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(54) Title of the Invention: **Vacuum system apparatus and method**
Abstract Title: **VACUUM SYSTEM HEAT EXCHANGER USING PURGE GAS**

(57) A vacuum system 1 comprising a vacuum pump 3 and a heat exchanger 7 for receiving a heat transfer gas, the heat exchanger thermally coupled to the vacuum pump to absorb thermal energy therefrom. The heat transfer gas may be a pump purge gas. The purge gas may be selectively supplied to the vacuum pump or pump exhaust, the supply conditions being determined by a controller 31. The system may include a gas heater 11 disposed between the heat exchanger and gas outlet port, for heating the heat transfer fluid. The supply of gas may be controlled by a control valve 9, which may reduce supply of gas to reduce absorption of heat from the pump in response to a signal indicating the pump is operating in low load condition. The system may comprise a cooling block 39 configured to receive a liquid coolant, the block being independent of the heat exchanger.

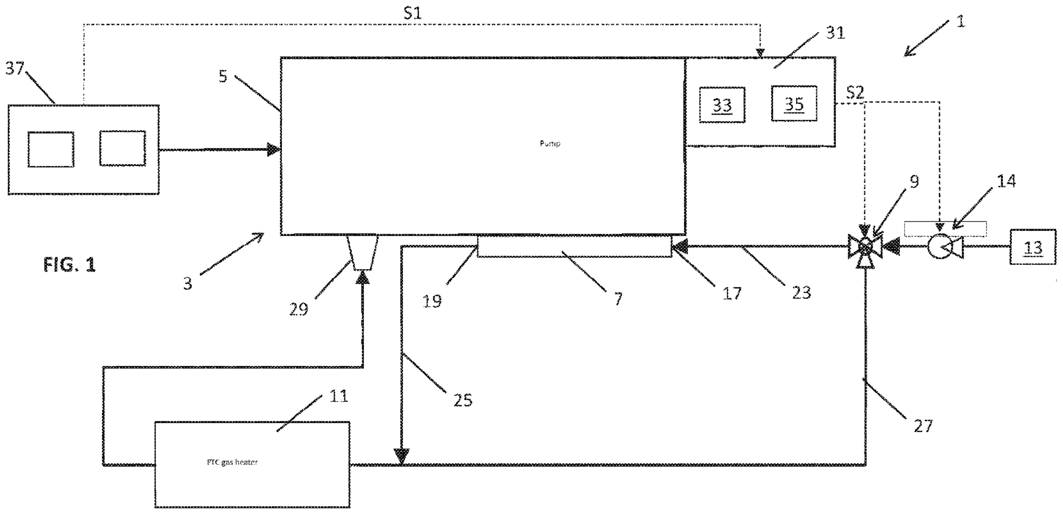

FIG. 1

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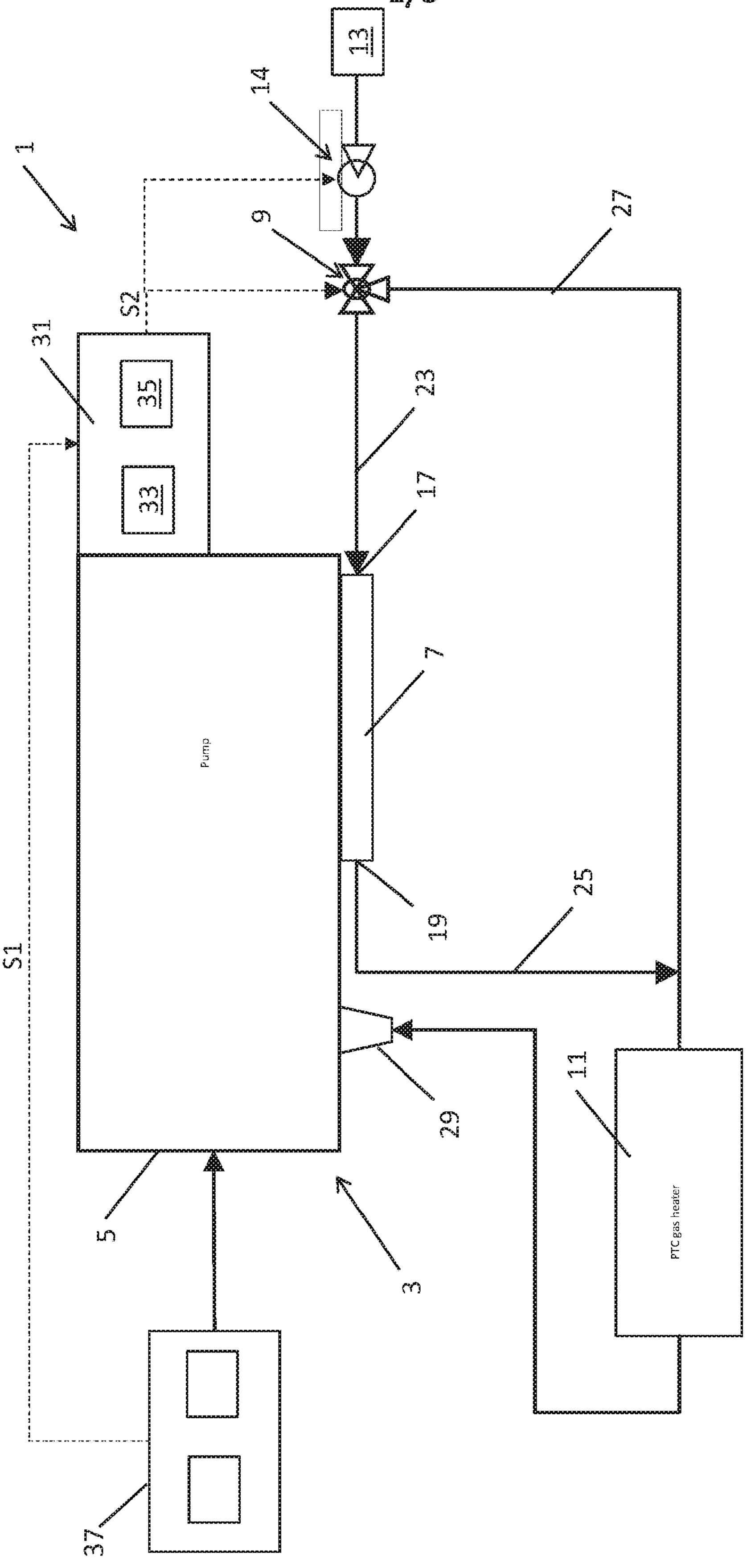
1
13
14
9
27
S2
31
35
33
23
17
7
Pump
19
25
S1
29
11
PTC gas heater
5
3
37

