums nach der Antriebseinheit (14), zum Beispiel der Temperatur und/oder des Drucks des Kühlmediums, und das Steuern des Einspritzens des Kühlmediums zumindest teilweise auf Grundlage der thermodynamischen Eigenschaft des Kühlmediums umfassend.

6. Verfahren nach einem der Ansprüche 2 bis 5, wobei das Einspritzen des Kühlmediums auf Grundlage des Überwachens einer thermodynamischen Eigenschaft des Dampfstroms unter Verwendung eines Dampfsensors gesteuert wird, um den Dampfstrom abzukühlen, um im Wesentlichen trockenen, gesättigten Dampf vorzusehen oder den Dampfstrom auf ein festgelegtes Temperaturniveau abzukühlen.

7. Verfahren des Betreibens einer Dampfkompressionsvorrichtung (10), die einen Kompressor (12) und eine Antriebseinheit (14) umfasst, wobei das Verfahren Folgendes umfasst:

Betreiben der Antriebseinheit (14), um den Kompressor (12) anzutreiben, um einen Heißdampfstrom vorzusehen;
gekennzeichnet durch
Kühlen der Antriebseinheit (14) mit einem flüssigen Kühlmedium, sodass das Kühlmedium Wärmeenergie von der Antriebseinheit (14) zurückgewinnt; und
Abkühlen des Dampfstroms vom Kompressor (12) durch indirekte Wärmeübertragung zwischen dem Dampfstrom und dem Kühlmedium nach der Antriebseinheit (14), wodurch ein Teil des Kühlmediums verdampft wird, um einen verdampften Strom vorzusehen, der sich mit dem Dampfstrom verbindet.

8. Dampfkompressionsvorrichtung (10), Folgendes umfassend:

einen Kompressor zum Vorsehen eines Heißdampfstroms;
eine Antriebseinheit zum Antreiben des Kompressors; und
gekennzeichnet durch:
eine Kühlvorrichtung, die dazu angeordnet ist, die Antriebseinheit (14) mit einem Kühlmedium zu versorgen,
sodass das Kühlmedium bei der Verwendung Wärmeenergie von der Antriebseinheit (14) zurückgewinnt; und
einen Dampfkühler (16), der dazu angeordnet ist, das Kühlmedium nach der Antriebseinheit (14) aufzunehmen, wobei der Dampfkühler (16) dazu angeordnet ist, den Dampfstrom vom Kompressor durch Einspritzen des Kühlmediums in den Dampfstrom abzukühlen.

9. Dampfkompressionsvorrichtung (10) nach Anspruch 8, wobei der Dampfkühler (16) ein Ventil und eine Ventilsteuerung (48) zum Steuern des Einspritzens des Kühlmediums in den Dampfstrom umfasst.

10. Dampfkompressionsvorrichtung (10) nach Anspruch 9, ferner einen Dampfsensor (36, 38, 40) zum Überwachen einer thermodynamischen Eigenschaft des Dampfstroms, zum Beispiel einen Temperatur-, Druck- und/oder Trockenheitssensor, umfassend, und wobei die Ventilsteuerung (48) das Einspritzen des Kühlmediums zumindest teilweise auf Grundlage der thermodynamischen Eigenschaft des Dampfstroms steuert.

11. Dampfkompressionsvorrichtung (10) nach Anspruch 9 oder 10, ferner einen Strömungsmesser (42) zum Überwachen der Strömungsgeschwindigkeit des Dampfstroms umfassend, wobei die Ventilsteuerung (48) das Einspritzen des Kühlmediums zumindest teilweise auf Grundlage der Strömungsgeschwindigkeit des Dampfstroms steuert.

12. Dampfkompressionsvorrichtung (10) nach einem der Ansprüche 9 bis 11, ferner einen Kühlmittelsensor (46) zum Überwachen einer thermodynamischen Eigenschaft des Kühlmediums nach der Antriebseinheit (14), zum Beispiel der Temperatur und/oder des Drucks des Kühlmediums, umfassend, wobei die Ventilsteuerung (48) das Einspritzen des Kühlmediums zumindest teilweise auf Grundlage der thermodynamischen Eigenschaft des Kühlmediums steuert.

