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Prast et al.

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[54] **COOLING SYSTEM**

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[30] **Foreign Application Priority Data**

Apr. 9, 1973 Netherlands 7304884

[52] **U.S. Cl.** **62/514;** 62/200; 62/525

[51] **Int. Cl.**^{2} **F25B 19/00**

[58] **Field of Search** 62/115, 200, 467, 498, 62/514, 525

[56] **References Cited**

UNITED STATES PATENTS

3,350,896 11/1967 Harnish 62/200

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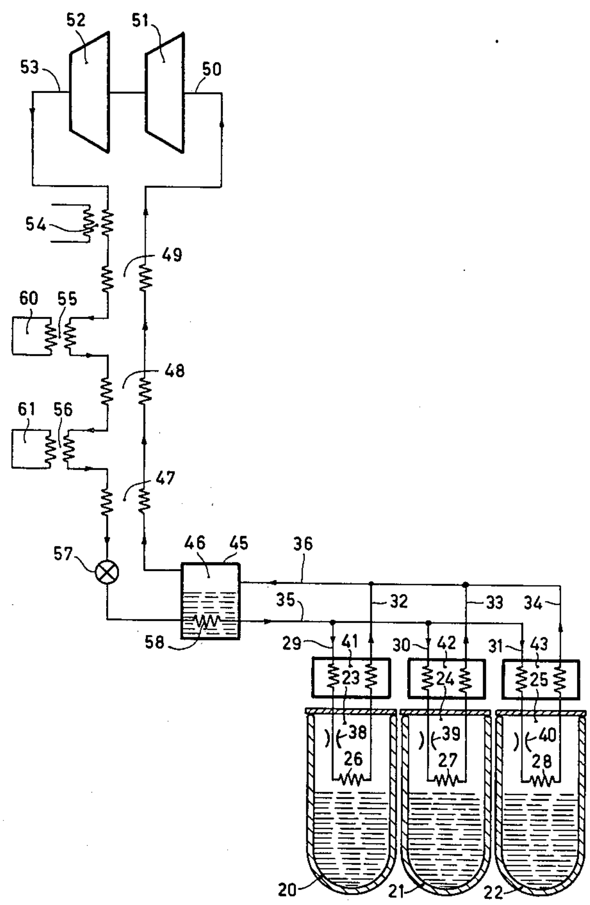
Attorney, Agent, or Firm—Frank R. Trifari

[57] **ABSTRACT**

A cooling system including a cooling element placed in the space to be cooled and provided with a blocking device comprising a restriction for blocking the flow of cooling fluid through the cooling element in the case of an intolerable temperature rise in said cooled space.