FIG. 1

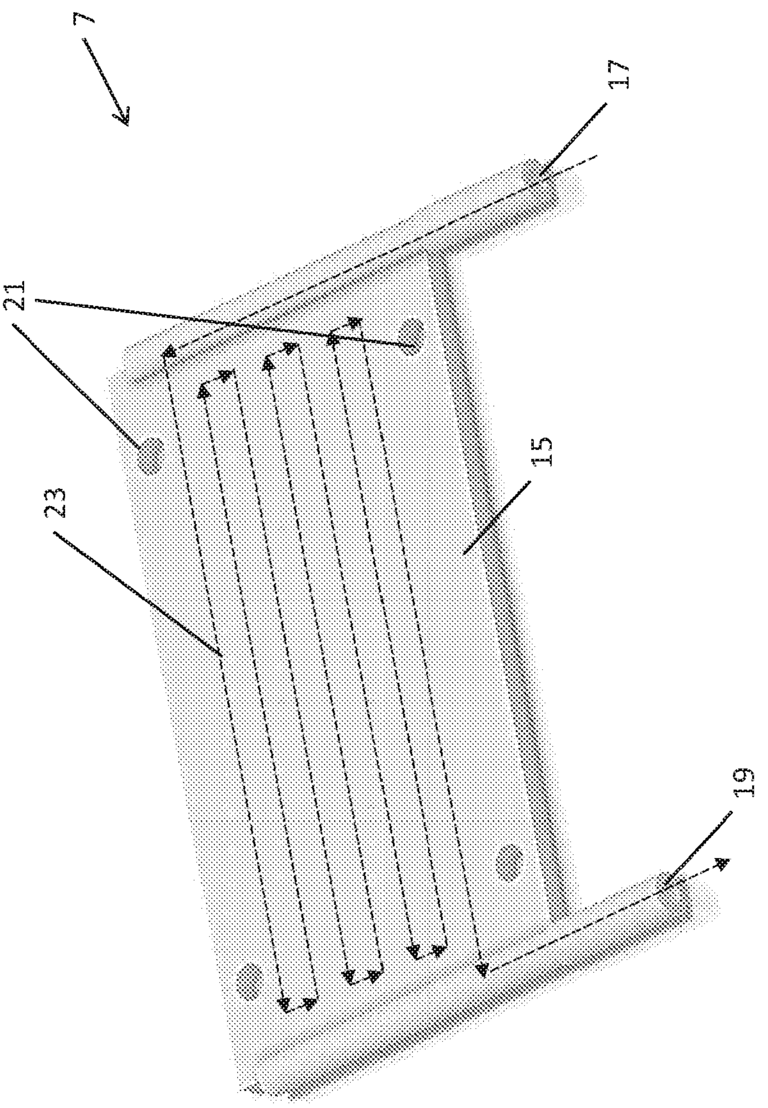

FIG. 2

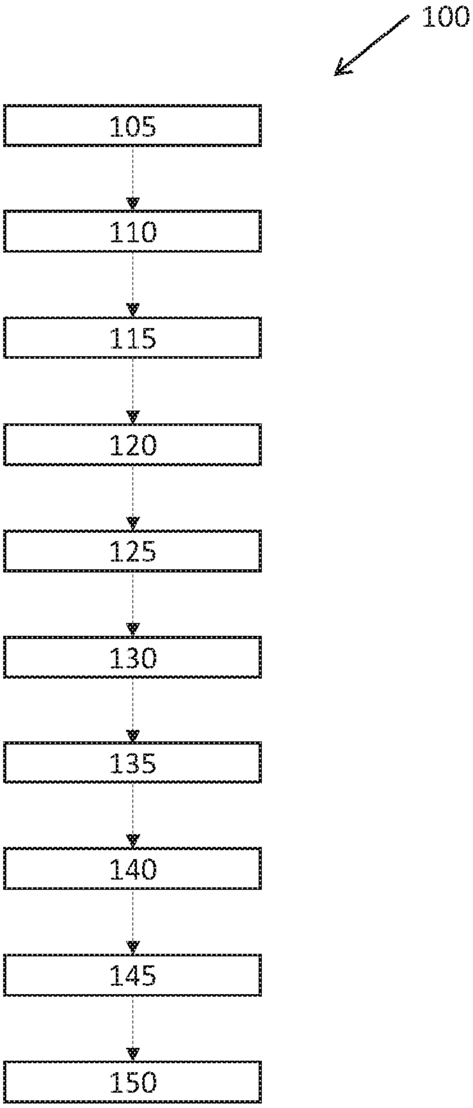

FIG. 3

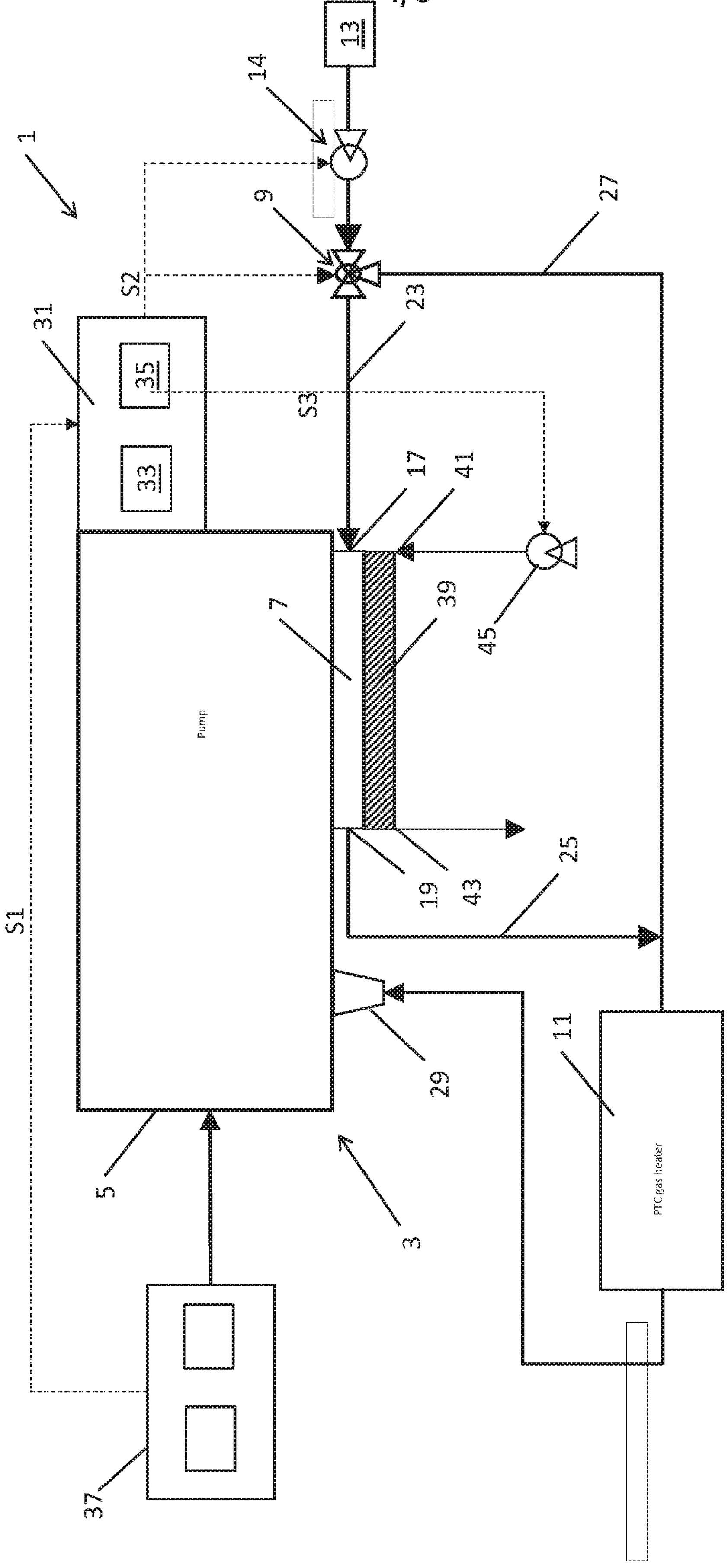
1
14
13
9
27
S2
31
23
35
S3
33
17
41
7
39
45
Pump
19
43
25
S1
29
11
5
3
PTC gas heater
37