13. Dampfkompressionsvorrichtung (10) nach einem der Ansprüche 9 bis 12, wobei die Ventilsteuerung (48) dazu ausgelegt ist, das Einspritzen des Kühlmediums auf Grundlage des Überwachens einer thermodynamischen Eigenschaft des Dampfstroms zu steuern, um den Dampfstrom abzukühlen, um im Wesentlichen trockenen, gesättigten Dampf vorzusehen oder den Dampfstrom auf ein festgelegtes

Temperaturniveau abzukühlen.

14. Dampfkompressionsvorrichtung (10), Folgendes umfassend:

einen Kompressor (12) zum Vorsehen eines Heißdampfstroms;
eine Antriebseinheit (14) zum Antreiben des Kompressors;
und **gekennzeichnet durch**
eine Kühlvorrichtung (18), die dazu angeordnet ist, die Antriebseinheit (14) mit einem flüssigen Kühlmedium zu versorgen, sodass das Kühlmedium bei der Verwendung Wärmeenergie von der Antriebseinheit (14) zurückgewinnt; und
einen Dampfkühler (16'), der dazu angeordnet ist, das Kühlmedium nach der Antriebseinheit (14) aufzunehmen, wobei der Dampfkühler Folgendes umfasst:

einen Kühlraum (58) zum Aufnehmen des Kühlmediums; und
ein Dampfrohr (52, 53), das sich durch den Kühlraum (58) erstreckt, um den Heißdampfstrom dort hindurch zu befördern, um den Dampfstrom durch indirekte Wärmeübertragung zum Kühlmedium abzukühlen, sodass bei der Verwendung ein Teil des Kühlmediums verdampft wird;
wobei der Dampfkühler (16') derart angeordnet ist, dass das verdampfte Kühlmedium im Kühlraum (58) mit dem Dampfrohr (52, 53) in Fluidverbindung steht, um sich mit dem Dampfstrom zu verbinden.

15. Dampfkompressionsvorrichtung (10) nach Anspruch 14, wobei das Dampfrohr (52, 53) ein offenes oberes Ende aufweist, das mit dem Kühlraum (58) in Fluidverbindung steht, sodass das von der Antriebseinheit aufgenommene Kühlmedium im Wesentlichen denselben Druck wie der Dampfstrom aufweist, und sodass das darin aufgenommene Kühlmedium bei der Verwendung zur Sättigungstemperatur des Dampfstroms tendiert.

Revendications

1. Procédé de fonctionnement d'un appareil de compression de vapeur (10) comprenant un compresseur (12) et une unité d'entraînement (14), le procédé comprenant l'étape consistant à :

faire fonctionner l'unité d'entraînement (14) pour entraîner le compresseur (12) de sorte à fournir un flux de vapeur surchauffé ;
caractérisé par les étapes consistant à
refroidir l'unité d'entraînement (14) avec un milieu de refroidissement liquide, de sorte que le milieu de refroidissement récupère l'énergie thermique provenant de l'unité d'entraînement (14) ; et
dé-surchauffer le flux de vapeur provenant du compresseur (12) en injectant le milieu de refroidissement dans le flux de vapeur en aval de l'unité d'entraînement (14).

2. Procédé selon la revendication 1, comprenant en outre l'étape consistant à commander l'injection du milieu de refroidissement dans le flux de vapeur.

3. Procédé selon la revendication 2, comprenant en outre l'étape consistant à surveiller une propriété thermodynamique du flux de vapeur telle que la température, la pression et/ou la sécheresse du flux de vapeur, et l'injection du milieu de refroidissement étant commandée au moins partiellement sur la base de la propriété thermodynamique.

4. Procédé selon la revendication 2 ou 3, comprenant en outre les étapes consistant à surveiller le débit du flux de vapeur et à commander l'injection du milieu de refroidissement au moins partiellement sur la base du débit du flux de vapeur.

5. Procédé selon l'une quelconque des revendications 2 à 4, comprenant en outre les étapes consistant à surveiller une propriété thermodynamique du milieu de refroidissement en aval de l'unité d'entraînement (14), telle que la température et/ou la pression du milieu de refroidissement, et à commander l'injection du milieu de refroidissement au moins partiellement sur la base de la propriété thermodynamique du milieu de refroidissement.

6. Procédé selon l'une quelconque des revendications 2 à 5, l'injection du milieu de refroidissement étant commandée sur la base de la surveillance d'une propriété thermodynamique du flux de vapeur au moyen d'un capteur de vapeur de sorte à dé-surchauffer le flux de vapeur pour fournir de la vapeur saturée sensiblement sèche ou à dé-surchauffer le flux de vapeur à un niveau de surchauffe prédéfini.