7 Claims, 2 Drawing Figures



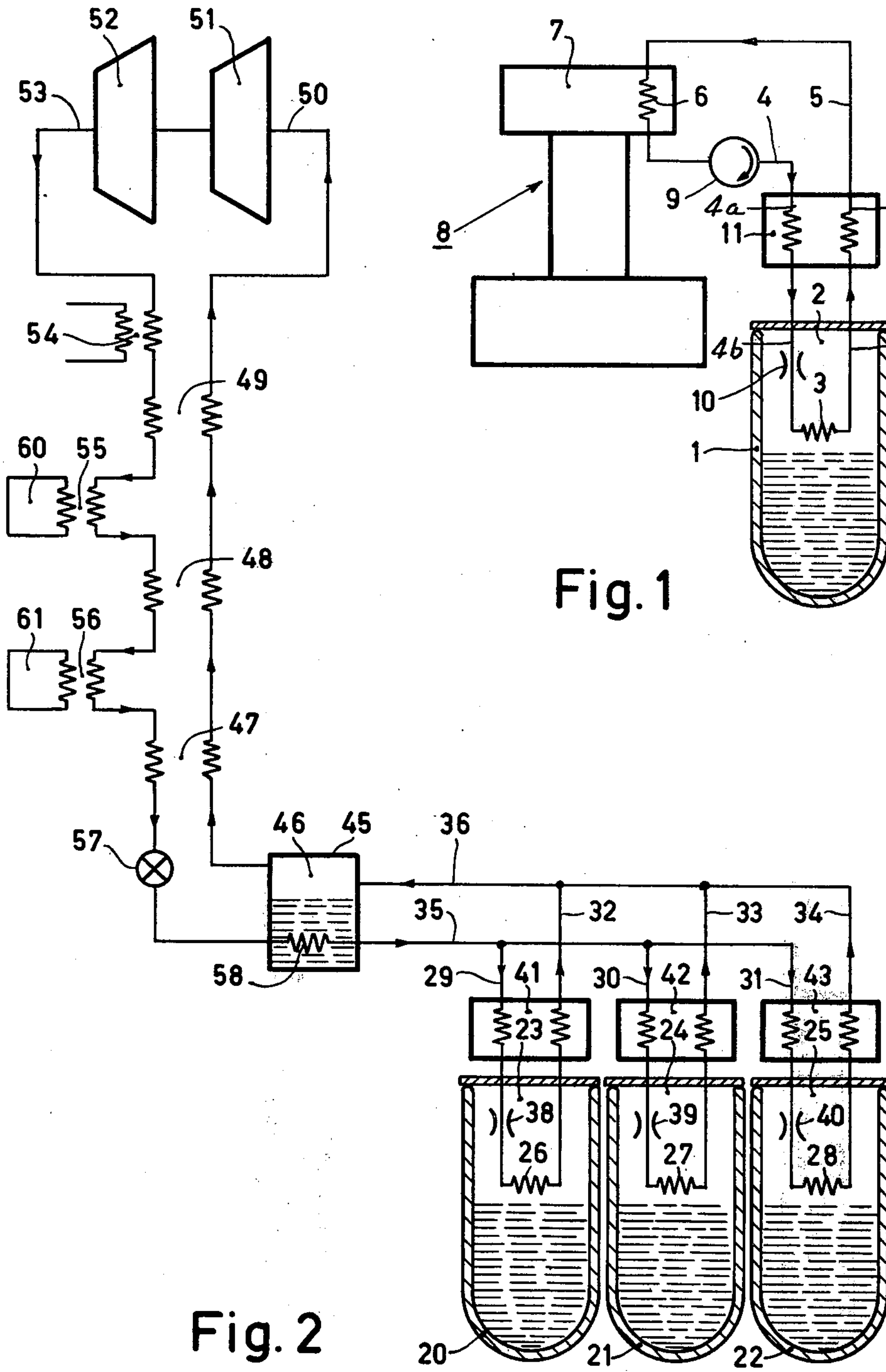


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Fig. 1

Fig. 2

COOLING SYSTEM

BACKGROUND OF THE INVENTION

The invention relates to a cooling system for cooling to a lower temperature at least one space which is closed in operation. The system comprises at least one cooling element which is placed in said space and through which a cooling fluid can flow, and the inlet of which is connected to a fluid supply pipe passed through a wall of the space, while the outlet is connected to a fluid discharge pipe passed through a wall of the space.

Cooling systems of the type referred to are described in British Pat. No. 521,792 and in U.S. Pat. No. 2,753,691, FIG. 4. In these known cooling systems the cooling elements are in the form of cooling coils placed in storage containers for liquefied gas. The cooling coils by recondensing liquid vaporized by heat leakage into the container or by direct cooling of the liquid, prevent the pressure in the storage containers from exceeding a given value.

The known cooling systems have a disadvantage which manifests itself in the case of increased heat flow from the ambient atmosphere into the cooled container as a result of leakage, for example when the evacuated sheath of the container has leaks due to mechanical shock or vibration. The increased heat leakage results in a substantial rise of the temperature in the container so that the cooling fluid flowing through the cooling coil is heated. This means that a considerable part of the available cooling power is wasted.

In addition, the heat leaking into the container spreads to the remainder of the cooling system. When the system comprises further containers equipped with cooling elements, cooling of these containers also is jeopardized.

The rise in temperature in the leaking container is accompanied by a rise in pressure. In cooling systems in which the amount of cooling fluid supplied to the cooling coil is regulated in accordance with the pressure prevailing in the container, leakage even involves additional losses of cooling power. This state of affairs is not improved by a vent valve opening at a given maximum pressure.

It is an object of the present invention to provide a cooling system of the type referred to in which the said above-described disadvantage is avoided.

SUMMARY OF THE INVENTION

A cooling system according to the invention is characterized in that a blocking device is provided which completely or partly blocks the flow of fluid to the cooling element in response to an intolerable rise in temperature of the cooled space.

This ensures that in the case of heat leakage into the cooled space, which shows itself by a considerable rise in temperature, the supply of cooling fluid is completely or partly blocked. Thus substantially no cooling power is wasted, and further cooled spaces which form part of the cooling system are unaffected by the leakage.