FIG. 4

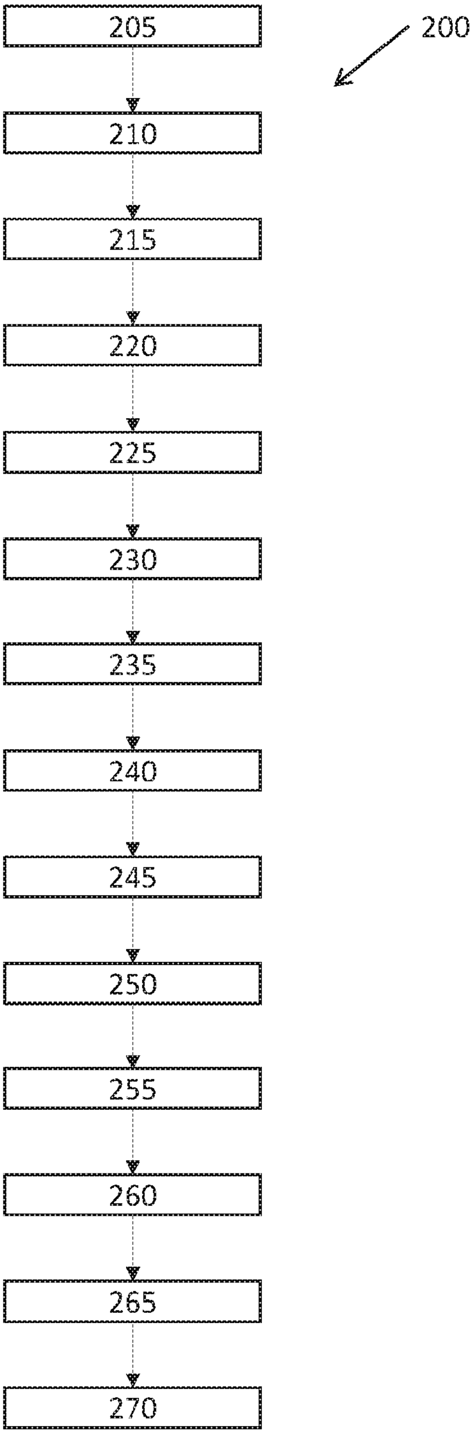

FIG. 5

VACUUM SYSTEM APPARATUS AND METHOD

TECHNICAL FIELD

The present disclosure relates to a vacuum system apparatus and method. Aspects of the invention relate to a vacuum system; a heat exchange apparatus; a method of operating a vacuum system and a controller for controlling operation of a vacuum system.

BACKGROUND

It is known to provide industrial vacuum systems with cooling blocks to maintain a target operating temperature for a vacuum pump. The target operating temperature is typically set to suit a particular industrial process. The target operating temperatures of vacuum pumps continue to increase in order to reduce process-related pump failures.

High power compression stages or active heating is required to achieve the target operating temperatures. The gas temperature in the exhaust conduit has to maintained similar to the pump outlet temperature to prevent or reduce condensation of the process gases. It is known to introduce a purge gas, such as nitrogen (N), into the vacuum pump or into an exhaust conduit of the vacuum pump to minimise condensation failures. As the process flow to the pump increases, there is an increase in the pump power while the pump operates under high load. There is a corresponding increase in the operating temperature of the vacuum pump. The vacuum pumps are equipped with cooling blocks to maintain the pump temperature during such an event. However, when the vacuum pump is operating at low loads, for example during idle operating conditions, the cooling block functions as a heat sink which absorbs thermal energy. The cooling block delays the vacuum pump reaching the target operating temperature. Thus, additional power is consumed to achieve the target operating temperature.

It is an aim of the present invention to address one or more of the disadvantages associated with the prior art.

SUMMARY OF THE INVENTION

Aspects and embodiments of the invention provide a vacuum system, a method of operating a vacuum system and a controller as claimed in the appended claims.

According to a first aspect of the present invention there is provided a vacuum system comprising:

a vacuum pump; and

a heat exchanger for receiving a heat transfer fluid, the heat transfer fluid comprising a gas;

wherein the heat exchanger is thermally coupled to the vacuum pump and is operable to absorb thermal energy from the vacuum pump.

The heat transfer fluid promotes heat rejection from the vacuum pump. At least in certain embodiments, the supply of heat transfer fluid to the heat exchanger can be controlled. Thus, the transfer of thermal energy from the vacuum pump can be controlled, for example in dependence on one or more operating parameters of the vacuum pump. At least in certain embodiments, the footprint of the vacuum system may be smaller than that of prior art systems. The power consumption of the vacuum system may be reduced; and/or emissions associated with operation of the vacuum system may be reduced.

The heat exchanger may comprise an inlet and an outlet. A flow path may be defined between the inlet and the outlet. In use, the heat transfer fluid introduced through the inlet follows the flow path and is discharged through the outlet. The flow path may, for example, comprise or consist of a serpentine path or a convoluted path to increase the heat exchange surface area. The heat exchanger may have one or more internal fins for promoting heat exchange with the heat transfer fluid.