7. Procédé de fonctionnement d'un appareil de compression de vapeur (10) comprenant un compresseur (12) et une unité d'entraînement (14), le procédé comprenant l'étape consistant à :

faire fonctionner l'unité d'entraînement (14) pour entraîner le compresseur (12) de sorte à fournir un flux de vapeur surchauffé ;
caractérisé par les étapes consistant à
refroidir l'unité d'entraînement (14) avec un milieu de refroidissement liquide, de sorte que le milieu de refroidissement récupère l'énergie

thermique provenant de l'unité d'entraînement (14) ; et
dé-surchauffer le flux de vapeur provenant du compresseur (12) par transfert de chaleur indirect entre le flux de vapeur et le milieu de refroidissement en aval de l'unité d'entraînement (14), vaporisant ainsi une partie du milieu de refroidissement pour obtenir un flux vaporisé qui se combine avec le flux de vapeur.

8. Appareil de compression de vapeur (10) comprenant :

un compresseur pour fournir un flux de vapeur surchauffé ;
une unité d'entraînement pour entraîner le compresseur ; et **caractérisé par** :

un appareil de refroidissement conçu pour fournir un milieu de refroidissement à l'unité d'entraînement (14) de sorte que, lors de l'utilisation, le milieu de refroidissement récupère l'énergie thermique provenant de l'unité d'entraînement (14) ; et
un dé-surchauffeur (16) conçu pour recevoir le milieu de refroidissement en aval de l'unité d'entraînement (14), le dé-surchauffeur (16) étant conçu pour dé-surchauffer le flux de vapeur provenant du compresseur en injectant le milieu de refroidissement dans le flux de vapeur.

9. Appareil de compression de vapeur (10) selon la revendication 8, le dé-surchauffeur (16) comprenant une vanne et un dispositif de commande de vanne (48) pour commander l'injection du milieu de refroidissement dans le flux de vapeur.

10. Appareil de compression de vapeur (10) selon la revendication 9, comprenant en outre un capteur de vapeur (36, 38, 40) pour surveiller une propriété thermodynamique du flux de vapeur, tel qu'un capteur de température, de pression et/ou de sécheresse, et le dispositif de commande de vanne (48) commandant l'injection du milieu de refroidissement au moins partiellement sur la base de la propriété thermodynamique du flux de vapeur.

11. Appareil de compression de vapeur (10) selon la revendication 9 ou 10, comprenant en outre un débitmètre (42) pour surveiller le débit du flux de vapeur, le dispositif de commande de vanne (48) commandant l'injection du milieu de refroidissement au moins partiellement sur la base du débit du flux de vapeur.

12. Appareil de compression de vapeur (10) selon l'une quelconque des revendications 9 à 11, comprenant en outre un capteur de milieu de refroidissement (46) pour surveiller une propriété thermodynamique du milieu de refroidissement en aval de l'unité d'entraînement (14), telle que la température et/ou la pression du milieu de refroidissement, le dispositif de commande de vanne (48) commandant l'injection du milieu de refroidissement au moins partiellement sur la base de la propriété thermodynamique du milieu de refroidissement.

13. Appareil de compression de vapeur (10) selon l'une quelconque des revendications 9 à 12, le dispositif de commande de vanne (48) étant conçu pour commander l'injection du milieu de refroidissement sur la base de la surveillance d'une propriété thermodynamique du flux de vapeur de sorte à dé-surchauffer le flux de vapeur pour fournir de la vapeur saturée sensiblement sèche ou à dé-surchauffer le flux de vapeur à un niveau de surchauffe prédéfini.

