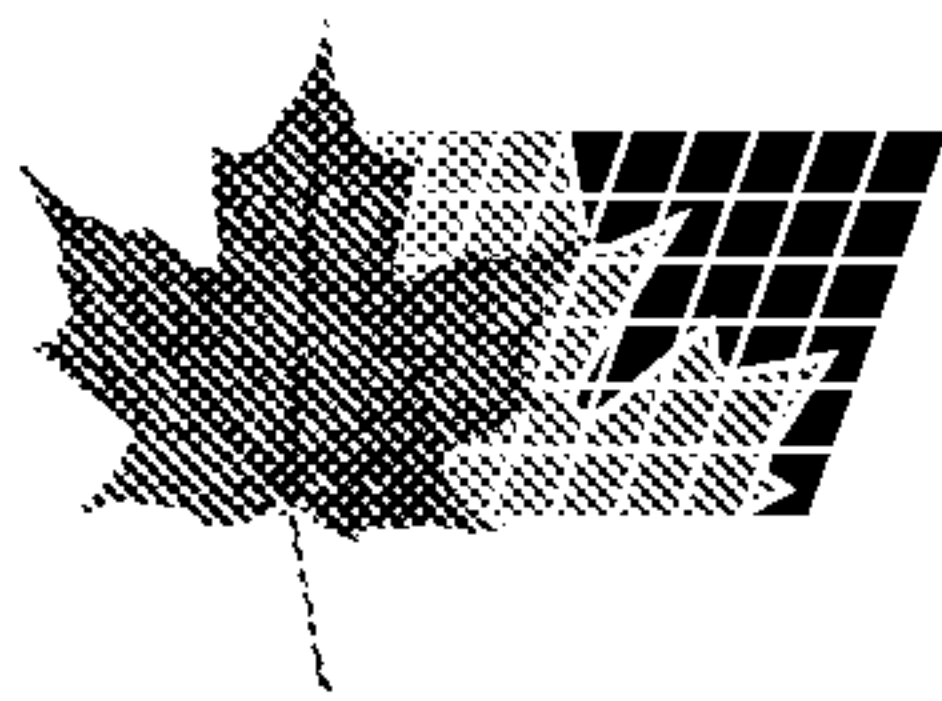
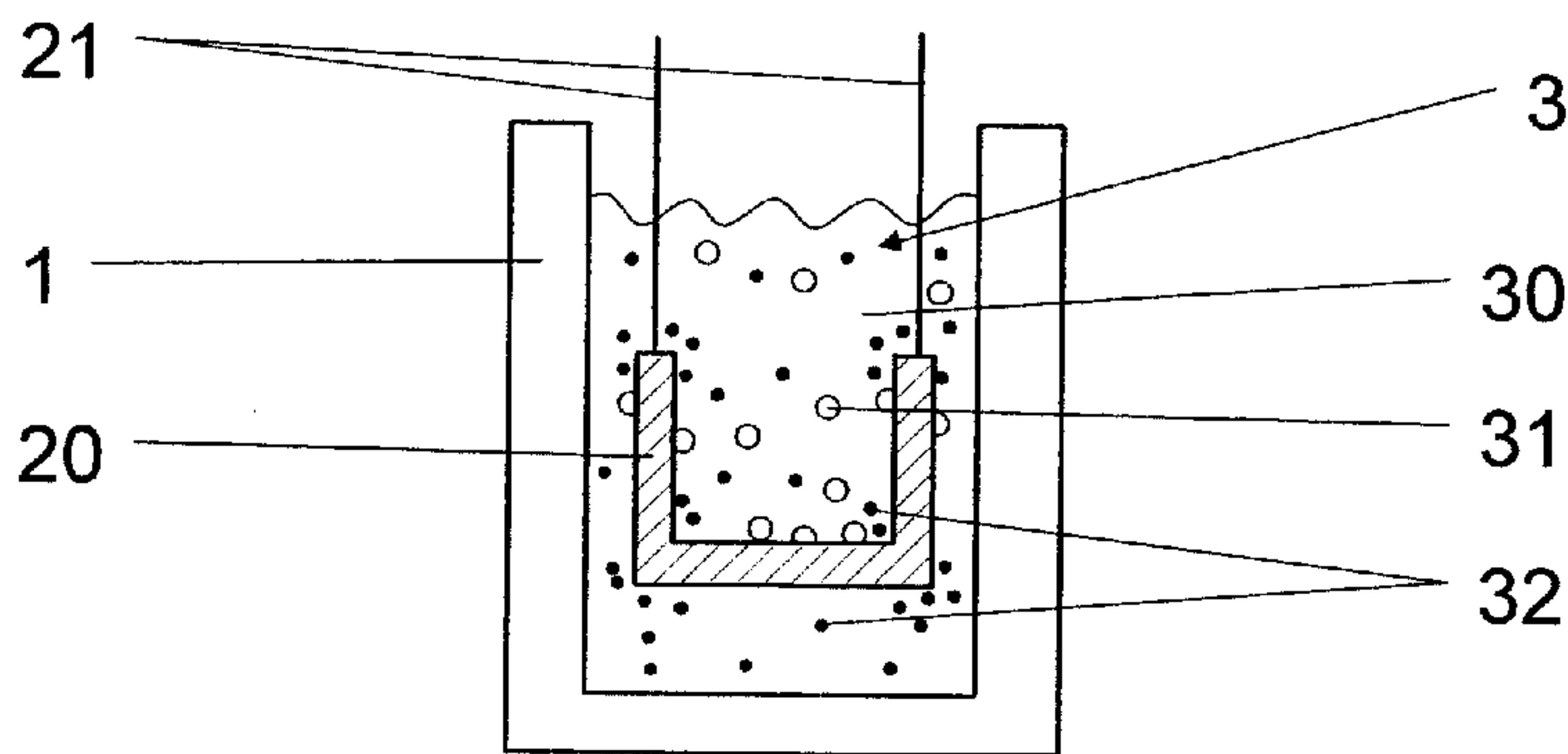