The heat exchanger may be mounted to the vacuum pump. The vacuum pump may comprise a pump housing. The heat exchanger may be thermally coupled to the pump housing. The heat exchanger may be mounted to the pump housing. A thermal coupler may be provided between the heat exchanger and the heat exchanger to promote thermal conduction.

The heat transfer fluid may comprise a purge gas for introduction into the vacuum pump.

The vacuum system may comprise at last one port. The heat exchanger may be connected to the at least one port. For example, a heat exchanger outline line may be connected to the or each port. In use, the heat transfer fluid from the heat exchanger may be introduced into the at least one port. The port may be provided in the vacuum pump to enable introduction of the heat transfer fluid into the vacuum pump. The port may, for example, be configured to introduce the heat exchange fluid into an intermediate stage of the vacuum pump. The port may, for example, comprise an inter-stage port of the vacuum pump. Alternatively, or in addition, the port may be provided in an exhaust (or final stage) of the vacuum pump to enable introduction of the heat transfer fluid into the exhaust.

The vacuum system may comprise a gas heater for heating the heat transfer fluid. The gas heater may, for example, be disposed between the heat exchanger and the port. The heat transfer fluid discharged from the heat exchanger may be supplied to the gas heater. The gas heater may perform additional heating prior to introducing the purge gas into the vacuum pump.

The vacuum system may comprise means for controlling the supply of the heat transfer fluid to the heat exchanger. The control means may comprise a pump, for example. Alternatively, the control means may comprise at least one control valve. The control valve(s) may be suitable for controlling the supply of the heat transfer fluid to the heat exchanger. The control valve(s) may, for example, comprise one or more three-way valve. Other types of valve are contemplated.

The at least one control valve may optionally control a supply rate of the heat transfer fluid. Alternatively, or in addition, a flow restrictor may be provided for controlling the supply rate. The flow restrictor may be fixed or variable.

The at least one control valve may be operable selectively to bypass the heat exchanger. The heat exchanger may, for example, be bypassed to supply the gas directly to the gas heater.

The vacuum system may comprise a valve controller for controlling operation of the at least one control valve. The valve controller may comprise at least one electronic processor having at least one input for receiving a signal indicating an operating state of the vacuum pump.

The valve controller may be configured selectively to actuate the control valve to decrease or inhibit the supply of the heat transfer fluid to the heat exchanger to reduce the absorption of thermal energy from the vacuum pump. The valve controller may be configured to control the control valve to reduce heat rejection during idle operation of the vacuum pump, for example during a start-up procedure. The heat exchanger may be configured to reduce heat rejection in dependence on a decreased load or a low load on the vacuum pump. The valve controller may be configured selectively to actuate the control valve to decrease the supply of the heat transfer fluid to the heat exchanger in dependence on the signal indicating that the vacuum pump is operating in a low load condition.

The valve controller may be configured selectively to actuate the control valve to increase the supply of the heat transfer fluid to the heat exchanger to increase the absorption of thermal energy from the vacuum pump. The valve controller may be configured to control the control valve to increase heat rejection during high load operating conditions. The heat exchanger may be configured to increase heat rejection in dependence on an increased load or a high load on the vacuum pump. The valve controller may be configured selectively to actuate the control valve to increase the supply of the heat transfer fluid to the heat exchanger in dependence on the signal indicating that the vacuum pump is operating in a high load condition.

The gas may be pre-heated before being supplied to the gas heater. The vacuum system may be configured to reduce heating performed by the gas heater while the heat exchanger is active.

The vacuum system may comprise a cooling block thermally coupled to the heat exchanger. The cooling block may be operable selectively to absorb thermal energy from the heat exchanger. The cooling block may be configured to receive a coolant. The coolant may comprise or consist of a liquid. The liquid may comprise water, for example.

The cooling block may have an inlet and an outlet for conveyance of the coolant. The liquid coolant may be introduced into the cooling block through the inlet and discharged through the outlet.

The vacuum system may comprise a cooling block controller for controlling a supply of the coolant to the cooling block. A coolant control valve may be provided to control the supply of the coolant to the cooling block. The cooling block controller may control operation of the coolant control valve. The cooling block controller may be configured to supply coolant in dependence on a determination that the temperature of the heat exchanger is greater than or equal to a predefined temperature threshold.

The heat exchanger and the cooling block may be operable independently of each other. For example, the vacuum system may be configured to activate the heat exchanger when the cooling block is inactive. The vacuum system may be configured to activate the heat exchanger and the cooling block concurrently.

According to a further aspect of the present invention there is provided a heat exchange apparatus for mounting to a vacuum pump, the heat exchange assembly comprising:

a gas heat exchanger having a first side for thermal coupling to the vacuum pump; and a cooling block for receiving a liquid coolant, the cooling block being thermally coupled to a second side of the gas heat exchanger. The first and second sides may be opposing sides of the gas heat exchanger. In use, the gas heat exchanger is disposed between the vacuum pump and the cooling block. At least in certain embodiments, the cooling block is spaced apart from the vacuum pump. In use, the cooling block may be at least partially thermally isolated from the vacuum pump. The gas heat exchanger may be operated to promote rejection of thermal energy from the vacuum pump. The cooling block may be operated to promote rejection of thermal energy from the gas heat exchanger. The gas heat exchanger and the cooling block may be operable independently of each other. In use, one or both of the gas heat exchanger and the cooling block may be active. For example, the gas heat exchanger may operate on its own or in conjunction with the cooling block.

The gas heat exchanger may comprise a gas inlet and a gas outlet. The gas inlet and the gas outlet may be connected by an internal conduit. The internal conduit may, for example, comprise a serpentine pathway. The cooling block comprises a liquid coolant inlet and a liquid coolant outlet. The gas inlet and the gas outlet are connected by an internal conduit. The internal conduit may, for example, comprise a serpentine pathway.

According to a further aspect of the present invention there is provided a method of operating a vacuum system, the vacuum system comprising a vacuum pump and a heat exchanger for absorbing thermal energy from the vacuum pump, the heat exchanger being configured to receive a heat transfer fluid;

wherein the heat transfer fluid comprises a purge gas and the method comprises selectively supplying the heat transfer fluid from the heat exchanger to the vacuum pump or into an exhaust of the vacuum pump.

The method may comprise controlling the supply of the heat transfer fluid to the heat exchanger in dependence on one or more operating parameters of the vacuum pump.

The method may comprise supplying the heat transfer fluid to the heat exchanger in dependence on a determination that the vacuum pump has an operating temperature greater than or equal to a predetermined threshold.

The method may comprise actuating a control valve to control the supply of the heat transfer fluid to the heat exchanger.

The method may comprise selectively actuating the control valve to bypass the supply of the heat transfer fluid to the heat exchanger.