14. Appareil de compression de vapeur (10) comprenant :

un compresseur (12) pour fournir un flux de vapeur surchauffé ;
une unité d'entraînement (14) pour entraîner le compresseur ; et **caractérisé par**
un appareil de refroidissement (18) conçu pour fournir un milieu de refroidissement liquide à l'unité d'entraînement (14) de sorte que, lors de l'utilisation, le milieu de refroidissement récupère l'énergie thermique provenant de l'unité d'entraînement (14) ; et
un dé-surchauffeur (16') disposé pour recevoir le milieu de refroidissement en aval de l'unité d'entraînement (14), le dé-surchauffeur comprenant :

un volume de refroidissement (58) pour recevoir le milieu de refroidissement ; et
un tube de vapeur (52, 53) s'étendant à travers le volume de refroidissement (58) pour y faire passer le flux de vapeur surchauffé afin de dé-surchauffer le flux de vapeur par transfert de chaleur indirect au milieu de refroidissement de sorte que, lors de l'utilisation, une partie du milieu de refroidissement soit vaporisée ;

le dé-surchauffeur (16') étant disposé de sorte que le milieu de refroidissement vaporisé dans le volume de refroidissement (58) soit en communication fluidique avec le tube de vapeur (52, 53) pour se combiner avec le flux de vapeur.

15. Appareil de compression de vapeur (10) selon la revendication 14, le tube de vapeur (52, 53) ayant une extrémité supérieure ouverte en communication fluidique avec le volume de refroidissement (58) de sor-

te que le milieu de refroidissement reçu de l'unité d'entraînement soit à une pression sensiblement identique à celle du flux de vapeur, et de sorte que lors de l'utilisation, le milieu de refroidissement reçu en son sein tende vers la température de saturation du flux de vapeur.