The blocking device may be a temperature sensor which is placed in the space to be cooled and operates a valve in the fluid supply pipe. However, moving parts are involved, which increases the complexity of the system.

Especially in systems which are required to operate unattended for comparatively long periods of time and hence have to satisfy very exacting reliability requirements, moving parts are undesirable. Moreover they are subject to wear.

These disadvantages are obviated by the invention. Accordingly an advantageous embodiment of the cooling system according to the invention is characterized in that the blocking device comprises a restriction included in the part of the fluid supply pipe situated within the cooled space and by a heat exchanger included on the one hand in the fluid supply pipe on the side of the restriction remote from the cooling element and on the other hand in the fluid discharge pipe.

In normal operation of the cooling system with normal heat leakage, the temperature of the cooling fluid issuing from the cooling element is substantially equal to the temperature at which it enters the element. In this case the heat exchanger in the fluid supply and discharge pipes is passive. When however the cooling fluid is considerably heated in the cooling element owing to heat leakage into the respective container, the cooling fluid flowing towards the cooling element is heated in the heat exchanger by warm cooling fluid flowing from the cooling element, possibly after vaporization. Thus the restriction, primarily because of the reduced density (transition from liquid to gas) or because of the reduced density and the increased viscosity (gas) of the cooling fluid, abruptly offers a flow resistance such to the cooling fluid that substantially no fluid is allowed to pass.

Thus a cooling system is obtained having a blocking device which operates automatically and reliably and comprises no moving parts, and in the case of heat leakage into the cooled container substantially blocks the flow of cooling fluid to this container, with the result that substantially no cooling power is wasted and the remainder of the system is unaffected by the heat leakage into the said container.

According to the invention the cooling system in which in operation gaseous cooling fluid is supplied to the fluid supply pipe, is characterized in that the restriction is a laminar restriction.

For a laminar restriction the following formula approximately applies

$$\dot{m} = C \frac{\Delta P}{T^{3/2}}$$

where:

m = fluid mass flow through the restriction

ΔP = pressure drop across the restriction

T = absolute temperature of the fluid at the location of the restriction

C = constant.

Because ΔP is determined by the cooling system and may be considered as a constant we have:

$$\dot{m} = \frac{C_1}{T^{3/2}}$$

where C_1 is a new constant.

Thus a small rise in temperature of the gas used as a cooling fluid which flows towards the restriction results in a considerable reduction in the gas flow allowed to pass through the restriction. The laminar restriction may for example comprise a system of small-diameter passages.

In the cooling device in which in operation liquid cooling fluid is supplied to the fluid supply pipe, the restriction according to the invention is a turbulent restriction. A turbulent restriction, such as a diaphragm provides the advantage that in general its manufacture is simpler than that of a laminar restriction.

The fact that in the present case, a turbulent restriction is sufficient and hence no costlier laminar restriction is required, is due to the circumstance that owing to the large change in density which occurs at the transition of the cooling fluid from the liquid to the gaseous state as a result of heating in the heat exchanger, the flow resistance of the cooling fluid in the restriction is greatly increased. Consequently the flow of cooling fluid through the restriction is greatly reduced.

The invention will now be explained more fully with reference to the accompanying drawings in which two exemplary embodiments of the cooling system are shown schematically and not to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a cooling system using a cooling fluid which circulates in a closed pipe system and on the one hand transfers thermal energy to the cold head of a cold gas refrigerator and on the other hand absorbs thermal energy from the vapor space of a storage container for liquefied gas.

FIG. **2** shows a cooling system in which three storage containers for liquefied gas are cooled by means of a compression-expansion refrigerating system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1,** a Dewar flask **1** contains liquid hydrogen. In a vapor space **2** of the flask a cooling coil **3** is placed, the inlet of which is connected to a supply pipe **4** for cooling fluid and the outlet of which is connected to a discharge pipe **5.** A heat exchanger **6** for heat exchange with the cold head **7** of a cold gas refrigerator **8** is connected at one end to the supply pipe **4** and at the other end to the discharge pipe **5.** Said supply and discharge ducts **4** and **5** have a first part **4***a*, **5***a*, respectively extending from the refrigerator **8** to said flask or closed space **1**, and a second part **4***a*, **5***a*, respectively within said space, with adjacent portions of said second parts forming said heat exchanger. A pumping device **9** connected in the supply pipe **4** serves to circulate the cooling fluid, in this case pressurized gaseous helium.

