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(54) **A CRYOGEN COOLING SYSTEM**

(57) The present invention provides a cryogen cooling system which utilises a venturi pump to effect a temperature reduction of a liquid cryogen which may be used to cool a superconducting material.

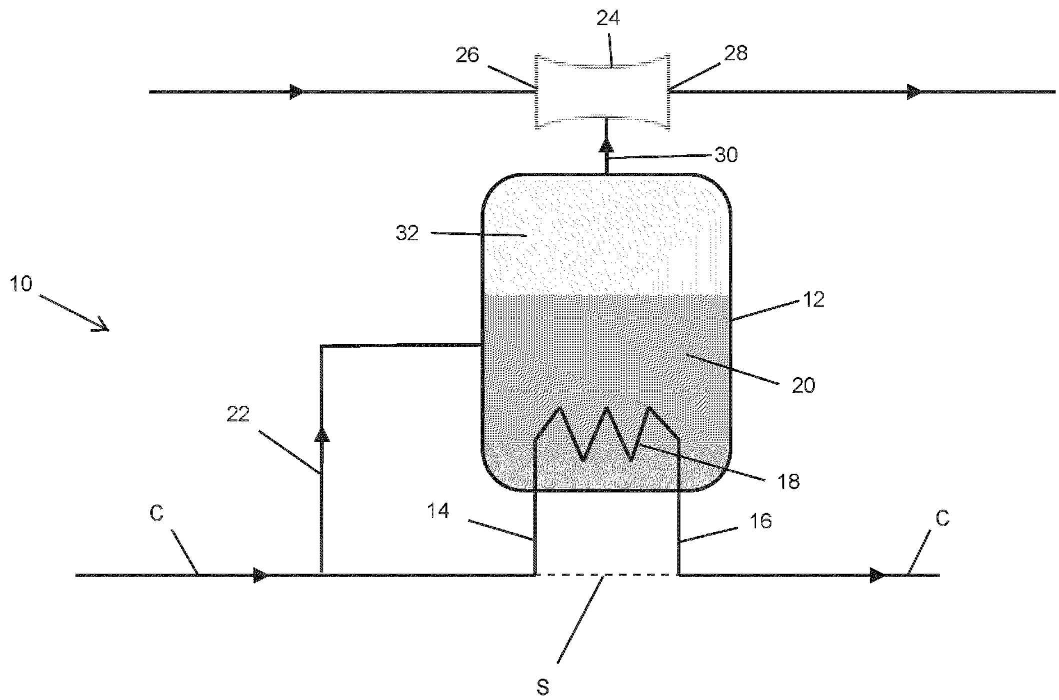

Fig. 1

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Description

Field of the invention

[0001] This invention relates to a cryogen cooling system for use in cooling cryogenic fluids, for example as used for cooling superconducting cables, and in particular a cryogen cooling system which utilises a venturi pump to effect a temperature reduction of the cryogenic fluid.

Background of the invention

[0002] Within superconducting cable systems, at least one electrically conducting element must be maintained at temperatures below the material transition temperature (T_c) to enable superconductivity. Superconductor transition temperatures vary from T_c <10 K for classic metallic superconductors up to values of T_c> 100 K for ceramic high-temperature superconductors (HTS).

[0003] Superconductors also require stable temperatures during operation to maintain predictable transmission characteristics. As a standard, cryogens such as liquefied gases (Hydrogen, Oxygen, Nitrogen, etc.) are used as cooling mediums to achieve and maintain these temperatures within superconductor systems. It is critical to maintain the HTS core temperature at a sufficiently low value to ensure that a suitable superconducting state is maintained, otherwise the tapes become resistive, develop heat through Joule heating leading to rising temperature and a potential catastrophic runaway situation.

[0004] Standard superconductor cable systems use a forced flow, subcooled, single-phase cryogenic fluid such as liquid nitrogen or helium to absorb and evacuate excess thermal energy in order to maintain operational temperatures. The cryogen is circulated within the system to achieve cooling using standard pressurization systems. Excess heat must be removed from the cryogen to maintain a liquefied state for continuous operation and avoid vaporization, which can be achieved through intermittent sub-coolers or cryocoolers. Increased system length necessitates both increased flow rates and system pressures to convey the cryogen which in turn increases the heat load due to the addition of frictional heating. This increases the requirements on heat removal systems and subsequent costs. Over extended distances (>2km) standard forced flow systems quickly prove uneconomical due to the high costs and low efficiency of the intermittent cooling stations.

[0005] Existing forced flow cooling systems require the use of complex and costly equipment and thus involve significant financial outlays, operating costs and maintenance overheads. An alternative to these large scale forced flow cooling systems is the use of sub-cooling of the cryogenic fluid in order to increase cooling capacity. However sub-cooling requires the use of pumping equipment and/or cryogenic cooling equipment which again increases the complexity of the overall system. This is particularly problematic in subsea, subterranean or other difficult to access environments where maintenance and repair is extremely difficult and potentially dangerous.

[0006] The above shortcomings may also be present when transporting liquid cryogen fluids over long distances, where there is again a requirement to maintain the fluid at cryogenic temperatures, which is conventionally achieved using similar forced flow cooling systems. Such cryogen transport pipelines may comprise an inner cryostat for conveying the liquid cryogen, surrounding by one or more layers of insulation.

[0007] It is therefore an object of the present invention to provide a cryogen cooling system which incorporates a simplified means of cooling the cryogenic fluid, whether being used to maintain the operating temperature of a superconducting material or simply being transported over long distances for use as a fuel or otherwise. It is a further object of the present invention to provide a cryogen cooling system which is adapted to effect cooling of the cryogenic fluid in the absence of an external power supply.

Summary of the invention

[0008] According to the invention there is provided a cryogen cooling system comprising a cryostat containing a supply of cryogen; a cooling chamber through which at least a portion of the cryogen is arranged to pass; and a venturi pump operable to reduce pressure within the cooling chamber in order to effect cooling of the passing cryogen.

[0009] Optionally, the fluid flow path extending through the cooling chamber defines a heat exchanger.

[0010] Optionally, the fluid flow path through the cooling chamber is in fluid isolation from, and in thermal communication with, the interior of the cooling chamber.

[0011] Optionally, the cooling chamber comprises a bath of cooling fluid through which the fluid flow path extends and which is operable to undergo evaporative cooling in response to the reduced pressure established by the venturi pump.

[0012] Optionally, the bath of cooling fluid comprises cryogen supplied from the fluid flow path.

[0013] Optionally, the venturi pump is driven by a supply of fluid derived from the bath of cooling fluid within the cooling chamber.

[0014] Optionally, the cooling system comprises a venturi supply line extending from the cooling chamber to the venturi pump and arranged so that the cooling chamber and part of the venturi supply line provide a pressure head in the venturi supply line sufficient to operate the venturi pump.

[0015] Optionally, the cryogen cooling system comprises a fluid driven motor on the venturi supply line upstream of the venturi pump.

[0016] Optionally, the fluid flow path through the cooling chamber is in fluid and thermal communication with an interior of the cooling chamber.

[0017] Optionally, the fluid flow path through the cooling chamber comprises an evaporator providing fluid communication between the fluid flow path and the cooling chamber and operable to effect evaporation of the cryogen in response to passage through the evaporator.

[0018] Optionally, the evaporator comprises an array of nozzles operable to effect evaporation of the cryogen in response to passage through the nozzles.

[0019] Optionally, the evaporator comprises a porous material.

[0020] Optionally, the fluid flow path comprises a cryostat.

[0021] Optionally, the cryostat passes through the cooling chamber.