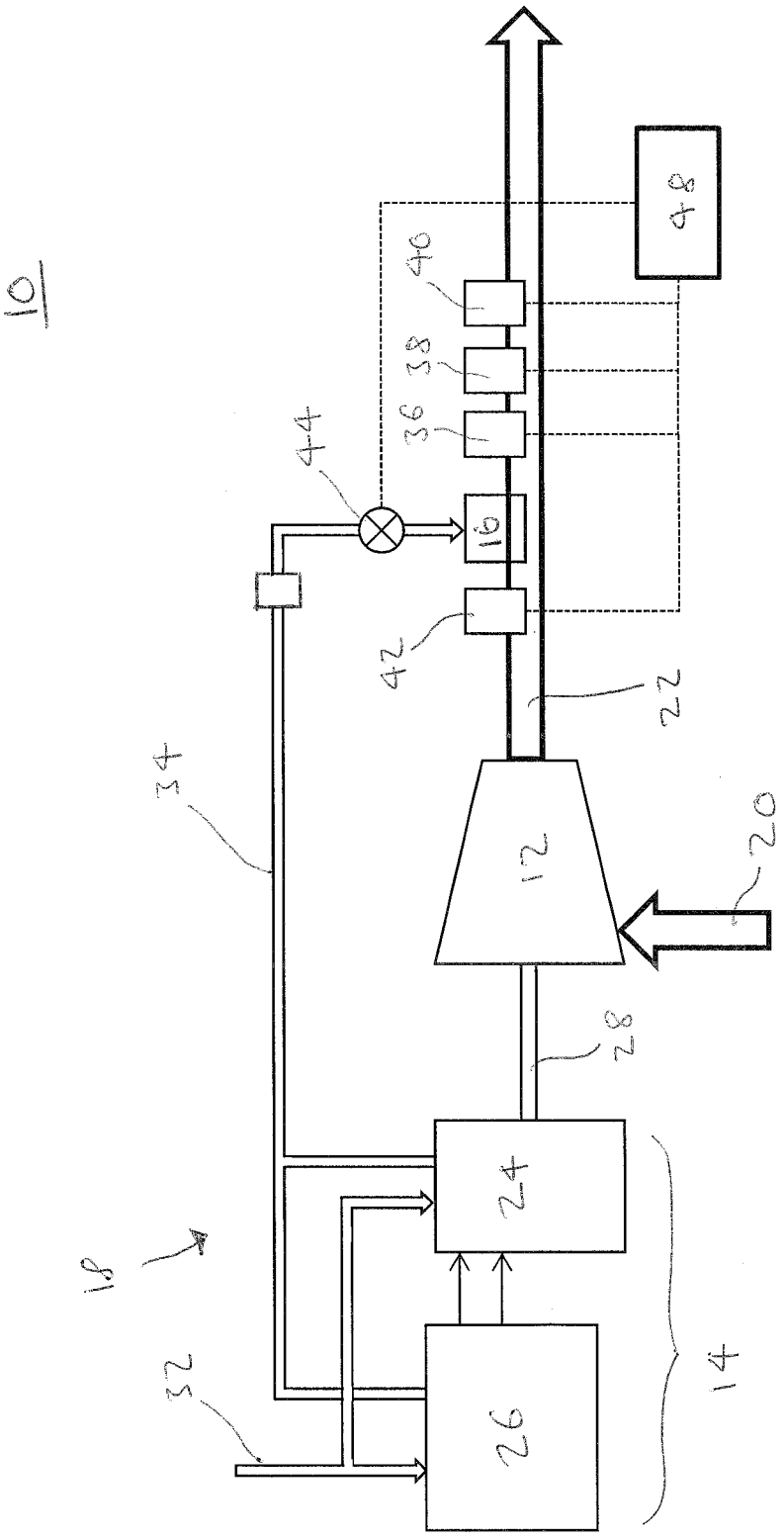


Figure 1

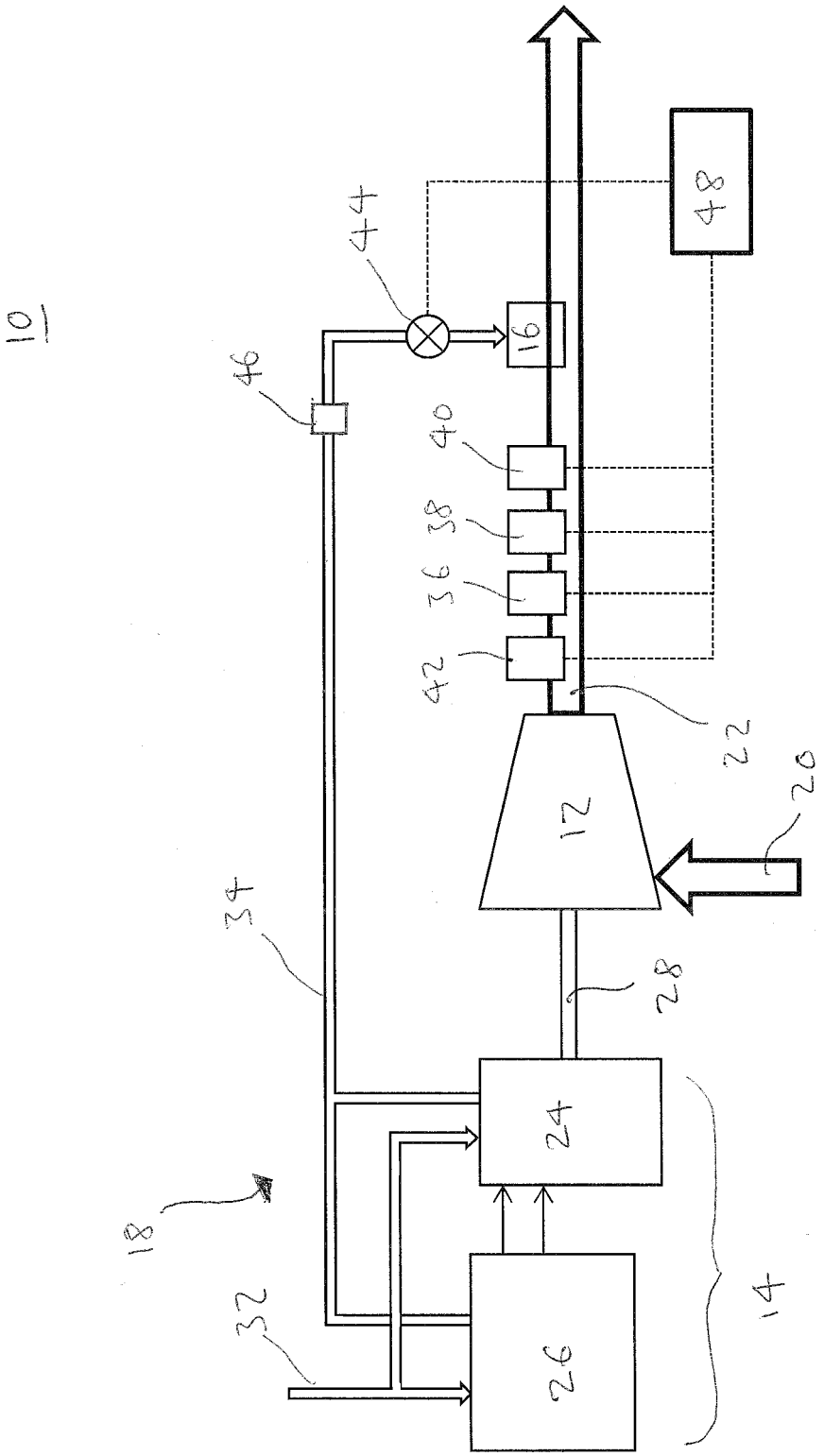


Figure 2