According to a further aspect of the present invention there is provided a controller for controlling operation of a vacuum system, the controller comprising at least one electronic processor and a memory, wherein a set of instructions is stored in the memory; and, when executed, the instructions cause the controller to implement the method as described herein.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows a schematic representation of a vacuum system in accordance with a first embodiment of the present invention;

Figure 2 shows a perspective view of a heat exchanger for mounting to the vacuum pump of the vacuum system shown in Figure 1;

Figure 3 shows a block diagram representing operation of the vacuum system shown in Figure 1;

Figure 4 shows a schematic representation of a vacuum system in accordance with a second embodiment of the present invention; and

Figure 5 shows a perspective view of a heat exchanger for mounting to the vacuum pump of the vacuum system shown in Figure 4.

DETAILED DESCRIPTION

A vacuum system 1 in accordance with an embodiment of the present invention is described herein with reference to the accompanying Figures.

The vacuum system 1 comprises a vacuum pump 3. The vacuum pump 3 is operable to create a vacuum in a vacuum chamber (not shown). The vacuum chamber is suitable for performing an industrial process. In use, process gases are introduced into the vacuum chamber. The vacuum pump 3 comprises a pump housing 5 which supports a rotor shaft (not shown). The vacuum pump 3 may, for example, be used in industrial and high vacuum processes. The vacuum pump 3 is a multi-stage pump comprising a plurality of stages. The vacuum pump 3 may, for example, having five (5), six (6) or seven (7) stages. The process gases are introduced into a first one of the stages through a process gas inlet; and exhausted through from a final one of the stages through a process gas outlet.

As shown in Figure 1, the vacuum system 1 comprises the vacuum pump 3, a heat exchanger 7, a control valve 9 and a gas heater 11. The heat exchanger 7 is thermally coupled to the pump housing 5 of the vacuum pump 3. As described herein, the heat exchanger 7 is operative to cool the vacuum pump 3. The control valve 9 in the present embodiment comprises a three-way valve. The control valve 9 controls the supply of a heat transfer fluid to the heat exchanger 7. The heat transfer fluid transfers thermal energy from the heat exchanger 7, thereby aiding heat rejection from the vacuum pump 3 and providing a cooling function. In the present embodiment, the heat exchanger comprises a gas heat exchanger and the heat transfer fluid consists of a gas. The gas is supplied from a main gas supply 13. A heat transfer fluid control valve 14 is provided for selectively controlling the supply of gas from the main gas supply 13. In the present embodiment, the heat transfer fluid is a purge gas suitable for introduction into the vacuum pump 3 to purge contaminants. The purge gas in the present embodiment is nitrogen (N), but it will be understood that different purge gases may be used for other industrial processes. It is not essential that the heat transfer fluid is also used as a purge gas.

A perspective view of the heat exchanger 7 is shown in Figure 2. The heat exchanger 7 comprises a body portion 15, a first inlet 17 for introduction of the heat transfer fluid; and a first outlet 19 for discharging the heat transfer fluid. The heat exchanger 7 is thermally coupled to the pump housing 5. In the present embodiment, the heat exchanger 7 is fastened to the pump housing 5 in a face-to-face arrangement. Mechanical fasteners (not shown) which locate in respective mounting apertures 21 formed in the body portion 15. The body portion 15 of the heat exchanger 7 and the pump housing 5 may have complementary profiles. For example, the pump housing 5 may comprise a planar section for contacting a sidewall of the body portion 15 of the heat exchanger 7. A thermal conductor, such as a thermal conductive gel, may optionally be provided at the interface between the pump housing 5 and the heat exchanger 7. In a variant, the heat exchanger 7 could be integrated into the pump housing 5. For example, the heat exchanger 7 could be formed in the pump housing 5.

The vacuum system 1 comprises an inlet line 23; an outlet line 25 and a bypass line 27. The inlet line 23 connects the first inlet 17 of the heat exchanger 7 to the control valve 9. The outlet line 25 connects the first outlet 19 of the heat exchanger 7 to the gas heater 11. In use, the inlet line 23 supplies the heat transfer fluid from the gas supply 13 to the heat exchanger 7; and the outlet line 25 conveys the heat transfer fluid from the heat exchanger 7 to the gas heater 11. At least one internal conduit is formed in the body portion 15 of the heat exchanger 7 to establish a flow path between the first inlet 17 and the first outlet 19. The at least one internal conduit forms a convoluted flow path for the heat transfer fluid to increase the internal heat exchange surface area of the heat exchanger 7. The at least one internal conduit may, for example, define a serpentine flow path within the heat exchanger 7. Alternatively, or in addition, one or more fins or projections may be provided inside the heat exchanger 7 to increase the internal heat exchange surface area. The heat exchanger 7 is composed of a thermally conductive material such as aluminium or a metal alloy. In the present embodiment, the heat exchanger 7 is formed using an additive manufacturing process, such as three-dimensional (3D) printing. Alternatively, or in addition, the heat exchanger 7 may be formed using casting and/or machining processes.

The gas heater 11 is provided to heat the purge gas prior to introduction into the vacuum pump 3. The gas heater 11 may comprise an inline heater. In the present embodiment, the gas heater 11 is a positive temperature coefficient (PTC) heater. The heat transfer fluid discharged from the heat exchanger 7 is conveyed to the gas heater 11 through the outlet line 23. As outlined above, the heat transfer fluid is a purge gas for introduction into the vacuum pump 3 (or another pump). This gas heater 11 heats the heat transfer fluid to a predetermined target temperature before mixing with the process gas. The heat transfer fluid is supplied to an inter-stage port 29 provided in the vacuum pump 3. The inter-stage port 29 introduces the heat transfer fluid to an intermediate stage, or a final (exhaust) stage of the vacuum pump 3. As described herein, the heat exchanger 7 can pre-heat the heat transfer fluid prior to introduction into the gas heater 11. The pre-heating of the heat transfer fluid may reduce energy consumption by the gas heater 11. Alternatively, the control valve 9 can be actuated to bypass the heat exchanger 7 and supply the heat transfer fluid directly to the gas heater 11. The introduction of the heat transfer fluid into the vacuum pump 3 (or another pump) after heating by the gas heater 11 is unchanged in this variant.

The vacuum system 1 comprises a valve controller 31 for controlling operation of the control valve 9. The valve controller 31 comprises at least one electronic processor 33 and a memory 35. A set of computational instructions is stored in the memory 35. When executed, the computational instructions cause the at least one electronic processor 33 to perform the method(s) described herein. The valve controller 31 is configured to receive one or more input signal S1 from a vacuum pump controller 37; and to output one or more control signal S2 to the control valve 9. The input signal S1 is configured to provide an indication of an operating state of the vacuum pump 3. The input signal S1 may indicate a load of the vacuum pump 3. The valve controller 31 may determine that the vacuum pump 3 is operating under a low load (for example, an idle state). The valve controller 31 may determine that the vacuum pump 3 is operating under a high load, for example when a process gas inlet valve is in an open state to supply process gases to the vacuum pump 3. The valve controller 31 is configured to actuate the control valve 9 in dependence on the determined operating state of the vacuum pump 3. Alternatively, or in addition, the input signal S1 may indicate a load condition of the vacuum pump 3. The operation of the vacuum pump 3 is controlled by the vacuum pump controller 37 in a conventional manner. It will be understood that the valve controller 31 and the vacuum pump controller 37 may be combined into a single controller. A single controller could control both the vacuum pump 3 and the control valve 9. For example, the vacuum pump controller 37 could be configured also to control the control valve 9 in accordance with the method(s) described herein.

Thermal energy generated by operation of the vacuum pump 3 conducts to the heat exchanger 7. The valve controller 31 controls the control valve 9 to control the supply of the heat transfer fluid to the heat exchanger 7, thereby controlling cooling of the vacuum pump 3 and the pump housing 5. The valve controller 31 outputs the control signal S2 to the control valve 9 and the heat transfer fluid control valve 14. The control valve 9 and the heat transfer fluid control valve 14 are actuated in dependence on the control signal S2. The valve controller 31 is configured to actuate the heat transfer fluid control valve 14 to a closed state when the input signal S1 indicates that the vacuum pump 3 is not operating. The valve controller 31 is configured to actuate the heat transfer fluid control valve 14 to an open state when the input signal S1 indicates that the vacuum pump 3 is operating either in a low load or a high load condition. The heat transfer fluid passes through the at last one internal conduit 23 (shown schematically in Figure 2) formed in the heat exchanger 7. The heat transfer fluid absorbs thermal energy from the heat exchanger 7 and is subsequently discharged from the heat exchanger 7. As described herein, the control valve 9 comprises a three-way valve in the present embodiment. To control operation of the heat exchanger 7, the control valve 9 can be configured selectively to operate in the following states:

(i) HEAT EXCHANGER SUPPLY - The inlet line 23 is placed in fluid communication with the main gas supply 13 such that the heat transfer fluid is supplied to the heat exchanger 7. The bypass line 27 is closed, thereby inhibiting (or reducing) the direct supply of the heat transfer fluid to the gas heater 11.

(ii) HEAT EXCHANGER BYPASS - The bypass line 27 is placed in fluid communication with the main gas supply 13 such that the heat transfer fluid is supplied directly to the gas heater 11. The inlet line 23 is closed, thereby inhibiting (or reducing) the supply of the heat transfer fluid to the heat exchanger 7.

The valve controller 31 is configured to actuate the control valve 9 to the HEAT EXCHANGER BYPASS state when the input signal S1 indicates that the vacuum pump 3 is operating under a low load. The heat transfer fluid bypasses the heat exchanger 7 and is supplied directly to the gas heater 11. This enables the vacuum pump 3 to achieve a target operating temperature more quickly under idle or low load conditions as the rejection of thermal energy from the pump housing 5 is reduced. The valve controller 31 is configured to actuate the control valve 9 to the HEAT EXCHANGER SUPPLY state when the input signal S1 indicates that the vacuum pump 3 is operating in a high load condition. The control valve 9 diverts the heat exchange fluid to the heat exchanger 7 at least partially to compensate for an increase in pump temperature due to the high load. The heat exchanger 7 is effective in maintaining or reducing the temperature of the vacuum pump 3. The heat exchange fluid is pre-heated by the heat exchanger 7 and supplied to the gas heater 11.

The operation of the vacuum system 1 will now be described with reference to a first block diagram 100 shown in Figure 3. The vacuum system 1 is activated (BLOCK 105). The vacuum pump 3 is initially not operating and the valve controller 31 actuates (or maintains) the heat transfer fluid control valve 14 in a closed state BLOCK 110). The supply of the heat transfer fluid to the heat exchanger 7 and the gas heater 11 is inhibited. The vacuum pump controller 37 activates the vacuum pump 3 (BLOCK 115). The vacuum pump 3 operates in an idle, low load condition. The valve controller 31 actuates the transfer fluid control valve 14 to an open state. The valve controller 31 actuates the control valve 9 to the HEAT EXCHANGER BYPASS state (BLOCK 120). The bypass line 27 is opened such that the heat transfer fluid bypasses the heat exchanger 7. In this configuration, the heat exchanger 7 provides limited cooling of the vacuum pump 3. The vacuum pump 3 reaches a target operating temperate (BLOCK 125). The process gas inlet valve is actuated to an open state and process gases are supplied to the vacuum pump 3. The vacuum pump controller 37 outputs the first control signal S1 to indicate that the vacuum pump 3 is operating in a high load condition (BLOCK 130). The valve controller 31 actuates the control valve 9 to the HEAT EXCHANGER SUPPLY state (BLOCK 135). The inlet line 23 is opened such that the heat transfer fluid is supplied to the heat exchanger 7. In this configuration, the heat exchanger 7 provides effective cooling of the vacuum pump 3. The heat transfer fluid is pre-heated by the heat exchanger 7 and then supplied to the gas heater 11. The gas heater 11 can provide controlled heating of the heat transfer fluid for introduction into the vacuum pump 3 and mixing with the process gases. The vacuum pump controller 37 closes the process gas supply valve to inhibit the supply of process gases to the vacuum pump 3. The first control signal S1 is output by the vacuum pump controller 37 to indicate that the vacuum pump 3 is operating in a low load condition. The vacuum pump controller 37 de-activates the vacuum pump 3 (BLOCK 140). The valve controller 31 actuates the transfer fluid control valve 14 to a closed state (BLOCK 143). The vacuum system 1 is deactivated (BLOCK 150).

At least in certain embodiments, the vacuum system 1 can provide advantages over prior art arrangements. By bypassing the heat exchanger 7, the conduction of thermal energy from the vacuum pump 3 (to the heat exchanger 7) can be reduced. As a result, the power consumption of the vacuum pump 3 may be reduced in certain embodiment. In a prior art arrangement, a cooler block may be mounted to the pump housing 5 of the vacuum pump 3. The cooler block uses a liquid coolant, typically water. At least in certain embodiments, the vacuum system 1 described herein may require less water for cooling of the vacuum pump 3. This may also reduce the requirement to cool the heated coolant (water), thereby reducing the need for operation of a cooler for reducing the temperature of the heated coolant prior to re-circulation. At least in certain embodiments, the heat exchanger 7 may be smaller in size (and potentially also have a lower mass) than a cooling block, thereby reducing the footprint of the vacuum pump 3. Excess heat generated by the vacuum pump 3 may be used to heat the purge gas. This may reduce the power consumption by the gas heater 11.