[0022] Optionally, the cryostat is located remotely of the cooling chamber, the fluid flow path comprising a supply line for transferring cryogen from the cryostat to the cooling chamber and a return line for transferring cryogen from the cooling chamber back to the cryostat.

[0023] Optionally, the venturi pump is driven by a supply of fluid derived from the cryogen within the cryostat.

[0024] Optionally, the cryogen cooling system comprises a venturi supply line extending from the cryostat to the venturi pump.

[0025] Optionally, the cryogen cooling system comprises a fluid driven motor on the venturi supply line upstream of the venturi pump.

[0026] Optionally, the cryogen cooling system comprises at least one thermoelectric device operable to convert a temperature differential generated by the cryogen in order to provide a local power source.

[0027] According to a second aspect of the invention there is provided a superconducting cable system comprising a superconductor and a cryogen cooling system according to the first aspect of the invention, wherein the supply of cryogen is in thermal communication with the superconductor.

[0028] As used herein, the term "cable" is intended to cover both subsea and subterranean power cables in addition to above ground or overhead power lines.

[0029] As used herein, the term "venturi pump" is intended to mean a negative pressure generating pump which utilises the flow of a fluid, Optionally a gas, along a primary flow path which includes a constriction, throat or choke section, from which constriction a secondary flow path extends and in which a negative pressure is established as a result of the flow of fluid through the constriction and which can therefore be used as a vacuum pump.

Brief description of the drawings

[0030] The present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 illustrates a schematic representation of a cryogen cooling system according to a first embodiment of the present invention;

Figure 2 illustrates a schematic representation of a cryogen cooling system according to a second embodiment of the present invention;

Figure 3 illustrates a schematic representation of a cryogen cooling system according to a third embodiment of the present invention;

Figure 4 illustrates a schematic representation of a cryogen cooling system according to a fourth embodiment of the present invention;

Figure 5 illustrates a schematic representation of a cryogen cooling system according to a fifth embodiment of the present invention;

Figure 6 illustrates a schematic representation of a cryogen cooling system according to a sixth embodiment of the present invention; and

Figure 7 illustrates a schematic representation of a cryogen cooling system according to a seventh embodiment of the present invention.

Detailed description of the drawings

[0031] Referring now to Figure 1 of the accompanying drawings there is illustrated part of a cryogen cooling system, generally indicated as 10, which may form part of a superconducting cable system for use in electrical power transmission and in particular over relatively long distances. The cryogen cooling system 10 may also be used for cooling a liquid cryogen during pipeline transport over relatively long distances, for example liquid nitrogen, hydrogen, oxygen, which may be used as fuel or in other applications. In either application the cryogen cooling system 10 comprises an elongate cryostat C defining at least a part of a fluid flow path for the liquid cryogen. The cryostat C may be part of a superconducting cable including superconducting material cooled by the liquid cryogen conveyed through the cryostat C alongside or surrounding the superconducting material. The cryogen is in thermal and optionally physical communication with the superconducting material in order to be capable of maintaining the temperature thereof at the requisite operating temperature, for example between 63 and 77 Kelvin in the case of a high temperature superconducting material. It will of course be understood that this is an exemplary temperature and is not essential to the operation of the present invention. Alternatively, in liquid cryogen transport applications no such superconducting material is present and the liquid cryogen is simply transported through the cryostat C which therefore defines a transport pipeline for the cryogen. While the following embodiments are described primarily with respect to superconducting cable applications it is to be understood that cryogen transport applications are equally applicable.

[0032] At one or more locations along the length of the cryostat C a cooling chamber 12 in the form of a pressure resistant vessel is provided, externally of the cryostat, and through which at least a portion of the working cryogen from the cryostat C is diverted in order to cool the cryogen back down to the above mentioned operating temperature before being reintroduced into the cryostat C. A cryogen supply line 14 extends from the cryostat C into the cooling chamber 12 while a cryogen return line 16 extends from the cooling chamber 12 back to the cryostat C, effectively forming an extension of the fluid flow path defined by the cryostat C. The supply line 14 and return line 16 may be provided on a joint assembly (not shown) connecting two lengths of the cryostat C or may otherwise be arranged to divert the working cryogen from the cable cryostat C at appropriate locations along the length of the cable. For example the supply line 14 may take cryogen at one joint (not shown) while the return line 16 may be feed cryogen back in at another joint on the cable.

[0033] In the embodiment illustrated a cooling element 18 extends through the interior of the cooling chamber 12 between the supply line 14 and the return line 16 to form a portion of the cryogen fluid flow path. In this embodiment the cooling element 18 is a simple fluid tight tube which is optionally undulating or coiled in order to increase the length of the fluid flow path defined by the cooling element 18. In this way the cryogen flow path from the supply line 14, through the cooling element 18 and through the return line 16 is in fluid isolation from the interior of the cooling chamber 12, but is in thermal communication therewith, for example by means of the material selected for at least the cooling element 18, namely a thermally conductive material. As a result heat transfer between the cryogen in the cooling element 18 and the interior of the cooling chamber 12 can occur while preventing fluid flow from the cooling element 18 into the interior space of the cooling chamber 12. The interior of the cooling chamber 12 is at least partially filled with a cooling fluid 20, optionally the same cryogen flowing through the cryostat C, such that the cooling element 18 is at least partially and optionally completely immersed in the cooling fluid. The cooling element 18 of the fluid flow path thus effectively defines a heat exchanger operable to transfer heat from the cryogen flowing through the fluid flow path defined by the cooling element 18 into the cooling fluid 20. A fill line 22 may be provided from the supply line 14 to the cooling chamber 12 in order to fill and maintain the level of cooling fluid 20 in the cooling chamber 12. Suitable flow controls (not shown) such as valves or the like may be provided on the fill line 22 in order to manage the flow rate of cooling fluid into the cooling chamber 12.

[0034] The cryostat C is continuous between the supply line 14 and return line 16, particularly in the case of superconducting cable applications, with electrically conducting superconducting material S shown as a broken line to illustrate that the cryostat C extends between the supply line 14 and return line 16 in order to enclose the superconducting material S. In the case of a cryogen transport application this continuity is not a requirement and could be omitted given that the liquid cryogen can flow uninterrupted along the flow path defined by the supply line 14, cooling element 18 and return line 16. This arrangement applies equally to the embodiments of Figures 2, 3 and 7 as described hereinafter.

[0035] The cooling system 10 further comprises a venturi pump 24 having an inlet 26 and outlet 28 across which a fluid, for example compressed air or any other suitable fluid, may be driven in order to create a reduced pressure region at a throat of the venturi pump 24, from which a low pressure suction line 30 is connected to the cooling chamber 12, optionally at a upper portion in which a head space 32 is formed above the bath of cooling fluid 20. The compressed air or other fluid may be supplied from any suitable location. For example in submarine applications the compressed air may be provided from an onshore location, or from a floating platform or the like, for example produce from power generated from a floating wind turbine or the like. The venturi pump 24 can then be utilised to create a reduced pressure within the cooling chamber 12, for example 200mbar, in order to effect evaporative cooling of the bath of cooling fluid 20. The pressure established in the cooling chamber 12 may be carefully controlled, for example by the design and operation of the venturi pump 24, to ensure that the temperature of the cooling fluid 20 is maintained at the correct level to achieve the desired cooling of the cryogen flowing through the cooling element 18. As a portion of the cooling fluid 20 will evaporate under the lowered pressure generated by the venturi pump 24 the fill line 22 can be operated to maintain a set level of cooling fluid 20 within the cooling chamber 12. In an exemplary embodiment the fill line 22 is operated to extract approximately 10% of the cryogen from the cryostat C in order to replace the evaporated cooling fluid 20.