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(54) **AGENT FRIGORIFIQUE POUR SUPRACONDUCTEURS A
HAUTE TEMPERATURE**
(54) **COOLING AGENT FOR HIGH-TEMPERATURE
SUPERCONDUCTORS**



(57) In the operation of subassemblies, based on high-temperature superconductors, at increased power, for example in the field of power supply, certain limits are set by cooling and shockproofness. Either, the nominal current I_N must be limited in order to keep the potential heat generation low, and/or the driving voltage is restricted in order to avoid high electric field strengths. According to the invention, there are suspended in a cooling liquid such as liquid nitrogen small particles which improve the heat transfer into the cooling agent and simultaneously increase the dielectric constant of the cooling agent.

COOLING AGENT FOR HIGH-TEMPERATURE SUPERCONDUCTORS

ABSTRACT

In the operation of subassemblies, based on
5 high-temperature superconductors, at increased power,
for example in the field of power supply, certain
limits are set by cooling and shockproofness. Either,
the nominal current I_N must be limited in order to keep
the potential heat generation low, and/or the driving
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According to the invention, there are suspended
in a cooling liquid such as liquid nitrogen small
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15 cooling agent and simultaneously increase the
dielectric constant of the cooling agent.

Figure 1

DESCRIPTION

COOLING AGENT FOR HIGH-TEMPERATURE SUPERCONDUCTORS

5 The invention relates to a cooling agent for cooling high-temperature superconductors in accordance with the preamble of patent claim 1. It relates, in particular, to a cooling agent for the use of subassemblies, components or devices based on high-
10 temperature superconductors in the field of power supply.

 Applications of high-temperature superconductors in the power supply sector, for example as transmission cables, transformers or current
15 limiters in the medium-voltage range, make specific demands on cooling and electrical insulation. On the one hand, a voltage drop which cannot be neglected, and corresponding heat generation come about in superconductors in the case of which the nominal
20 current density is in the region of the critical current density. On the other hand, in the case of alternating-current applications, alternating-current losses still occur in the superconductor and likewise contribute to heating of the superconductor, frequently
25 to a yet more extensive degree. Correspondingly, in continuous operation the nominal current (I_N) may not exceed a certain current intensity, in order for the superconductor not to be heated above its critical temperature (T_c). The cooling of the superconductor to
30 its operating temperature below T_c is performed most simply by immersing the superconductor in a cooling liquid such as liquid nitrogen, liquid helium, liquid neon or a mixture of liquid nitrogen and oxygen which is located in a special container known as a cryostat.

35 Furthermore, a superconductor which can be at an electric potential of above 100 kV, must also be electrically insulated from the cryostat. Field intensifications, that is to say inhomogeneous

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distributions of the electric field, occur, in particular, in the region of tips or edges. The presence of a cooling agent and/or the absence of air or gas insulation is rendered noticeable by a reduced electric breakdown strength. The latter is a modest 10 kV/mm in pure LN₂ in a large volume, and is even less in the case of boiling nitrogen accompanied by the production of bubbles. The maximum voltage occurring must correspondingly remain limited and/or more care must be taken to avoid sites at risk of breakdown when designing a superconducting subassembly.