The part of the supply pipe **4** situated within the vapor space **2** of the Dewar flask **1** includes a laminar restriction **10,** while outside the Dewar flask a heat exchanger **11** is included in the supply pipe **4** and also in the discharge pipe **5.** The restriction or first means **10** and the heat exchanger or second means **11** together form a blocking device.

During normal operation the gaseous helium at a pressure of for example 20 atmospheres which circulates in the pipe system is cooled in the heat exchanger **6** to for example 15° K. In the Dewar flask **1** the cold gaseous helium just ensures recondensation of hydrogen vaporized by heat leakage. Hence the hydrogen pressure remains at a value below atmospheric pressure. The temperature of the helium gas streams entering and leaving the cooling coil are nearly equal. Hence the temperatures of the two helium gas streams which pass through the heat exchanger **11** are substantially equal also. Thus this heat exchanger **11** plays no active part.

If owing to leakage of the Dewar flask there is increased heat leakage into the system, the temperature in the flask rises and the helium gas is heated in the cooling coil **3.**

As a result, in the heat exchanger **11** the hot helium gas issuing from the Dewar flask heats the cold helium stream from the cold head **7.** Mainly because of the ensuing increase in viscosity of the helium of the latter current, and to a lesser extent because of the reduced helium density, the laminar restriction **10** allows only a fraction of the initial helium stream to pass. Hence substantially no thermal energy is wasted in the Dewar flask **1**, and at the same time heating of the cold head **7** of the cold gas refrigerator **8** is prevented.

In the system shown in FIG. **2** three Dewar flasks **20, 21** and **22** contain liquid helium. In vapor spaces **23, 24** and **25** respectively of these flasks cooling coils **26, 27** and **28** respectively are placed which via supply pipes **29, 30** and **31** and discharge pipes **32, 33** and **34** respectively are connected in parallel relationship to a common supply pipe **35** and a common discharge pipe **36.** Turbulent restrictions **38, 39** and **40** are included in the parts of the supply pipes **29, 30** and **31** situated within the Dewar flasks **20, 21** and **22** respectively. Outside the Dewar flasks heat exchangers **41, 42** and **43** are included in the associated supply and discharge pipes **29, 32; 30, 33;** and **31, 34** respectively. Each assembly comprising a restriction and a heat exchanger **38, 41; 39, 42; 40, 43** constitutes a blocking device.

The three turbulent restrictions have substantially equal internal cross-sectional areas so that in normal operation they also ensure that substantially equal cooling fluid streams flow to the cooling coils.

The common discharge pipe **36** opens into a container **45** the vapor space **46** of which communicates via heat exchangers **47, 48** and **49** with the suction inlet **50** of a low-pressure compressor **51** the outlet of which is coupled to the inlet of a high-pressure compressor **52.** The outlet **53** of the high-pressure compressor **52** is connected to the common supply pipe **35** via, in the enumerated order, a cooler **54,** heat exchangers **49, 55,** 48, 56 and **47,** a throttle valve **57** and a heat exchanger **58** arranged in the container **45.**

A cold source **60** forms part of the heat exchanger **55,** and a cold source **61** forms part of the heat exchanger **56.** The two cold sources may be the cold areas of a two-stage cold gas refrigerator. The cooling device uses helium as the cooling fluid. In operation gaseous helium is compressed to a high pressure in the compressors **51** and **52** and then supplied via the outlet **53** to the cooler **54** in which the compressed helium gives off the heat of compression. In the heat exchanger **49** the compressed helium then gives off heat to helium at a lower pressure and temperature. In the heat exchanger **55** the high-pressure helium is cooled by the cold source **60** to a temperature of, for example, 60°K and then in the heat exchanger **48** again gives off heat to helium at a low pressure and temperature. Subsequently in the heat exchanger **56** the compressed helium is cooled further to a temperature of, for example, 15°K by the cold source **61.** Finally in the heat exchanger **47** the high-pressure helium again gives off heat to helium at a lower pressure and temperature. The high-pressure helium then enters a throttle valve **57** in which it expands isenthalpically to below the critical pressure of 2.26 atmospheres and to below the critical temperature of 5.3°K, so that about 50 percent of the gaseous helium is liquefied. In the heat exchanger **58** the remaining 50 percent of gaseous helium is condensed by the liquid helium in the container **45,** so that substantially only liquid helium is supplied to the cooling coils **26, 27** and **28.** In these cooling coils about one-half of the helium flowing through them is vaporized. In the container **45** helium in the gaseous state is separated from helium in the liquid state. The 50 percent of liquid helium then are used to condense the 50 percent of gaseous helium in the helium stream from the throttle valve **57.** The helium vapor in the container **45** is sucked into the compressor **51.**

In the process of cooling the latent heat (heat of evaporation) of the liquid helium is utilized. This means that the temperatures of the two helium streams flowing through each of the heat exchangers **41, 42** and **43** normally are equal, so that these heat exchangers then are passive.