[0036] Although in this embodiment and following embodiments the venturi pump 24 is located externally of the cooling chamber 12 it is also envisaged that the venturi pump 24 could be located within the cooling chamber 12, in particular in the head space 32. In that configuration the suction line 30 could be omitted as the throat of the venturi pump 24 is in direct fluid communication with the head space 32. This alternative arrangement could equally be employed in any embodiment in which the cooling chamber has a bath of cooling fluid and a headspace above same.

[0037] It will therefore be appreciated that the temperature of the cryogen returned to the cryostat C through the return line 16 can be maintained at the necessary level by means of the cooling chamber 12 and venturi pump 24 which do not include any moving parts, thus greatly improving the reliability of the cooling process.

[0038] Turning then to Figure 2 there is illustrated a second embodiment of a cryogen cooling system, generally indicated as 110, for use in electrical power transmission and optionally over relatively long distances, or in liquid cryogen transport. In this second embodiment like components have been accorded like reference numerals and unless otherwise stated perform a like function.

[0039] The cooling system 110 comprises a cryostat C, a cooling chamber 112 into which extends a supply line 114 from the cryostat C and out of which runs a return line 116 back to the cryostat C, with a cooling element 118 connected therebetween within the interior space of the cooling chamber 112. The cooling element 118 is in the form of a coiled or corrugated tube of thermally conductive material, the cooling chamber 112 being filled with a cooling fluid 120 to immerse the cooling element 118. The cryostat C, supply line 114, cooling element 118 and return line 116 define a fluid flow path along which a liquid cryogen is conveyed and which is in fluid isolation from, but in thermal communication with, the cooling fluid 120 within the interior of the cooling chamber 112. A fill line 122 is provided between the supply line 114 and the cooling chamber 112 in order to allow the level of the cooling fluid 120 to be maintained despite evaporation during use.

[0040] A venturi pump 124 is provided, with an inlet 126 being connected via a venturi supply line 140 to a base of the cooling chamber 112 such that the cooling fluid 120 is then used as the source of driving fluid for the venturi pump 124. In the embodiment illustrated the venturi supply line 140 extends below the cooling chamber 112 before extending upwardly to the venturi pump 124. The distance the venturi supply line 140 extends below the cooling chamber 112 is selected to establish a hydraulic pressure head in the venturi supply line 140 which can then support the pressurised evaporation of the cooling fluid 120, for example liquid nitrogen, in the upwardly extending portion of the venturi supply line 140 to create a pressurised flow of gaseous nitrogen (or other cryogen) to be driven through the venturi pump 124. The pressure head can also act to prevent backflow of the cooling fluid 120 in the venturi supply line 140. A check valve (not shown) and/or expansion valve (not shown) may be provided in the venturi supply line 140, for example along the lowermost section thereof, to facilitate the phase change from liquid to gaseous cryogen. Optionally, the thermal design of the venturi supply line 140 may be such as to effect controlled evaporation and pressurisation of the gaseous cryogen in order to drive the venturi pump 124. Further optionally heating elements (not shown) may be employed to effect vaporisation of the liquid cryogen in the venturi supply line 140. This flow of gaseous cryogen is then the driving fluid of the venturi pump 124 which can be utilised to reduce the pressure in the cooling chamber 112 by means of a suction line 130 connected between a throat of the venturi pump 124 and a headspace 132 of the cooling chamber 112.

[0041] It will therefore be appreciated that in this second embodiment no external supply of gas such as compressed air or other fluid is required in order to power the venturi pump 124, thus establishing a fully self-contained cooling process which again includes little or no moving parts.

[0042] Referring now to Figure 3 there is illustrated a third embodiment of a cryogen cooling system, generally indicated as 210, again for use in electrical power transmission or cryogen transport. In this third embodiment like components have been accorded like reference numerals and unless otherwise stated perform a like function.

[0043] The cooling system 210 comprises a cryostat C defining a fluid flow path for a liquid cryogen, a cooling chamber 212 into which extends a supply line 214 and out of which runs a return line 216, with a cooling element 218 connected therebetween within the interior space of the cooling chamber 212. The cooling element 218 is in the form of a coiled or corrugated tube of thermally conductive material, the cooling chamber 212 being filled with a cooling fluid 220 to immerse the cooling element 218. A fill line 222 is provided between the supply line 214 and the cooling chamber 212 in order to allow the level of the cooling fluid 220 to be maintained despite evaporation during use.

[0044] The cryogen cooling system 210 further comprises a venturi pump 224 having an inlet 226 being connected via a venturi supply line 240 to the supply line 214 such that the cryogen from the cable cryostat C is used directly as the source of driving fluid for the venturi pump 224. The liquid cryogen is then allowed to evaporate to create a pressurised flow of gaseous nitrogen (or other cryogen) to be driven through the venturi pump 224. An expansion valve (not shown) may be provided in the venturi supply line 240 to facilitate this phase change from liquid to gaseous cryogen. This flow of gaseous cryogen is then the driving fluid of the venturi pump 224.

[0045] It is envisaged in this and any other embodiment of the invention that one or more thermoelectric devices (not shown) such as a peltier cell may be employed to generate local electrical power based on a temperature differential which may be established using the reduced temperatures of the cryogenic fluids employed.

[0046] Referring now to Figure 4 there is illustrated a fourth embodiment of a cryogen cooling system, generally indicated as 310, for use in electrical power transmission or cryogen transport. In this fourth embodiment like components have been accorded like reference numerals and unless otherwise stated perform a like function. As with previous embodiments the cryogen cooling system 310 comprises a cryostat C for an elongate superconducting cable including superconducting material cooled by a cryogen conveyed alongside or surrounding the superconducting material in the cryostat C. The cooling system 310 further comprises a cooling chamber 312 and directly through which the cryostat C extends unlike in the previous embodiments. The cryostat C comprises an evaporator 318 on that portion of the cryostat C contained within the interior space of the cooling chamber 312. The cryostat C thus solely defines the fluid flow path for conveying cryogen through the cooling chamber 312.

[0047] In this fourth embodiment the evaporator 318 differs from the previous embodiments by facilitating fluid transfer in the form of evaporation of a portion of the cryogen flowing through the cryostat C within the interior volume of the cooling chamber 312 in order to effect cooling of the remaining liquid cryogen in the catheter C via the latent heat of vaporisation. Unlike the previous embodiments the interior volume of the cooling chamber 312 is not filled with a cooling fluid in order to allow this evaporation to take place. The evaporator 318 is in the form of a tube of porous or wick like material forming an outer wall of the cryostat C and across which a portion of the liquid cryogen will migrate. Due to the low pressure environment within the cooling chamber 312, the liquid cryogen will evaporate into the interior volume of the cooling chamber 312. This evaporation will effect cooling of the remaining liquid cryogen with the cryostat C which then flows out of the cooling chamber to continue cooling the superconducting material. Such porous or wick lick material is disclosed in the Applicant's International patent application PCT/EP2022/085848.

[0048] In order to produce and maintain the requisite low pressure within the cooling chamber 312 the cryogen cooling system 310 comprises a venturi pump 324 having an inlet 326 being connected via a venturi supply line 340 to the cryostat C such that the cryogen from the cable cryostat C is used as the source of driving fluid for the venturi pump 324 as hereinbefore described. The venturi supply line 340 is adapted to effect the evaporation of the liquid cryogen so as to create a pressurised flow of gaseous cryogen to be driven through the venturi pump 324. An expansion valve (not shown) may be provided in the venturi supply line 340 to facilitate this evaporation. This flow of gaseous cryogen is then the driving fluid of the venturi pump 324. As with the embodiment of Figure 2, the venturi supply line 340 may be extended below the cryostat C before extending upwardly to the venturi pump 324 in order to establish a hydraulic pressure head in the venturi supply line 340 which can then support the pressurised evaporation of the cryogen in portion of the venturi supply line 340 above the cryostat so as to create a pressurised flow of gaseous cryogen to be driven through the venturi pump 324. A check valve (not shown) and/or expansion valve (not shown) may be provided in the venturi supply line 340 to facilitate the phase change from liquid to gaseous cryogen. The venturi pump 324 is connected to the cooling chamber 312 via a suction line 330 in order to allow the pressure reduction in the cooling chamber 312 to be established which then drives evaporation and thus cooling of the cryogen flowing through the evaporator 318.