The valve controller 31 is described herein as controlling the control valve 9 in dependence on the input signal S1 received from the vacuum pump controller 37. In a variant, the input signal S1 may comprise or consist of a temperature signal indicating an operating temperature of the vacuum pump 3. The temperature signal could be measured, for example by one or more temperature sensors; or could be modelled based on one or more operating parameters of the vacuum pump 3.

A vacuum system 1 according to a further embodiment of the present invention will now be described with reference to Figure 4. The vacuum system 1 is a development of the above embodiment and the description herein focuses on the differences. Like reference numerals are used for like components.

The vacuum system 1 comprises a vacuum pump 3 operable to create a vacuum in a vacuum chamber for performing an industrial process. Process gases may be introduced into the vacuum chamber. The vacuum pump 3 comprises a rotor shaft (not shown) which is supported in a pump housing 5. The vacuum system 1 comprises the vacuum pump 3, a heat exchanger 7, a control valve 9 and a gas heater 11. The heat exchanger 7, the control valve 9 and the gas heater 11 correspond to the same components in the above embodiment. The operation of these components is substantially unchanged.

The vacuum system 1 also comprises a cooling block 39. A liquid coolant is supplied to the cooling block 39 to provide cooling. The cooling block 39 is thermally coupled to the heat exchanger 7. In the present embodiment, the cooling block 39 is mounted to the heat exchanger 7 in a face-to-face arrangement. As shown in Figure 4, the cooling block 39 is mounted to an external face of the heat exchanger 7 spaced apart from the pump housing 5. Thus, the heat exchanger 7 is disposed between the pump housing 5 and the cooling block 39. The cooling block 39 may, for example, have mounting holes which align with the mounting holes 21 formed in the heat exchanger 7. The mechanical fasteners may fasten the heat exchanger 7 and the cooling block 39 to the pump housing 5. In a variant, the heat exchanger 7 and the cooling block 39 may be formed integrally.

The cooling block 39 comprises a second inlet 41 and a second outlet 43. A coolant control valve 45 is provided for controlling the supply of the liquid coolant to the second inlet 41. The coolant control valve 45 is actuated selectively to control the absorption of thermal energy from the heat exchanger 7. The liquid coolant is discharged through the second outlet 43. The coolant discharged from the second outlet 43 may be supplied to a chiller (not shown) for cooling and then recirculated through the cooling block 39.

The vacuum system 1 comprises a valve controller 31 which is configured to control the cooling block 39. In the present embodiment, the valve controller 31 controls operation of the coolant control valve 45 to control the supply of coolant to the cooling block 39. As shown in Figure 4, the valve controller 31 outputs a pump control signal S3 to control operation of the coolant control valve 45. In a variant, the valve controller 31 may selectively open and close a control valve to control the supply of coolant to the cooling block 39. The valve controller 31 may control operation of the coolant control valve 45 in dependence on an operating temperature of the vacuum pump 3 and/or the heat exchanger 7. The operating temperature of the vacuum pump 3 and/or the heat exchanger 7 may be measured, for example by one or more temperature sensor; or may be modelled in dependence on one or more operating parameter of the vacuum pump 3. The valve controller 31 may be configured to control the coolant control valve 45 to supply coolant to the cooling block in dependence on a determination that the operating temperature of the vacuum pump 3 and/or the heat exchanger 7 is greater than or equal to a predetermined temperature threshold. The cooling block 39 can be deployed when the workload of the vacuum pump 3 is such that the temperature exceeds (or is expected to) a capability of the heat exchanger 7.

The operation of the vacuum system 1 according to the present embodiment will now be described with reference to a second block diagram 200 shown in Figure 6. The vacuum system 1 is activated (BLOCK 205). The vacuum pump 3 is initially not operating. The valve controller 31 actuates (or maintains) the heat transfer fluid control valve 14 to a closed state (BLOCK 210). The supply of the heat transfer fluid to the heat exchanger 7 and the gas heater 11 is inhibited. The supply of coolant to the cooling block 39 is inhibited (BLOCK 215). The vacuum pump controller 37 activates the vacuum pump 3 (BLOCK 220). The vacuum pump 3 operates in an idle, low load condition. The valve controller 31 actuates the heat transfer fluid control valve 14 to an open state and actuates the control valve 9 to the HEAT EXCHANGER BYPASS state (BLOCK 225). The bypass line 27 is opened such that the heat transfer fluid bypasses the heat exchanger 7. In this configuration, the heat exchanger 7 provides limited cooling of the vacuum pump 3. The vacuum pump 3 reaches a target operating temperate (BLOCK 230). The process gas inlet valve is actuated to an open state and process gases are supplied to the vacuum pump 3. The vacuum pump 3 operates in a high load state (BLOCK 235). The valve controller 31 actuates the control valve 9 to the HEAT EXCHANGER SUPPLY state (BLOCK 240). The inlet line 23 is opened such that the heat transfer fluid is supplied to the heat exchanger 7. The valve controller 31 determines that the operating temperature of the vacuum pump 3 is greater than a predefined operating threshold (BLOCK 245). The valve controller 31 determines that additional cooling is appropriate for the vacuum pump 3. The valve controller 31 activates the coolant control valve 45 to supply coolant to the cooling block 39 (BLOCK 250). The valve controller 31 deactivates the coolant control valve 45, for example when the temperature of the vacuum pump 3 decreases below the predefined operating threshold (BLOCK 255). The vacuum pump controller 37 closes the process gas supply valve to inhibit the supply of process gases to the vacuum pump 3. The first control signal S1 is output by the vacuum pump controller 37 to indicate that the vacuum pump 3 is operating in a low load condition. The vacuum pump controller 37 de-activates the vacuum pump 3 (BLOCK 260). The valve controller 31 actuates the control valve 9 to the CLOSED state (BLOCK 265). The vacuum system 1 is deactivated (BLOCK 270).

It will be appreciated that various changes and modifications can be made to the present invention without departing from the scope of the present application.

FIRST BLOCK DIAGRAM (100) LABELS

105	Vacuum system activated.
110	Heat transfer fluid supply inhibited.
115	Vacuum pump operates in a low load condition.
120	Heat transfer fluid supply inhibited, or heat exchanger bypassed.
125	Vacuum pump reaches a target operating temperature.
130	Vacuum pump operates in a high load condition.
135	Heat transfer fluid supplied to the heat exchanger.
140	Vacuum pump deactivated.
143	Heat transfer fluid supply inhibited.
150	Vacuum system deactivated.