When however heat leakage into one of the Dewar flasks occurs, for example into the middle flask **21,** the temperature in it rises. As a result all the liquid helium flowing through the cooling coil **27** evaporates and the resulting helium gas is heated. In the heat exchanger **42** the hot helium gas gives off heat to the liquid helium flowing through the supply pipe **30,** so that this liquid helium evaporates. The turbulent restriction **39** then "sees" gaseous helium instead of liquid helium, the density of this gaseous helium being far less than that of liquid helium. Mainly because of this difference in density the turbulent restriction **39** allows much less helium to pass. Thus very little thermal energy is wasted in the Dewar flask **21,** while the Dewar flasks **20** and **22** are not affected by the heating of the leaky Dewar flask **21.**

Although the embodiments described relate to the cooling of cryostats filled with liquefied gas, obviously there are many other possible applications, such as the cooling of chambers in freeze-drying systems, the cooling of evacuated spaces in high-vacuum technology or in vapor deposition apparatus, the cooling of deep-freeze containers, and so on.

What is claimed is:

1. In a cooling system operable with a source of cooled fluid for refrigerating a closed space, including a cooling element which is situated in said space and through which said fluid is flowable for refrigerating said space, a supply duct for communicating said fluid from said source to said cooling element, a discharge duct for communicating said fluid from said element to said source, and means for circulating said fluid through said system, the improvement in combination therewith, wherein said supply and discharge ducts each comprise a first part extending from said source to said closed space and a second part within said closed space extending to said cooling element, said first part of said supply and discharge ducts having adjacent portions in heat exchange relationship forming a heat exchanger, the improvement being a blocking device comprising said heat exchanger and a fluid flow restriction means in said second part of the supply duct, whereby a heat leak into said closed space causing a temperature rise therein causes heat transfer into fluid in said cooling element and in said discharge duct, and further heat transfer from fluid in said discharge duct to fluid in said supply duct via said heat exchanger, and wherein said restriction means restricts flow in said supply duct of fluid to which said heat has been added.

2. Apparatus according to claim **1** wherein said restriction means comprises a laminar flow restriction means.

3. Apparatus according to claim **1** wherein said restriction means comprises a turbulent flow restriction means.

4. Apparatus according to claim **1** wherein said source of cooling fluid comprises continuous duct means including as parts thereof said supply and discharge ducts, a quantity of helium in said duct means, and a cold gas refrigerator for cooling said helium in said duct means.

5. Apparatus according to claim **1** wherein said closed space comprises a Dewar flask.

6. In a cooling system operable with a source of fluid for refrigerating a closed space, including a cooling element which is situated in said space whereby said fluid becomes heated and through which said fluid is flowable for refrigerating said space, a supply duct for communicating said fluid from said source to said cooling element, a discharge duct for communicating said fluid from said element to said source, and means for circulating said fluid through said system, the improvement in combination therewith, comprising first means in said closed space, and second means for transferring heat from said fluid heated in said cooling element to fluid in said supply duct upstream of said space, said first means operable to restrict flow in the supply duct of said fluid when it has been heated by said second means.

7. Apparatus according to claim **6** wherein said second means comprises a heat exchanger formed of adjacent portions of said discharge and supply ducts whereby heat from said fluid when heated in said cooling element is transferred to fluid in said supply duct, which fluid then becomes less dense and flow thereof is restricted by said first means.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,908,397 Dated Sept. 30, 1975

Inventor(s) GIJSBERT PRAST and JAN MULDER

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 47, after "second part" delete "4a, 5a", and insert --4b, 5b--

Col. 4, line 53, "In operation gaseous helium" should be a new paragraph

Col. 6, lines 34 and 35, after "in said space" delete "whereby said fluid becomes heated"

line 36, after "said space" insert --whereby said fluid becomes heated--

Signed and Sealed this

sixteenth **Day of** *December 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks