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(54) **METAL-TO-COMPOSITE HIGH-PRESSURE CYLINDER**

(57) This invention is intended for exclusion of loading of the ring-type welded joint of the cylinder-shaped part with the bottom. Metal-composite high-pressure cylinder contains thin-wall welded metal liner and external pressure-resistant shell made of composite material and formed by combination of groups of layers of high-modulus and low-modulus fibers of the reinforcing materials, which fibers are oriented in spiral and circular directions, while in the zone of ring-type welded seam in the liner's envelope there is a ring-type lens-shaped compensator, and while wall structure of the composite pressure-resistant shell of the cylinder includes at least one ring-type bracelet - limiter of axial deformations, which bracelet is installed above the lens-shaped compensator and over all its surface is rigidly connected with the independent groups of continuous reinforcing fibers, while width of this bracelet exceeds width of the compensator, and number of the bracelets - limiters is determined proceeding from the condition of limitation of axial deformation of the compensator, and from resilience of the used material.

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Description

Technical field

[0001] This invention belongs to the art of gas apparatus, namely to metal-composite high-pressure cylinders used, in particular, in the oxygen breathing apparatus intended for mountain climbers, rescue workers, in portable cryogenic and fire fighting equipment, in gas supply systems, etc.

State of the art

[0002] Metal-composite high-pressure cylinders produced currently include thin internal hermetic envelope (liner) made of metal, and external pressure-resistant shell made of composite material formed by braids of high-modulus fiber (e.g. carbon fiber) winded over the liner and impregnated by binding substance.

[0003] Among the requirements to high-pressure gas cylinders the following have top priority: reduction of the cylinder's specific material consumption determined by ration of the cylinder's mass to its volume, and assurance of the cylinder's useful life as regards number of the pressurization cycles with safe operation of the cylinder.

[0004] Currently known is the metal-plastic high-pressure cylinder including stamped-welded hermetic steel liner and external pressure-resistant shell made of composite material. The liner includes middle cylinder-shaped part, two bottoms, and has wall thickness 0.5-0.9 mm. The bottoms are connected with the middle part by means of welding through spacing rings ensuring the liner's smooth external surface in the place of welding seam. A nipple is welded to at least one of the bottoms (see RU 2077682 C1, 20.04.1997),

[0005] To manufacture the liner, one is to use steel blank part made of thin rolled sheet. The cylinder-shaped part of the liner is to be made of steel-sheet plank part rolled up into a cylinder form and butt-welded by, for instance, electron-beam welding. The bottom is to be made by known method of cold stretch from the same rolled sheet. When doing this, since depth of the bottoms is insignificant, that is, as a rule, not more than 0.32 of the external diameter, their thickness upon the stretching is comparable with the thickness of the cylinder-shaped blank part. The bottoms are to be welded along their perimeter to the cylinder-shaped part through the spacer rings. This welding is performed, for instance, electron-beam or laser welding. Welding and stamping-welding technologies allow to produce steel liners with rather thin walls and, thereby, to ensure the cylinder's rather low specific consumption of materials.

[0006] However, currently known construction of the metal-plastic cylinders with welded or stamped-welded steel liners have rather low useful life as regards number of the pressurization cycles due to possibilities of the liner destruction in the area of the bottom's welded joint.

[0007] Currently known is the composite high-pressure cylinder including thin-walled metal welded liner and external pressure-resistant shell made of composite material formed by combination of groups of layers of high-modulus and low-modulus fibers of reinforcing materials, which fibers are oriented in spiral and circular directions. The cylinder is furnished with rings made of stainless steel and installed at external and internal sides of the liner in the places of connection of the cylinder-shaped shells with the bottoms (see RU 2140602 C1, 27.10.1999).

[0008] Disadvantage of the known construction of the cylinder with welded steel liner consists in rather low useful life as regard number of the pressurization cycles due to possibility of the liner destruction in the area of the bottom's welded joint.

Essence of Invention

[0009] Results of thorough investigations of fatigue behavior of the welded seems of steel pipes show, that even minor defects in the welded seam may significantly affect its serviceability. Important peculiarity of the ring-type welded joints is necessity of their aligning (adjustment). Any skew in this case will result in formation of secondary bending when the joint is loaded by transverse force with respect to the welded seam. Skewing the joint of the parts is the main cause of rather low fatigue properties of the welded seam. Another significant aspect of welding the ring-type ring-type seams is the character of the residual welding stresses. There are no rigid and established rules determining nature of the residual stresses in the welded ring-type seams, but experience based on measurement results, together with analysis conducted by the finite elements method show, that these stresses are always stretching in the near-root zone of the ring-type welded seams. In this case, even if external loads were cyclically varying from stretching to compression, actual range of stresses would always stay stretching.

[0010] This invention is based on challenge to create metal-plastic high-pressure cylinder allowing to exclude loading of the ring-type welded joint of the cylinder-shaped part with the bottom, and thereby to improve strength of the liner and useful life of the cylinder as regards pressurization cycles number with preservation of low material consumption of the cylinder.

[0011] Technical result of the invention is:

- Fulfillment of condition of conformity of deformations of the materials in the local zone of the welded seam, whereat axial strength of the composite shell is changed so that to attain zero stretching or compressing axial deformations in the liner's material, and thereby to completely exclude axial loading of the welded seam;
- Complete exclusion of deformation of the welded seam without introduction of additional disturbances into the liner's deformation in circular direction;
- Assurance of homogenous structure of the liner envelope and exclusion of effect of the welded seam on serviceability on the cylinder construction as a whole.

[0012] This technical result has been reached by that the metal-composite high-pressure cylinder contains thin-wall welded metal liner and external pressure-resistant shell made of composite material and formed by combination of groups of layers of high-modulus and low-modulus fibers of the reinforcing materials, which fibers are oriented in spiral and circular directions, while in the zone of ring-type welded seam in the liner's envelope there is a ring-type lens-shaped compensator, and while wall structure of the composite pressure-resistant shell of the cylinder includes at least one ring-type bracelet - limiter of axial deformations, which bracelet is installed above the lens-shaped compensator and over all its surface is rigidly connected with the independent groups of continuous reinforcing fibers, while width of this bracelet exceeds width of the compensator, and number of the bracelets-limiters is determined proceeding from the condition of limitation of axial deformation of the compensator, and from resilience of the used material.

[0013] Generatrix surface of the lens-shaped compensator may be executed as a surface composed of two nodoids connected by welded seam.

Generatrix surface of the lens-shaped compensator may be executed as a surface composed of parts of donut surfaces with their cross-section radiuses equal to 5-7 heights of the lens-shaped compensator.

[0014] Lens-shaped compensator may have at least one peripheral comb located in the welded seam's section.

[0015] Width of the lens-shaped compensator is at least 30-40 thicknesses of the liner envelope.

[0016] Generatrix surface of the lens-shaped compensator may be executed as a cylinder-shaped surface; in this case the compensator is partially inserted into the bracelet - limiter of axial deformations.

[0017] That bracelet - limiter of axial deformations, which is installed first from the liner's surface, may have meridional curvature actually coinciding with meridional curvature of the compensator, while the subsequent limiters are located in parallel with the first one within the structure of the composite material with mutual binding by reinforcing fibers of the composite shell.

[0018] Ring-type bracelets - limiters of axial deformations may have various longitudinal and transversal deformation factors.

[0019] Ring-type bracelets - limiters of axial deformations may be made of single-strand high-modulus cord fabric.

[0020] Ring-type bracelets - limiters of axial deformations may be made of combination of high-modulus and low-modulus groups of flexible continuous fibers.

[0021] Group of the high-modulus fibers may be made of metal cord threads, while group of the low-modulus fibers - of the fiberglass threads.

[0022] Group of the high-modulus fibers may be made of the high-modulus carbon fibers, while group of the low-modulus fibers - of the polyamide threads.

<u>List of drawings</u>

[0023]

- Figure 1 shows general view of the high-pressure cylinder.
- Figure 2 shows general view of the cylinder's liner.
- Figure 3 shows general view of the high-pressure cylinder.
- Figure 4 shows scheme of installation of the bracelets - limiters of axial deformation.
- Figure 5 shows process of alteration of axial deformation in the composite shell's material along the cylinder's genetratrix in the welded seam zone.
- Figure 6 shows nodoid form of generatrix of the compensator's surface.

<u>Embodiments of the invention</u>

[0024] Fig. 1 shows high-pressure cylinder including liner 1 and composite shell 2. With this, liner in its turn is composed of cylinder-shape wall 3, bottoms 4 welded to the wall, and nipple 5, which is welded to one of the bottoms 4. In the zone of welded joint of the cylinder-shaped wall and bottom in the liner there is a lens-shaped compensator, which is shown in Fig. 4 И Fig. 5.

[0025] Since main load in the course of the cylinder's operation is internal pressure of the media, deformations of various intensity may occur in liner's material and composite shell when the construction is working. With this, while in the circular direction the deformations of the liner material and of the composite shell are in conformity, in axial direction this condition is not always fulfilled, and there is a possibility of liner's sliding with respect to the composite shell. This sliding will result in increased deformations occurring in the liner's material and localizing in the welded joint. In order to insure conformity of axial deformations in the local zone of the liner's welded seam it is envisaged to use lens-shaped compensator, which, due to change of geometry and thrust by the internal pressure, ensures fulfillment of this condition of conformity of deformation of materials of the zone in question.

[0026] It is obvious, that serviceability of the ring-type welded seam in the liner is mainly determined by the meridional deformation $\varepsilon_{m\alpha}$ in its material. When condition of conformity of deformations of materials in the local zone of welded seam is fulfilled, varying axial stiffness of the composite shell it is possible to attain zero stretching or compressing axial deformations in the liner material, and thereby to completely exclude loading of the welded seam (see Fig. 5). To perform this task, it would be expedient that the structure of the composite material to include bracelets - limiters of axial deformations 6. Essence of construction of such bracelet consists in that its axial stiffness to stretching in combination with axial stiffness of the composite shell significantly reduces deformations in local zone of the welded seam and simultaneously does not disturb stiffness of the composite shell in circular direction. Such properties of construction of the bracelets - limiters of axial deformations allow to completely cancel deformation of the welded seam without introducing additional disturbances into deformations of the liner in circular direction. Fig. 5 shows process of alteration of axial deformations in the liner material in case the cylinder's construction includes bracelets - limiters of axial deformations.

[0027] Bracelets - limiters of axial deformations may be embodied with use of various constructive schemes. For instance, bracelet may be embodied as profiled metal lamella plates connected in circular direction by a low-modulus material. Also, bracelet may be embodied as a combination of high-modulus and low-modulus fibers oriented in various directions, or with use of the single-strand high-modulus cord fabric. Also, it is possible to combine the aforesaid schemes.

[0028] When the cylinder is under internal pressure, bracelets - limiters are subjected to pronounced gradient deformations resulting in occurrence of longitudinal and transversal shear stresses between them and intercrossing layers of the composite material. These stresses may result in formation of cracks in the composite and exert negative effect on useful life of the cylinder. It is known from the mechanics, that when considering the process of operation of axial stiffness of the bracelets - limiters and of the pressure-resistant shell's composite material, minimum distance necessary for exclusion of the aforesaid crack formation should be at least 3 - 5 thickness of the wall of the composite material, or, if compared with thickness of the liner wall, this ratio should be at least 15 - 20. On the basis of these considerations, width of the local compensator in the liner should be at least 30 - 40 thicknesses of the liner wall.

[0029] It is obvious, that when embodying the compensator it is necessary to provide for special form of its surface so that to exclude effect of the moment strains in the liner material. In mechanics such surfaces are called nodoid and unduloid surfaces.

[0030] Generatrices of the nodoid and unduloid shells are given in Fig. 6 and in parametric form are described as follows:

$$\begin{cases} x = (2\lambda - r_1)F(k', \varphi) + r_1 E(k', \varphi); \\ y = r_1\sqrt{1 - k'^2 \sin^2\varphi}, \end{cases}$$

where $k = (2\lambda - r_1)/r_1$ - modulus of elliptic integral, $k' = \sqrt{1 - k^2}$ - complementary modulus, F, E - elliptic integrals of 1st and 2nd genus, $\varphi = \arcsin \dfrac{\sqrt{r_1^2 - y^2}}{k' r_1}$ - current coordinate, λ - parameter characterizing the generatrix curve, r_1 - radius of the cylinder-shaped part of the shell.

At $0 < \lambda < r_1/2$ the shell is called unduloid, while at $r_1/2 < \lambda < r_1$ the shell is called nodoid, at $\lambda = r_1/2$ the shell becomes spherical. Mention should be made that generatrix of the nodoida (unduloid) is described by ellipse (hyperbola) focus moved along the straight live. Such shells possess maximum volume and minimum surface area, while angle of inclination of their tangent to generatrix tends to zero while approaching the place of joint with the cylinder-shaped or any other shell.

[0031] Nodoid and unduloid shells, when loaded by internal pressure, possess property of uniform strength, and with respect to strength they have advantage as compared with elliptic and spherical shells. Stresses occurring in nodoid and unduloid shells under this type of loading are significantly lower. Also, it is easy to see that one of the typical properties of the shells in question is that, while approaching the place of joint with the cylinder-shaped wall, this joint is rather smooth and there is almost no bending stress in it, that is edge effects are completely excluded.

[0032] Use of such form of the compensator surface allows to exclude occurrence of local deformation zones in the liner and thereby to significantly increase reliability of its operation.

[0033] In such a way, if constructing the cylinder as per the aforesaid scheme, we almost fully ensure uniform structure of the liner envelope end exclude effect of the welded seam on serviceability of the cylinder's construction as a whole. Operation of the high-pressure cylinder of the proposed construction consists in its filling with fluid substance/liquid or gas to required level of pressure, storing, transportation, discharging, subsequent refilling, consumption of the fluid substance, i.e. in repetition of actions and operations with multiple cyclic pressurization.

Industrial use

[0034] Creation of this device provides actual possibility to use high-pressure vessels made of different materials with use of internal welded thin-wall metal envelope - the liner. Manufacture and testing of the high-pressure vessels furnished with the proposed liner for hermetic sealing thereof have confirmed their high reliability and efficiency.

[0035] This invention may be used in the oxygen breathing apparatus intended for mountain climbers, rescue workers, in portable cryogenic and fire fighting equipment, in gas supply systems, and in automotive engineering.

Claims

1. Metal-composite high-pressure cylinder **characterized in that** it contains thin-wall welded metal liner and external pressure-resistant shell made of composite material and formed by combination of groups of layers of high-modulus and low-modulus fibers of the reinforcing materials, which fibers are oriented in spiral and circular directions, while in the zone of ring-type welded seam in the liner's envelope there is a ring-type lens-shaped compensator, and while wall structure of the composite pressure-resistant shell of the cylinder includes at least one ring-type bracelet - limiter of axial deformations, which bracelet is installed above the lens-shaped compensator and over all its surface is rigidly connected with the independent groups of continuous reinforcing fibers, while width of this bracelet exceeds width of the compensator, and number of the bracelets - limiters is determined proceeding from the condition of limitation of axial deformation of the compensator, and from resilience of the used material.

2. Cylinder as per item 1 above, wherein generatrix surface of the lens-shaped compensator is embodied as a surface composed of two nodoids connected by welded seam.

3. Cylinder as per item 1 above, wherein generatrix surface of the lens-shaped compensator is embodied as a surface composed of parts of donut-shaped surfaces with their cross-section radiuses equal to 5-7 heights of the lens-shaped compensator.

4. Cylinder as per item 1 above, wherein lens-shaped compensator has at least one peripheral comb located in the welded seam's section.

5. Cylinder as per item 1 above, or as per any of the items 2 - 4 above, wherein width of the lens-shaped compensator is at least 30-40 thicknesses of the liner envelope.

6. Cylinder as per item 1 above, wherein generatrix surface of the lens-shaped compensator is executed as a cylinder-shaped surface, while the compensator is partially inserted into the bracelet - limiter of axial deformations.

7. Cylinder as per item 1 above, wherein that bracelet - limiter of axial deformation, which is first from the liner surface, has meridional curvature actually coinciding with meridional curvature of the compensator, while subsequent limiters are located in parallel to the first one within the structure of the composite material with mutual binding by reinforcing fibers of the composite shell.

8. Cylinder as per item 1 above, wherein ring-type bracelets - limiters of axial deformations are executed with different longitudinal and transversal deformation factors.

9. Cylinder as per item 1 above, wherein ring-type bracelets - limiters of axial deformations are made of single-strand high-modulus cord fabric.

10. Cylinder as per item 1 above, wherein ring-type bracelets - limiters of axial deformations are executed as combination of high-modulus and low-modulus groups of continuous flexible fibers.

11. Cylinder as per item 1 above, wherein the group of high-modulus fibers is made of metal cord threads, while the group of low-modulus fibers - of the fiberglass threads.

12. Cylinder as per item 1 above, wherein the group of high-modulus fibers is made of high-modulus carbon threads, while the group of low-modulus fibers - of the polyamide threads.

Fig. 1

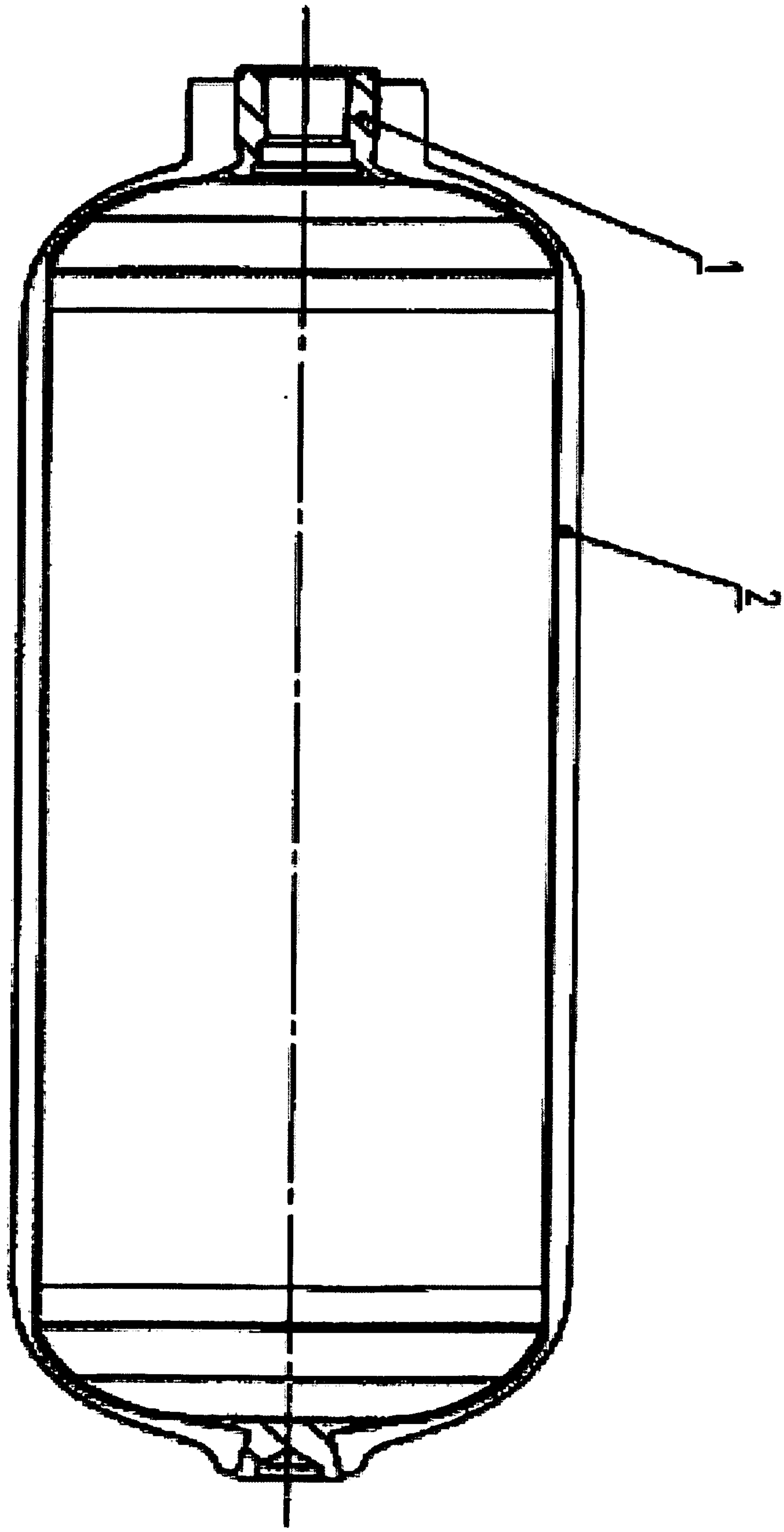


Fig. 2

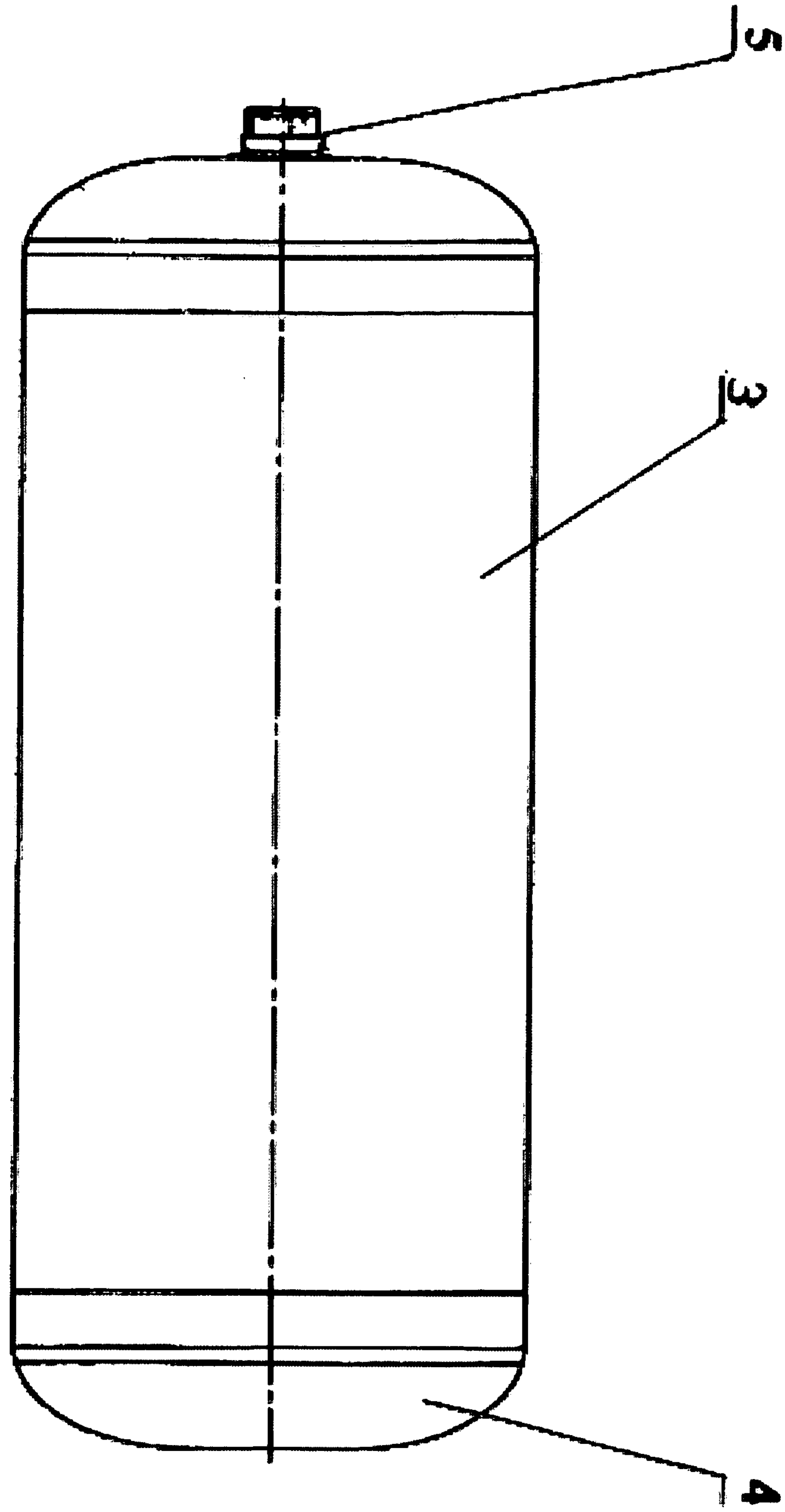


Fig. 3

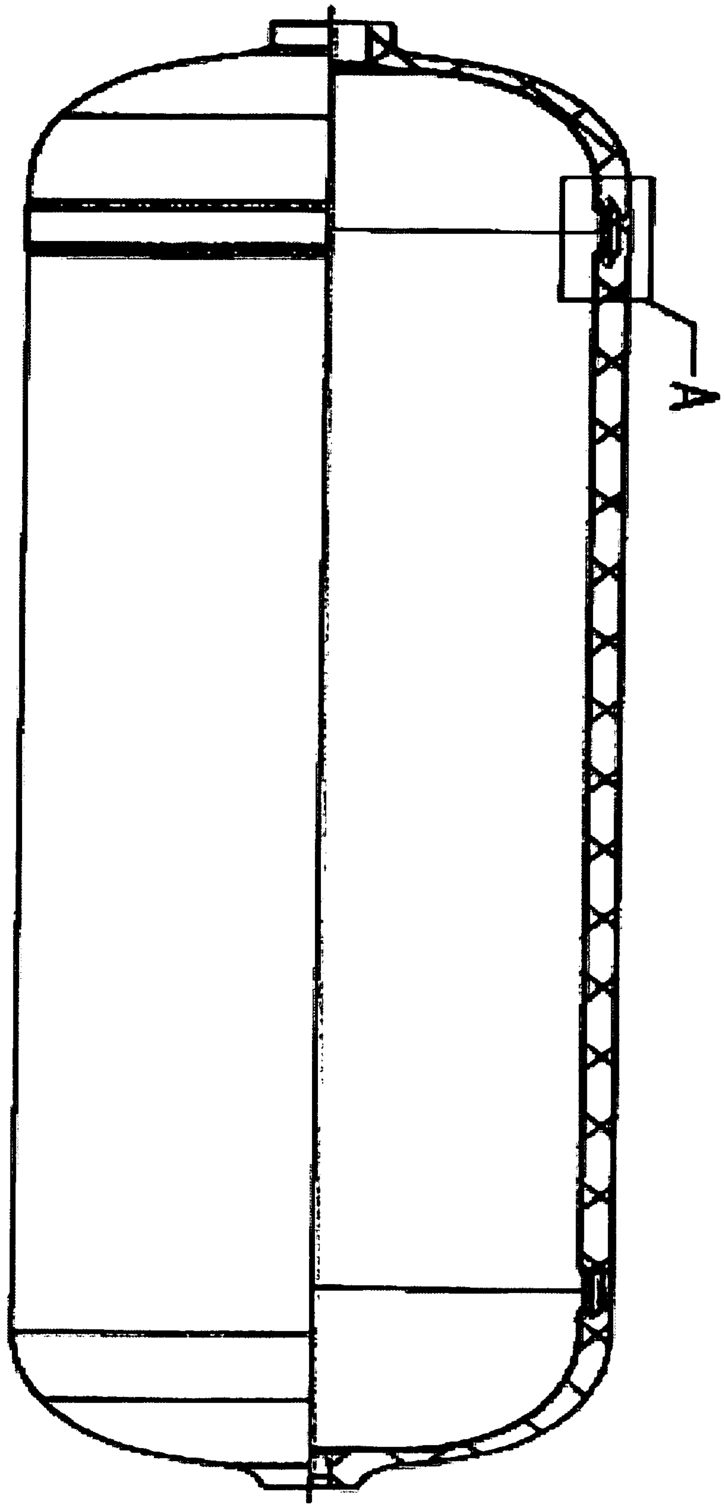


Fig. 4

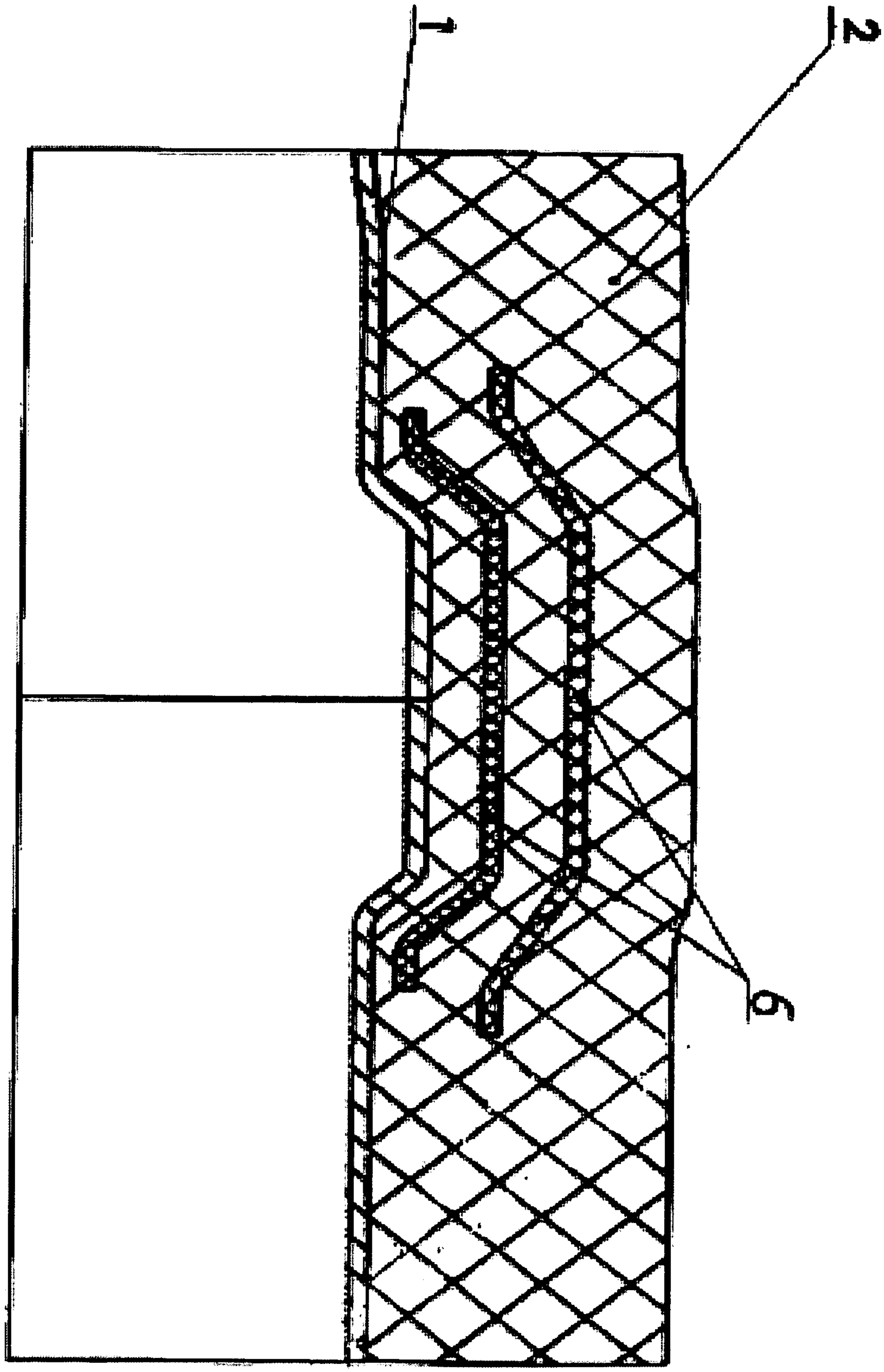
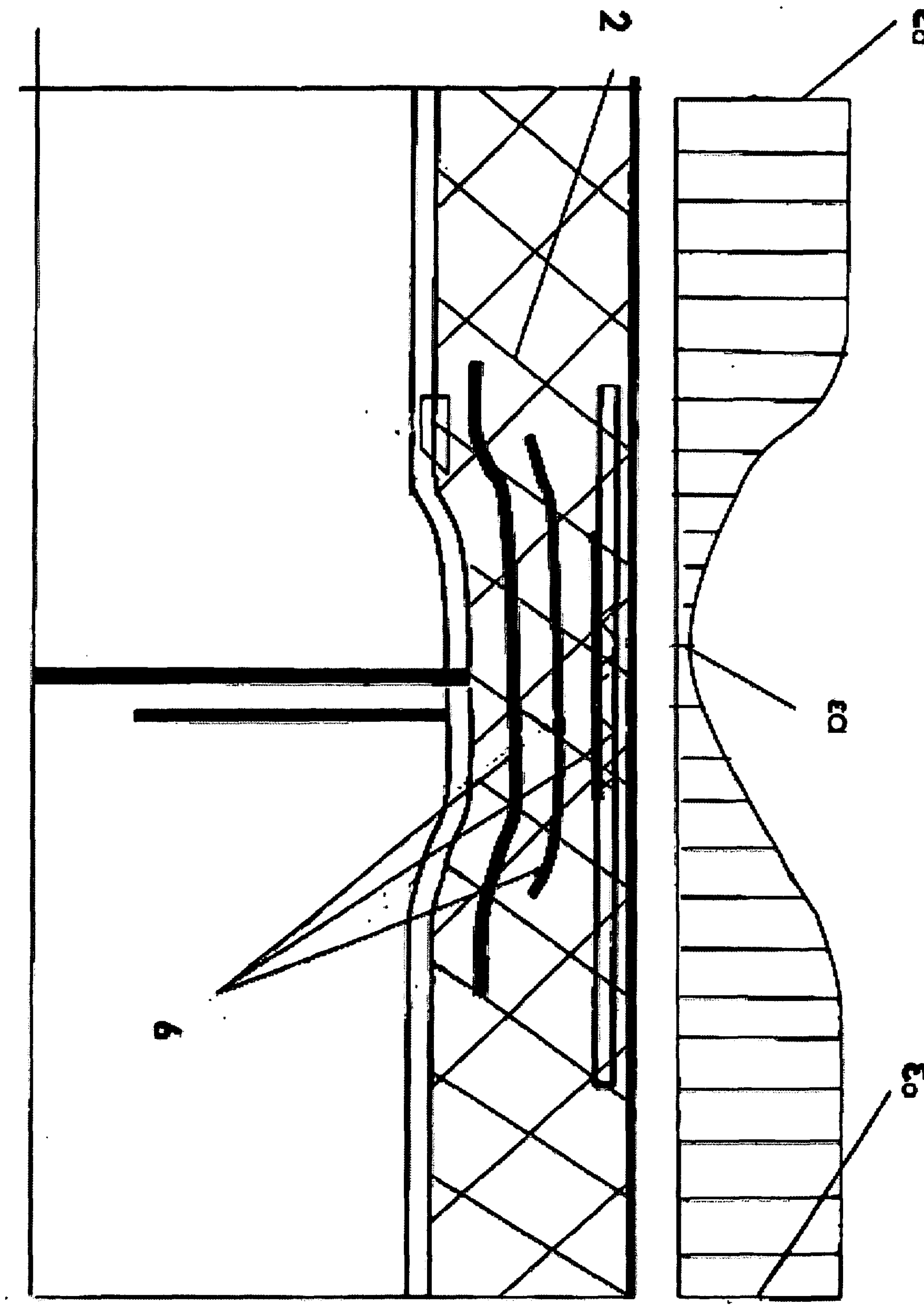


Fig. 5



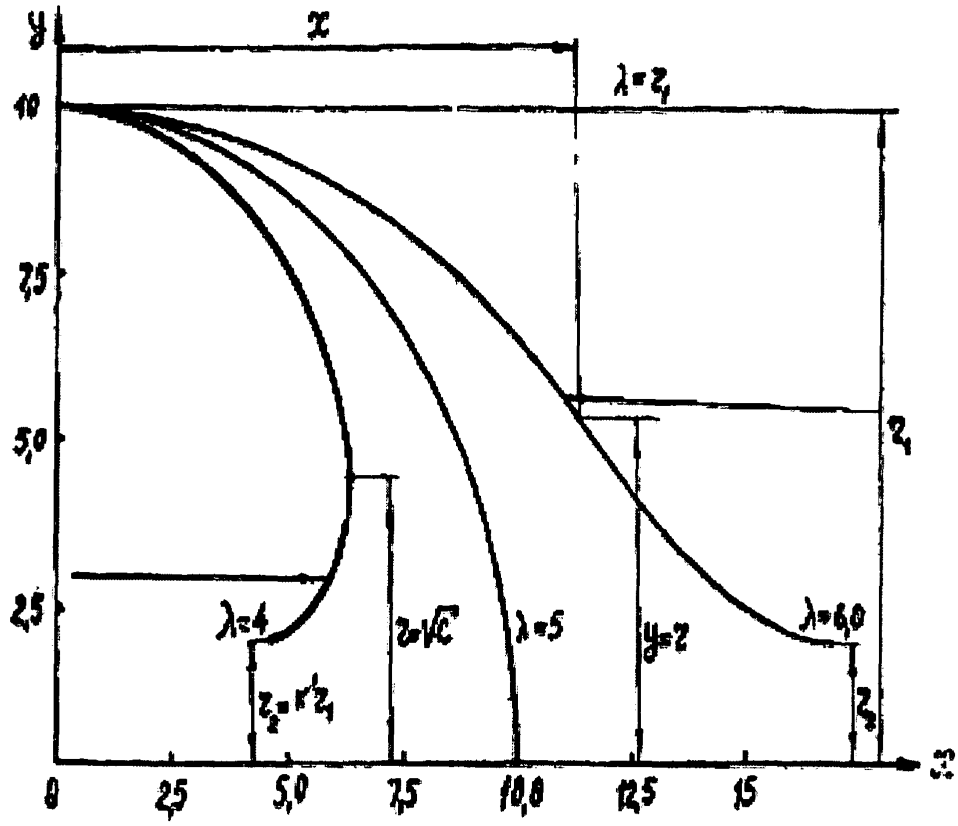


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/RU 2009/000232

A. CLASSIFICATION OF SUBJECT MATTER

F17C 1/00 *(2006.01)*
F17C 1/06 *(2006.01)*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F17C 1/00-1/06, 1/14, 1/16, F16L 9/00-9/147, F16J 12/0

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

RUPAT, Esp@cenet, USPTO DB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RU 2140602 C1 (TADTAEV VLADIMIR IRAKLIEVICH) 27.10.1999, the claims, the description, page 3	1-12
A	RU 2077682 C1 (TOVARISCHESTVO S OGRANICHENNOY OTVETSTVENNOSTJU NAUCHNO-PROIZVODSTVENNOE OBIEDINENIE "POISK") 20.04.1997, the claims, the description, page 3	1-12
A	RU 2205330 C1 (TADTAEV VLADIMIR IRAKLIEVICH et al.) 27.05.2003, the claims	1-12
A	RU 2002160 C1 (NAUCHNO-PROIZVODSTVENNOE PREDPRIYATIE "TEMP") 30.10.1993, the claims	1-12
A	WO 2004/029504 A1 (TADTAEV VLADIMIR IRAKLIEVICH et al) 08.04.2004, the claims	1-12
A	US 20050006394 Al (KAZUO FUJIHARA et al.) 13.01.2005	1-12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 December 2009	24 December 2009
Name and mailing address of the ISA/ RU Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 1998)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- RU 2077682 C1 **[0004]**
- RU 2140602 C1 **[0007]**