The problems named are further accentuated in the case of current limiters based on superconductors. In the case of limitation, when a fault current or overcurrent greater than the critical current I_c goes through the superconductor, the superconductor goes over into the resistive state. Correspondingly, even more heat is dissipated and has to be removed by the cooling agent. Since, in the case of limitation, the driving voltage for the most part drops across the superconductor, there is also the risk of an electric breakdown between individual sections of the superconductor which are not at the same potential.

A decisive point is for heat transfer into the liquid cooling agent from the high-temperature superconductor arrangement which, in addition to the actual superconductor, can further comprise normally conducting shunt resistors and/or insulating layers. If the temperature difference between the superconductor arrangement and the cooling liquid (for example 77 K for LN₂) is too great, the film boiling region of the cooling liquid is being encountered. In the case of the use of liquid nitrogen (LN₂), a continuous film of gaseous nitrogen forms on the surface of the structure to be cooled. This entails a relatively poor heat transfer and signifies, on the one hand, a retarded cooling down of the object immersed in the coolant or, on the other hand, at worst a further temperature

increase of the latter if it produces heat itself. By contrast therewith, an increased heat transfer is to be expected in the bubble boiling region which is formed between the cooling liquid and the object to be cooled at least in the case of a small temperature gradient. The corresponding temperature profile of a sample under constant heat absorption is found, for example, in the article "Transient heat transfer from smooth surfaces into liquid nitrogen", by V. Drach and J. Fricke, Cryogenics, Volume 36 (1996), pages 263 to 269.

It is the object of the invention to create a cooling agent for high-temperature superconductors which improves the economics of its use, in particular in the field of power supply in the case of medium and high powers.

The object is achieved by means of a cooling agent for high-temperature superconductors having the features of patent claim 1.

The core of the invention is the finding that in addition to the configuration of a superconductor itself, the cooling agent surrounding it also influences the economics of its application. Savings can be achieved in the construction and in the design of high-temperature superconductor arrangements by simple modifications of a known cooling liquid.

The requirements made of the cooling agent by the invention comprise, for example, protecting the superconductor against thermal overloading and against electric breakdown between different sections of a superconductor or between the superconductor and a cryostat containing the cooling agent. For this purpose, small particles are dispersed or suspended, that is to say finely distributed in a floating state, in a cooling liquid.

In accordance with a first preferred embodiment, the dispersed particles act as condensation nuclei for the cooling liquid, it being possible to delay the transition from the bubble region into the

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film boiling region. Thus, subassemblies immersed in the dispersion are better protected against excessive heating and can be operated at higher nominal currents.

In accordance with a further embodiment, the
5 suspended particles have a dielectric constant which is higher than that of the cooling liquid. A cooling agent based on a cooling liquid with properties modified in such a way protects a subassembly from electric breakdowns, and permits operation at higher voltages.

10 Liquid nitrogen LN_2 is preferably used as cooling liquid.

The invention is explained in more detail below with the aid of exemplary embodiments in conjunction with the drawing. The reference numerals used are
15 summarized in the list of reference numerals.

Figure 1 illustrates a cryostat with a cooling agent for high-temperature superconductors according to the invention.

Figure 1 shows a cryostat 1, which is filled
20 with a cooling liquid 30 and which insulates the latter thermally from the surroundings. Immersed in the cooling liquid 30 is a high-temperature superconductor arrangement 20 which is connected into a circuit via normally conducting supply leads 21. Dispersed in the
25 cooling liquid 30 are small particles 32 which are suspended in the cooling liquid 30 and, together with the latter, form the cooling agent 3 according to the invention in the form of a suspension or dispersion. Evaporating cooling liquid 30 forms rising bubbles 31.
30 Not shown in Figure 1 is a cover for closing the cryostat 1 and any bushings of the supply leads 31 through the cryostat. The high-temperature superconductor arrangement 20 is, for example, part of a transformer of a current limiter or of some other
35 unit in the field of power transmission.

The dispersed particles 32 act as condensation nuclei (nucleation centers) and delay the formation of a continuous film composed of evaporated cooling liquid

31 on the surface of the object 20 to be cooled. Thus, bubble boiling will prevail, together with its better heat transfer properties by comparison with film boiling, even in the case of a relatively large
5 temperature gradient. It is possible owing to the improved cooling effect for the superconductor 20 to be loaded with a higher nominal current.