SECOND BLOCK DIAGRAM (200) LABELS

205	Vacuum system activated.
210	Heat transfer fluid supply inhibited.
215	Coolant supply inhibited.
220	Vacuum pump operates in a low load condition.
225	Heat transfer fluid supply inhibited, or heat exchanger bypassed.
230	Vacuum pump reaches a target operating temperature.
235	Vacuum pump operates in a high load condition.
240	Heat transfer fluid supplied to the heat exchanger.
243	Vacuum pump temperature exceeds threshold.
250	Supply coolant to the cooling block to provide additional cooling.
255	Inhibit supply of coolant to the cooling block.
260	Vacuum pump deactivated.
265	Heat transfer fluid supply inhibited.
270	Vacuum system deactivated.

Reference Numerals

1	Vacuum System
3	Vacuum Pump
5	Pump Housing
7	Heat Exchanger (Gas Heat Exchanger)
9	Control Valve
11	Gas Heater
13	Gas Supply
14	Heat Transfer Gas Control Valve
15	Body Portion
17	First Inlet
19	First Outlet
21	Mounting Aperture
23	Inlet Line
25	Outlet Line
27	Bypass Line
29	Port
31	Valve Controller
33	Processor
35	Memory
37	Vacuum Pump Controller
39	Cooling Block
41	Second Inlet
43	Second Outlet
45	Coolant control valve

CLAIMS

1. A vacuum system (1) comprising:

a vacuum pump (3); and

a heat exchanger (7) for receiving a heat transfer fluid, the heat transfer fluid comprising a gas;

wherein the heat exchanger (7) is thermally coupled to the vacuum pump (3) and is operable to absorb thermal energy from the vacuum pump (3).

2. A vacuum system (1) as claimed in claim 1 comprising at least one port (29) for introducing the heat transfer fluid from the heat exchanger (7) into the vacuum pump (3) and/or into an exhaust of the vacuum pump (3).

3. A vacuum system (1) as claimed in claim 2 comprising a gas heater (11) for heating the heat transfer fluid, the gas heater (11) being disposed between the heat exchanger (7) and the port (29).

4. A vacuum system (1) as claimed in any one of claims 1, 2 or 3 comprising a control valve (9) for controlling the supply of the heat transfer fluid to the heat exchanger (7).

5. A vacuum system (1) as claimed in claim 4, wherein the control valve (9) is operable selectively to bypass the heat exchanger (7).

6. A vacuum system (1) as claimed in claim 4 or claim 5 comprising a valve controller (31) for controlling operation of the control valve (9), the valve controller (31) comprising at least one electronic processor having at least one input for receiving a signal indicating an operating state of the vacuum pump (3).

7. A vacuum system (1) as claimed in claim 6, wherein the valve controller (31) is configured selectively to actuate the control valve (9) to decrease the supply of the heat transfer fluid to the heat exchanger (7) to reduce the absorption of thermal energy from the vacuum pump (3).

8. A vacuum system (1) as claimed in claim 6 or claim 7, wherein the valve controller (31) is configured selectively to actuate the control valve (9) to decrease the supply of the heat transfer fluid to the heat exchanger (7) in dependence on the signal indicating that the vacuum pump (3) is operating in a low load condition.

9. A vacuum system (1) as claimed in any one of claims 6, 7 or 8, wherein the valve controller (31) is configured selectively to actuate the control valve (9) to increase the supply of the heat transfer fluid to the heat exchanger (7) so as to increase the absorption of thermal energy from the vacuum pump (3).

10. A vacuum system (1) as claimed in any one of claims 6 to 9, wherein the valve controller (31) is configured selectively to actuate the control valve (9) to increase the supply of the heat transfer fluid to the heat exchanger (7) in dependence on the signal indicating that the vacuum pump (3) is operating in a high load condition.

11. A vacuum system (1) as claimed in any one of the preceding claims comprising a cooling block (39) thermally coupled to the heat exchanger (7) and operable selectively to absorb thermal energy from the heat exchanger (7); the cooling block (39) being configured to receive a coolant wherein the coolant comprises a liquid.

12. A vacuum system (1) as claimed in claim 11, wherein the cooling block (39) has an inlet and an outlet for conveyance of the coolant.

13. A vacuum system (1) as claimed in claim 11 or claim 12 comprising a cooling block controller (31) for controlling a supply of the coolant to the cooling block (39), the cooling block controller (31) being configured to supply coolant in dependence on a determination that the temperature of the heat exchanger (7) is greater than or equal to a predefined temperature threshold.

14. A vacuum system (1) as claimed in any one of claims 11, 12 or 13, wherein the heat exchanger (7) and the cooling block (39) are operable independently of each other.

15. A method of operating a vacuum system (1), the vacuum system (1) comprising a vacuum pump (3) and a heat exchanger (7) for absorbing thermal energy from the vacuum pump (3), the heat exchanger (7) being configured to receive a heat transfer fluid;

wherein the heat transfer fluid comprises a purge gas and the method comprises selectively supplying the heat transfer fluid from the heat exchanger (7) to the vacuum pump (3) or into an exhaust of the vacuum pump (3).

16. A method as claimed in claim 15 comprising controlling the supply of the heat transfer fluid to the heat exchanger (7) in dependence on one or more operating parameters of the vacuum pump (3).

17. A method as claimed in claim 16 comprising supplying the heat transfer fluid to the heat exchanger (7) in dependence on a determination that the vacuum pump (3) has an operating temperature greater than or equal to a predetermined threshold.

18. A method as claimed in claim 15 or claim 16 comprising actuating a control valve (9) to control the supply of the heat transfer fluid to the heat exchanger (7).

19. A method as claimed in claim 18 comprising selectively actuating the control valve (9) to bypass the supply of the heat transfer fluid to the heat exchanger (7).

20. A controller (31) for controlling operation of a vacuum system (1), the controller (31) comprising at least one electronic processor (33) and a memory (33), wherein a set of instructions is stored in the memory (33); and, when executed, the instructions cause the controller (31) to implement the method claimed in any one of claims 15 to 19.

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Claims searched:	1-20	**Date of search:**	2 November 2020

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-20	US 2018/202445 A1 (LEYBOLD) See figures 9-10, paragraphs 0077-0078 in particular.
X	1-20	EP 3176434 A1 (EDWARDS) See figure 1, paragraph 0046-0046.
X	1, 2, 4-7, 9	US 2005/019169 A1 (OERLIKON) See figure 3, paragraphs 0024-0030.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

F04B; F04C; F04D

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC, Patent Fulltext

International Classification:

Subclass	Subgroup	Valid From
F04D	0029/58	01/01/2006
F04C	0025/02	01/01/2006