[0049] Referring now to Figure 5 there is illustrated a fifth embodiment of a cryogen cooling system, generally indicated as 410, for use in electrical power transmission or the like. In this fifth embodiment like components have been accorded like reference numerals and unless otherwise stated perform a like function. As with previous embodiments the cryogen cooling system 410 comprises an elongate cryostat C which may include superconducting material cooled by a cryogen conveyed alongside or surrounding the superconducting material in said cryostat C. The cooling system 410 further comprises a cooling chamber 412 through which the cryostat C directly extends, an evaporator 418 being provided on that portion of the cryostat C contained within the interior space of the cooling chamber 412.

[0050] In this fifth embodiment the evaporator 418 is similar in function to the fourth embodiment, facilitating fluid transfer in the form of evaporation of a portion of the cryogen flowing through the cryostat C within the interior volume of the cooling chamber 412 in order to effect cooling of the remaining liquid cryogen via the latent heat of vaporisation. The evaporator 418 is in the form of a tube or wall of the cryostat C incorporating a plurality of nozzles (not shown) which may be provided on or formed integrally with the tube. The nozzles (not shown) are configured to effect evaporation of the cryogen in response to passage through the nozzles in combination with a low pressure environment within the cooling chamber 412. This evaporation of a portion of the cryogen through the nozzles will effect cooling of the remaining liquid cryogen which then flows out of the cooling chamber 412 within the cryostat C to cool the superconducting material. Examples of such nozzles and a detailed explanation of the configuration and operation of exemplary configurations are disclose in the Applicant's International patent application PCT/EP2023/061767.

[0051] Low pressure within the cooling chamber 412 is established by a venturi pump 424 having an inlet 426 being connected via a venturi supply line 440 to the cryostat C as hereinbefore described. The venturi pump 424 is connected to the cooling chamber 412 via a suction line 430 in order to allow the pressure reduction in the cooling chamber 412 to be established which then drives evaporation through the nozzles (not shown) and thus cooling of the cryogen flowing through the evaporator 418.

[0052] Turning to Figure 6 there is illustrated a sixth embodiment of a cryogen cooling system, generally indicated as 510. In this sixth embodiment like components have been accorded like reference numerals and unless otherwise stated perform a like function. The cryogen cooling system 510 again comprises an elongate cryostat C which including superconducting material cooled by a cryogen conveyed alongside or surrounding the superconducting material in a cryostat C or may simply transport the cooled cryogen for alternative applications as hereinbefore described.

[0053] The cryogen cooling system 510 further comprises a cooling chamber 512 into which the cryostat C extends directly and which is in open fluid communication with an interior of the cooling chamber 512 and thus unlike previous embodiments the supply feeds the cryogen directly into the interior of the cooling chamber 512 to mix with a reservoir of cooling fluid 520 located therein. The portion of the cryostat C entering the cooling chamber 512 is therefore only in fluid communication with the opposed portion of the cryostat C exiting the cooling chamber 512 by means of the interior volume of the cooling chamber 512 and the cooling fluid 520 therein. There is no cooling or evaporating element within the cooling chamber 512 as with all previous embodiments. The cooling fluid 520 is therefore used as a reservoir into which the warm cryogen from the cryostat C is fed and a reservoir from which cooled cryogen is fed into the exiting portion of the cryostat C. In order to maintain the cooling fluid 520 at the requisite temperature, for example 67 Kelvin, despite the influx of warm cryogen, for example at 77 kelvin, the pressure in the cooling chamber 512 is maintained at a level low enough to effect evaporative cooling of the cooling fluid 520.

[0054] This reduced pressure is produced by means of a venturi pump 524 having an inlet 526 being connected via a venturi supply line 540 to the cryostat C such that the cryogen from the cryostat C is used as the source of driving fluid for the venturi pump 524 as described with reference to previous embodiments. The venturi supply line 540 is adapted to effect the evaporation of the liquid cryogen so as to create a pressurised flow of gaseous cryogen to be driven through the venturi pump 524. The venturi pump 524 is connected at a headspace 532 of the cooling chamber 512 via a suction line 530 in order to allow the pressure reduction in the cooling chamber 512 to be established to drives evaporation and thus cooling of the cooling fluid 520.

[0055] As the cryogen is fed from the cryostat C directly into the reservoir of cooling fluid 520, which is at a reduced pressure within the cooling chamber 512, it is necessary to manage the pressure of the cryogen in the cryostat C to be compatible with the pressure in the cooling chamber 512. For example the pressure in the cooling chamber 512 may be at 200mbar, and as a result the pressure in the cryostat C, at least directly upstream of the cooling chamber 512, should be reduced to match or closely approximate the pressure in the cooling chamber 512. Any suitable pressure metering device (not shown) may be provided on the supply cryostat C in order to achieve the necessary pressure change.

[0056] Referring now to Figure 7 there is illustrated a seventh embodiment of a cryogen cooling system, generally indicated as 610, for use in electrical power transmission or liquid cryogen transport. In this seventh embodiment like components have been accorded like reference numerals and unless otherwise stated perform a like function. The cryogen cooling system 610 is a modified arrangement of the cooling system 110 of the second embodiment illustrated in Figure 2. The cooling system 610 again comprises a cryostat C conveying a liquid cryogen to be cooled, a cooling chamber 612 through which a fluid flow path comprising the cryostat C extends, and a venturi pump 624 to effect reduced pressure and therefore temperature within the cooling chamber 612 as hereinbefore described. The venturi pump 624 is fed via a venturi supply line 640 which is supplied directly from the cooling chamber 612 which applies a pressure head within the venturi supply line 640. Located on the venturi supply line 640 upstream of the venturi pump 624 is a fluid powered motor 650 through which the liquid cryogen flows, under pressure, in order to drive the motor 650 and produce electrical power which can be utilised by the cooling system 10. Thus a source of local electrical power can be generated for use as required by the cooling system 10. As the liquid cryogen passes through and drives the motor 650 it may be allowed to undergo evaporation in order to be in a gaseous state for driving the venturi pump 624. Additional or alternative expansion valves (not shown) or the like may be provided between the motor 650 and venturi pump 624 in order to ensure the correct phase and pressure are achieved to efficiently drive the venturi pump 624. This motor arrangement may be implemented on any of the embodiments of Figures 2 to 6 which incorporate a venturi supply line which is locally supplied with cryogen.

[0057] It will therefore be understood that the cryogen cooling systems 10; 110; 210; 310; 41; 510; 610 of the invention allow for localised cooling of the cryogen flowing through the cryostat C, and by means of a venturi pump 24; 124; 224; 324; 424; 524; 624 which avoids the need for a conventional vacuum pump. Such conventional vacuum pumps employ high speed drive shafts/-rotors, seals, and other moving parts that can wear and thus reduce performance. In the case of superconducting cables, any reduction in performance of such a crucial component, which would lead to a reduction in the cooling performance and therefore an unacceptable increase in the temperature of the superconducting material, can lead to catastrophic failure.

[0058] The invention is not limited to the embodiments described herein but can be amended or modified without departing from the scope of the present invention.

Claims

1. A cryogen cooling system comprising a fluid flow path for conveying a supply of cryogen; a cooling chamber through which at least a portion of the fluid flow path extends; and a venturi pump operable to reduce pressure within the cooling chamber in order to effect cooling of the cryogen within the fluid flow path extending through the cooling chamber.

2. A cryogen cooling system according to claim 1 in which the fluid flow path extending through the cooling chamber defines a heat exchanger.

3. A cryogen cooling system according to claim 1 or 2 in which the fluid flow path through the cooling chamber is in fluid isolation from, and in thermal communication with, the interior of the cooling chamber.

4. A cryogen cooling system according to any preceding claim in which the cooling chamber comprises a

bath of cooling fluid through which the fluid flow path extends and which is operable to undergo evaporative cooling in response to the reduced pressure established by the venturi pump.

5. A cryogen cooling system according to claim 4 in which the bath of cooling fluid comprises cryogen supplied from the fluid flow path.

6. A cryogen cooling system according to claim 4 or 5 in which the venturi pump is driven by a supply of fluid derived from the bath of cooling fluid within the cooling chamber.

7. A cryogen cooling system according to claim 6 comprising a venturi supply line extending from the cooling chamber to the venturi pump and arranged so that the cooling chamber and part of the venturi supply line provide a pressure head in the venturi supply line sufficient to operate the venturi pump.

8. A cryogen cooling system according to claim 1 or 2 in which the fluid flow path through the cooling chamber is in fluid and thermal communication with an interior of the cooling chamber.

9. A cryogen cooling system according to claim 8 in which the fluid flow path through the cooling chamber comprises an evaporator providing fluid communication between the fluid flow path and the cooling chamber and operable to effect evaporation of the cryogen in response to passage through the evaporator.

10. A cryogen cooling system according to claim 9 in which the evaporator comprises an array of nozzles operable to effect evaporation of the cryogen in response to passage through the nozzles.

11. A cryogen cooling system according to claim 10 in which the evaporator comprises a porous material.

12. A cryogen cooling system according to any preceding claim in which the fluid flow path comprises a cryostat.

13. A cryogen cooling system according to claim 12 in which the cryostat passes through the cooling chamber.

14. A cryogen cooling system according to claim 12 in which the cryostat is located remotely of the cooling chamber, the fluid flow path comprising a supply line for transferring cryogen from the cryostat to the cooling chamber and a return line for transferring cryogen from the cooling chamber back to the cryostat.

15. A cryogen cooling system according to claim 13 or 14 in which the venturi pump is driven by a supply of fluid derived from the cryogen within the cryostat.

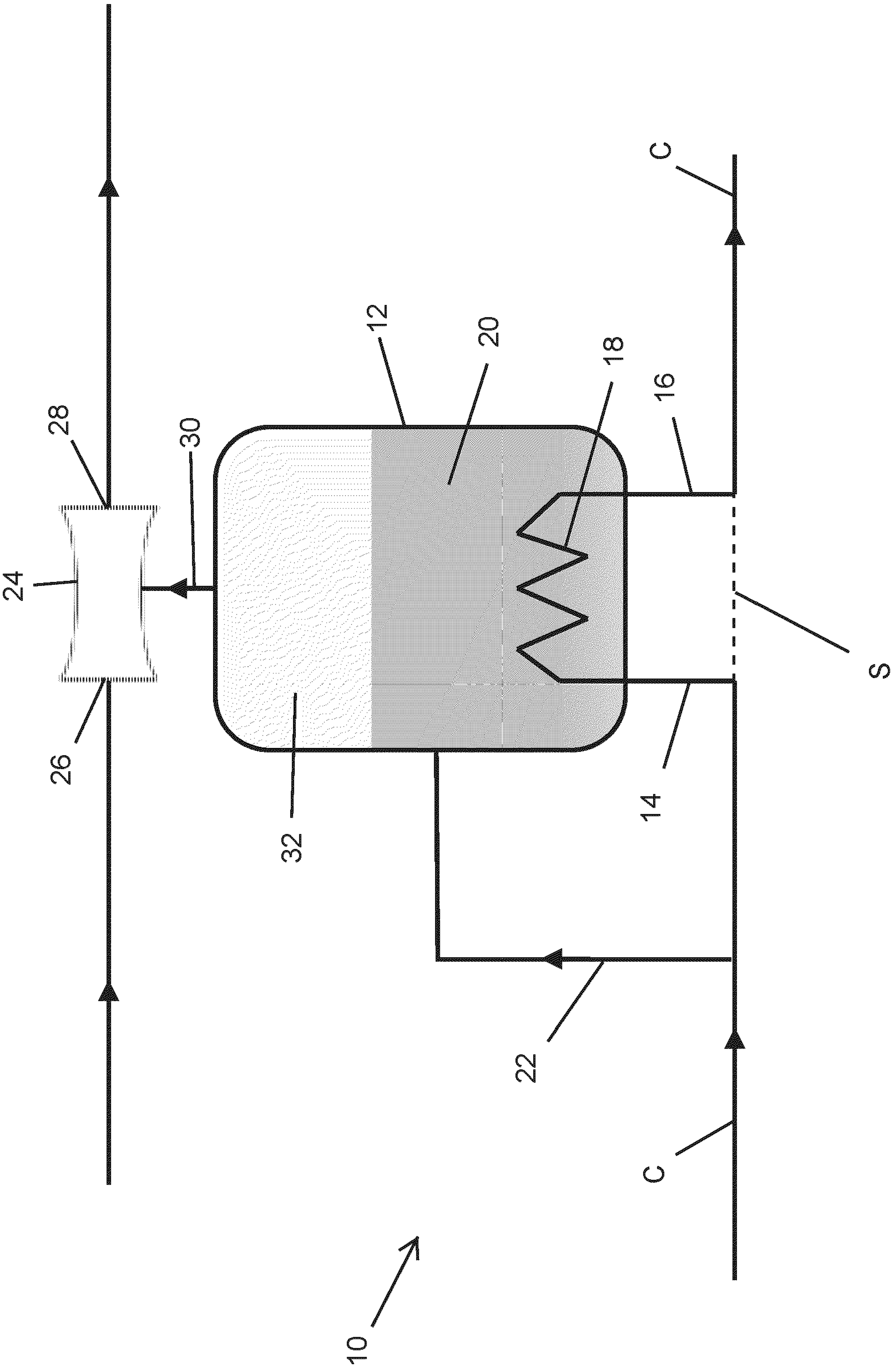

Fig. 1

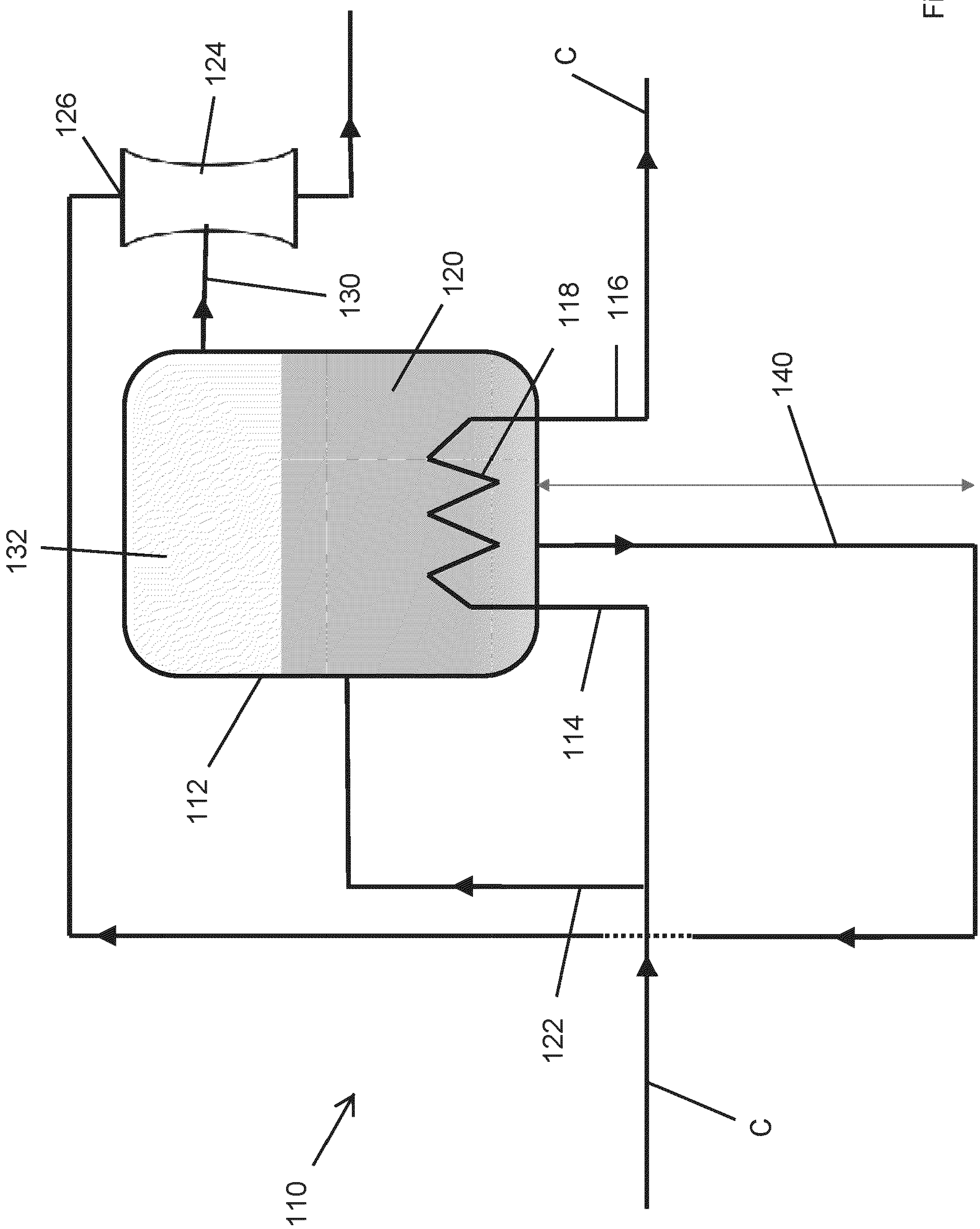

Fig. 2

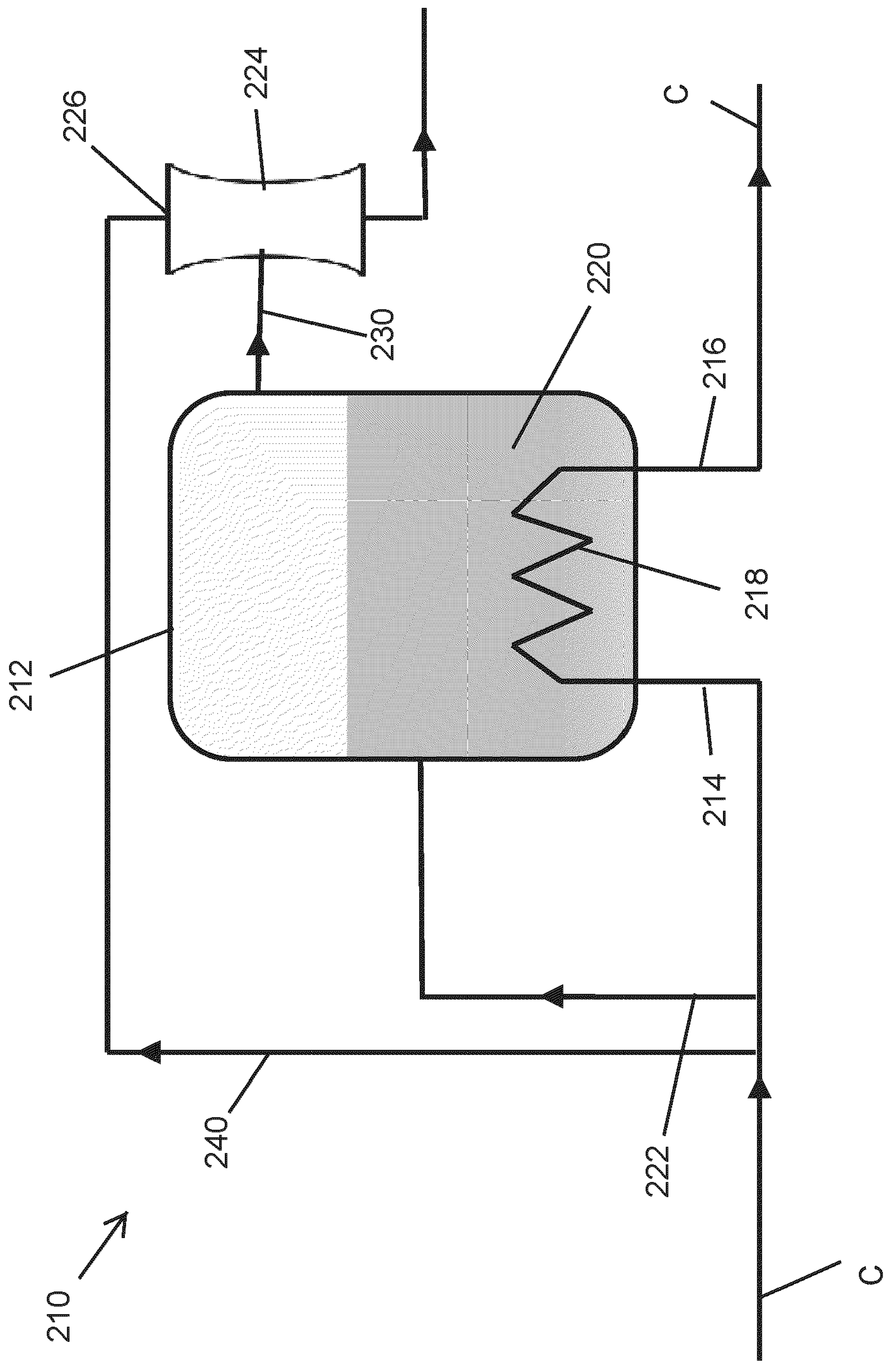

Fig. 3

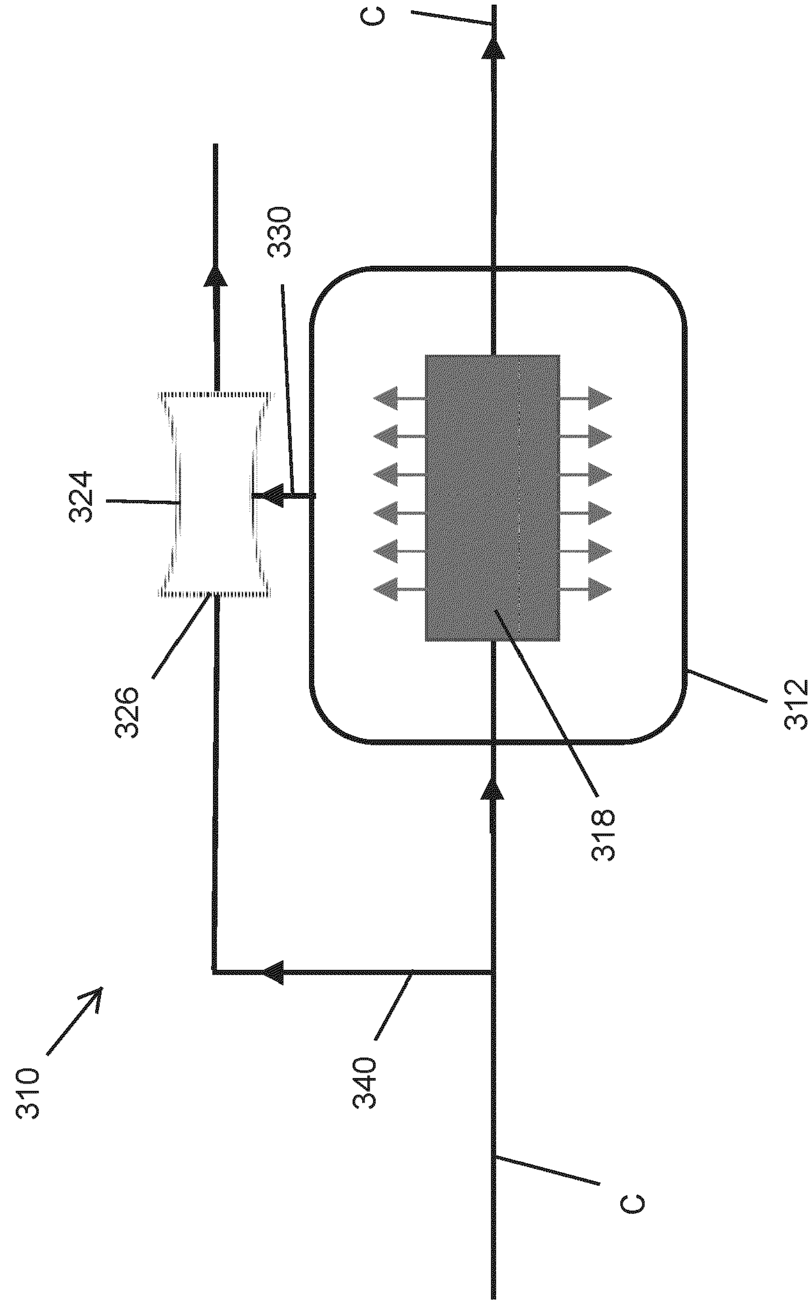

Fig. 4

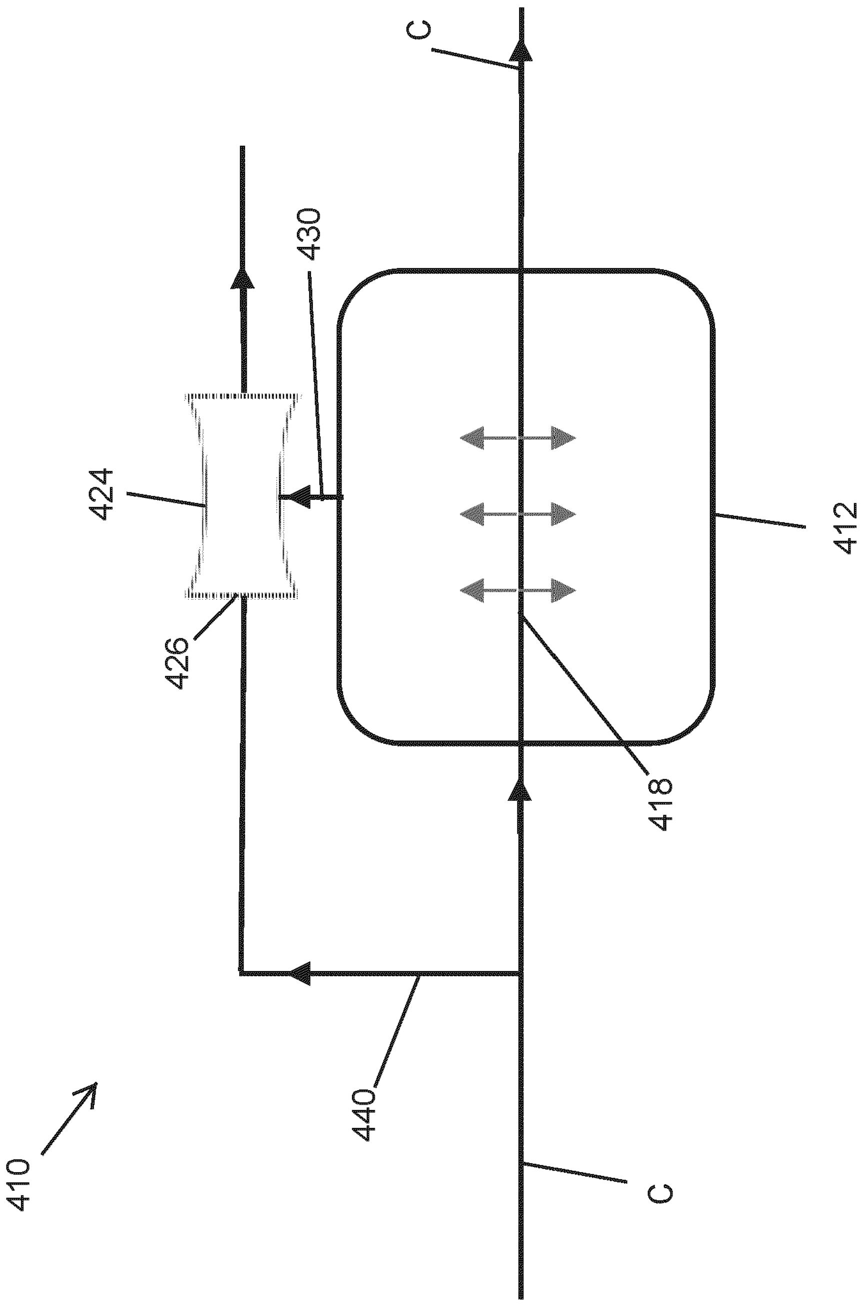

Fig. 5

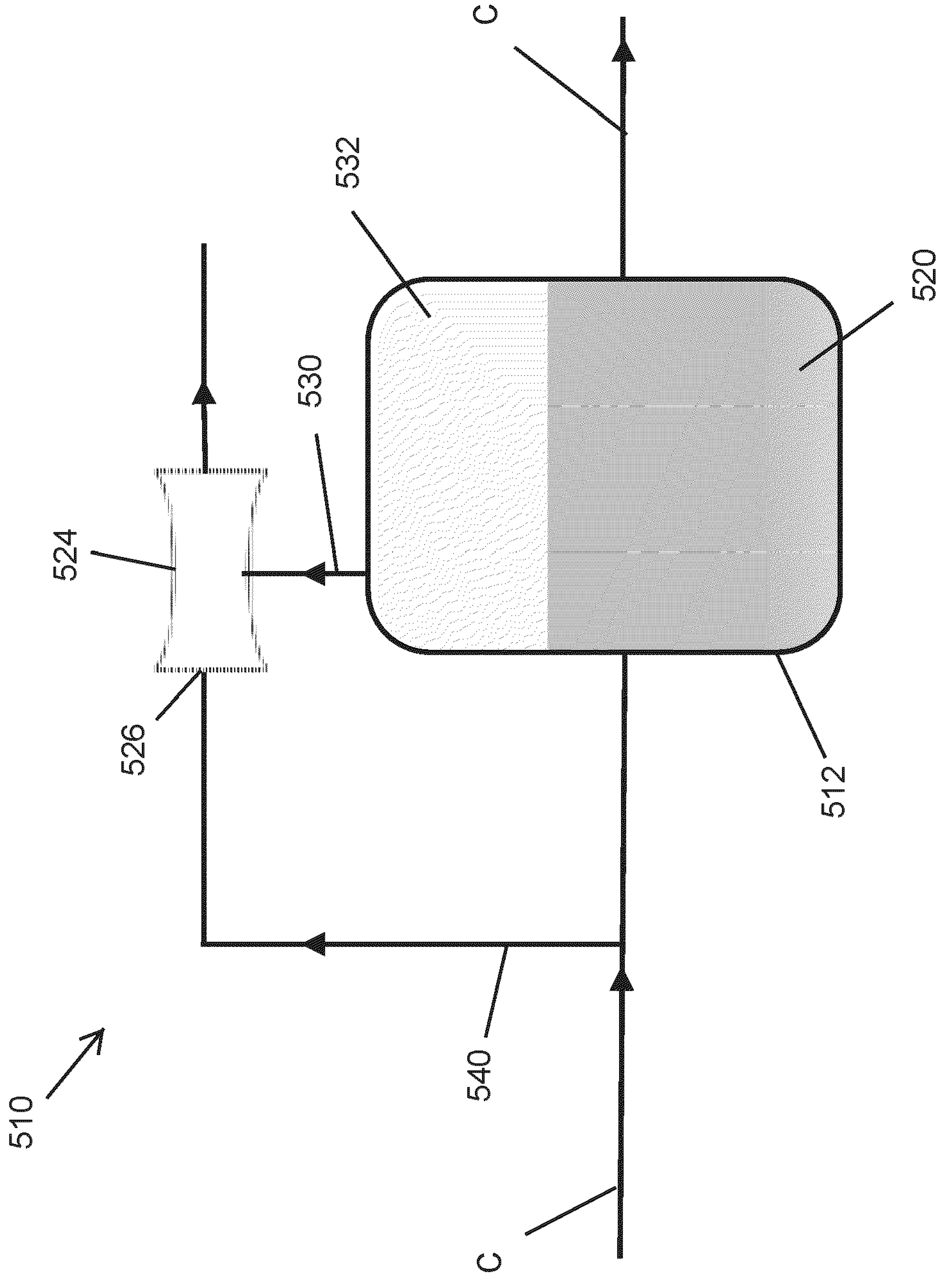

Fig. 6

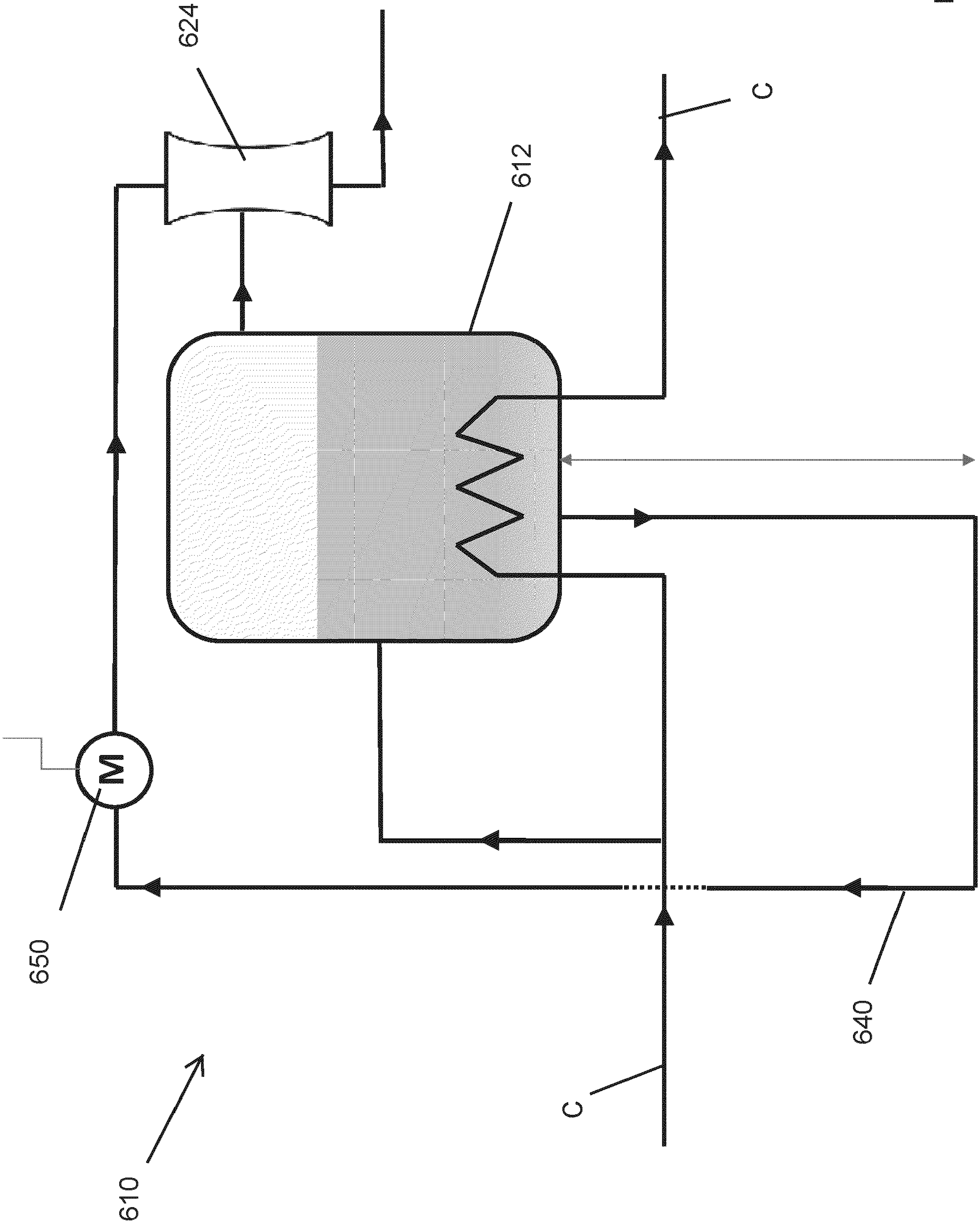

Fig. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 23 18 7129

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 10 2017 003105 A1 (LINDE AG [DE]) 4 October 2018 (2018-10-04) * paragraphs [0037] - [0045]; figures 2,3a *	1-7, 12-15	INV. F25B19/00 F17C13/08 F25D3/10 H01F6/04
X	JP 2003 307375 A (AIR LIQUIDE JAPAN LTD) 31 October 2003 (2003-10-31) * paragraphs [0017] - [0031]; figure 1 *	1-7, 12-15	
X	US 6 145 321 A (MILLER JEREMY PAUL [GB] ET AL) 14 November 2000 (2000-11-14) * column 4, lines 3-54 *	1-3,12, 13	
X	US 6 164 078 A (LAK TIBOR I [US] ET AL) 26 December 2000 (2000-12-26)	1,8	
A	* column 2, line 54 - column 3, line 60; figure 1 *	9-11	

TECHNICAL FIELDS SEARCHED (IPC)

F25B
F25D
F17C
H01F

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	12 February 2024	Weisser, Meinrad

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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Application Number
EP 23 18 7129

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

- [ ] Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

- [ ] No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- [x] All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

- [ ] As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

- [ ] Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

- [ ] None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

- [ ] The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 23 18 7129

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-7, 12-15

Cryogen cooling system comprising a fluid flow path which is in fluid isolation from the cooling chamber; wherein the supply fluid of the venturi pump is driven by a supply derived from the bath of cooling fluid.

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2. claims: 8-11

Cryogen cooling system comprising a fluid flow path in fluid and thermal communication with the interior of the cooling chamber; wherein the cooling chamber comprises an evaporator.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 23 18 7129

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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12-02-2024

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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