The cooling agent 3 according to the invention also serves to increase the electric breakdown
10 strength. An electric breakdown is to be expected at the site with the highest electric field strength. So-called field intensifications occur, in particular, where the conductor forms tips, corners or edges. Dielectrics with a high dielectric constant ϵ generally
15 have a higher breakdown strength. In order to avoid the need to provide disproportionately large spacings between the superconductor 20 and the cryostat 1, or between sections of the superconductor, which are possibly at a different potential, particles 32 with a
20 dielectric constant ϵ which is higher than that of the cooling liquid 30 (for example $\epsilon(\text{LN}_2) = 1.45$) are added to the cooling liquid 30. This leads to an increase in the dielectric constant of the cooling agent 3, and to an improved shielding of the electric field.

25 In addition, the desired shielding is favored by the dielectrophoretic effect. In a less strongly polarizable fluid, particles with a higher dielectric constant are acted on in the inhomogeneous electric field by a force which draws them into zones with a
30 higher absolute field strength. Consequently, the particles accumulate at the potentially endangered sites mentioned and further intensify the shielding there. This effect also serves the improved cooling addressed above, since in the case of a corner of the
35 conductor, for example, the current distribution is increased inhomogeneously and in accordance with the losses.

The particles 32 mixed as an additive with the cooling liquid 30 preferably consist of ceramic materials such as SiO_2 , Al_2O_3 , SrTiO_3 , BaSrO_3 , TiO_2 , SiC , ZnO and/or of materials which are present in the solid state only at the temperature of the coolant (77 K for LN_2), such as, for example, H_2O , CO_2 , Ar, methane or ethylene. The dielectric constants of the latter are 1.5 (Ar) to 2.2 (H_2O), and up to 1000 (SrTiO_3) or more for the ceramic materials. A certain roughness of the particle surface is advantageous. The particle size is preferably so large that agglomerations are prevented. Typical linear extents are between 1 and 100 μm . The specific density of the suspended particles is preferably in the range of the density of the cooling liquid. The latter is, for example, 0.8 g/cm^3 for LN_2 and still 1.2 g/cm^3 for liquid oxygen. In another embodiment, means are provided for preventing sedimentation of the particles. such means comprise, for example, a pump or a stirrer arranged in the cryostat. The particle density is preferably less than 2% by volume.

Examples:

A steel strip of width 2 cm and thickness 500 μm , coated on one side with a varnish and provided on the other side with a 1 mm thick glass fiber epoxy layer was immersed in liquid nitrogen and connected to a current source. A stable state ensued up to a current intensity of 160 A, that is to say the heat generated could be extracted by the cooling agent, and the voltage dropped remained constant.

Thereupon, an Al_2O_3 powder with an average particle size of 10 μm was mixed into the liquid nitrogen (2 Vol%), and the experiment was repeated. This time, a thermally stable state could be established up to a current intensity of 200 A. This corresponds to 56% increase in the cooling performance!

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Breakdown tests in accordance with IEEE standard 1.2/50 μ s (IEC-60) were carried out in liquid nitrogen. After the addition of small particles in the form of snowflakes and ice crystals, the breakdown voltage was increased by 35% by comparison with pure nitrogen.

Overall, given the use of a cooling agent according to the invention it is possible to improve the economics of the use of units based on superconductors.

In particular, in the case of transition to higher powers the increasing demands placed on cooling and breakdown strength can be transferred at least partially to the cooling agent, and this leads to savings in the design of the unit itself.

LIST OF REFERENCE NUMERALS

- | | | |
|----|----|----------------------------------|
| | 1 | Cryostat |
| 20 | 20 | High-temperature superconductor |
| | 21 | Supply lead |
| | 3 | Cooling agent |
| | 30 | Cooling liquid |
| | 31 | Evaporated cooling liquid |
| 25 | 32 | Suspended or dispersed particles |

PATENT CLAIMS

1. A cooling agent for cooling high-temperature superconductors (2), having a cooling liquid (30),
5 wherein small particles (32) are dispersed or suspended respectively in the cooling liquid (30).
2. The cooling agent as claimed in claim 1, wherein the small particles (32) are condensation nuclei for the cooling liquid (30).
- 10 3. The cooling agent as claimed in claim 1, wherein the particles (32) have a dielectric constant which is increased by comparison with the cooling liquid (30).
4. The cooling agent as claimed in claim 2 or 3,
15 wherein the particles (32) have a linear extent in the region of 1-100 μm .
5. The cooling agent as claimed in claim 2 or 3, wherein the total volume of the particles (32) makes up less than 2% of a volume of the cooling liquid (30).
- 20 6. The cooling agent as claimed in claim 2 or 3, wherein the particles consist of SiO_2 , Al_2O_3 , SrTiO_3 , BaSrO_3 , TiO_2 , SiC , ZnO or frozen H_2O , CO_2 , Ar or mixtures thereof.
7. The cooling agent as claimed in claim 2 or 3,
25 wherein the cooling liquid (30) consists of liquid nitrogen (LN_2).
8. The cooling agent as claimed in claim 2 or 3, wherein the specific density of the particles (32) and of the cooling liquid (30) are at least approximately
30 of equal magnitude.
9. The cooling agent as claimed in claim 2 or 3, wherein means are provided for preventing sedimentation of the particles (32).