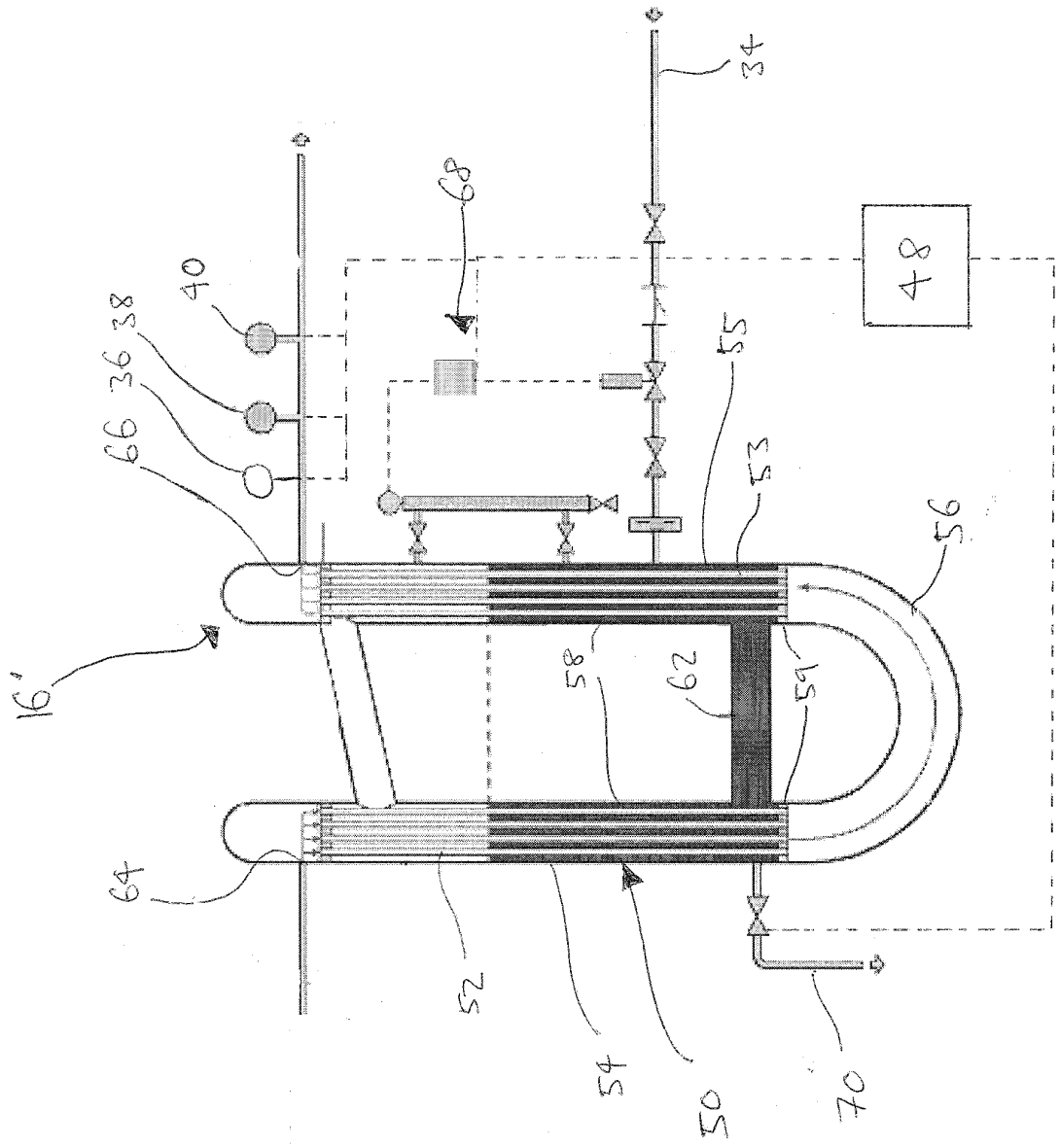


Figure 3

REFERENCES CITED IN THE DESCRIPTION

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