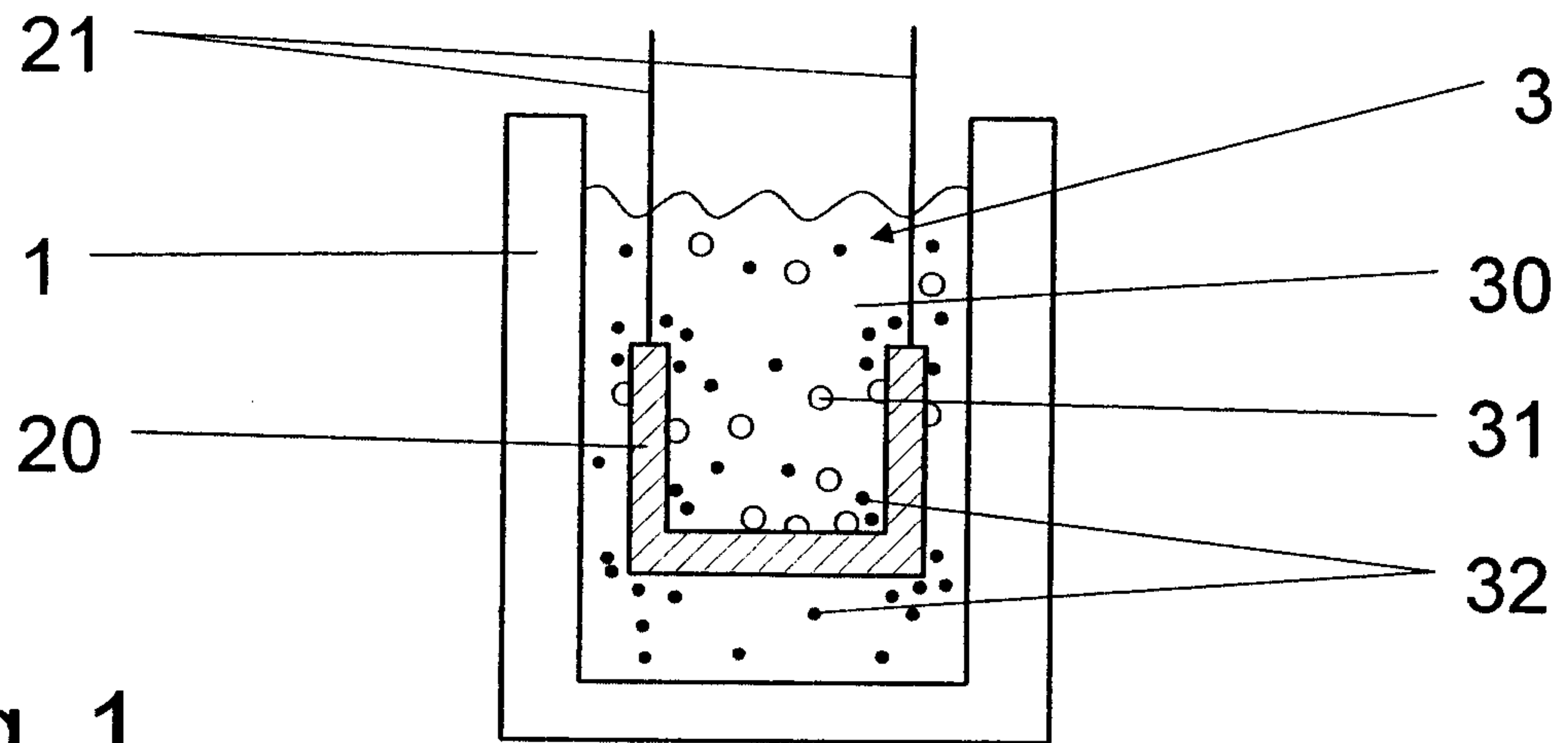


Fig. 1

