Material design and test verification of high impedance composite membrane of water container used in Chinese Space Station

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Abstract. A novel high impedance composite membrane material has been developed to satisfy the save demand of many kinds of space liquid medium in Chinese Space Station. Considering the high gas-resistance and water-resistance, and its compatibility with the liquid in Space Station, the composite membrane was skillfully designed using 9 layers materials. The compatibility experiment and mechanical properties experiment showed that the high impedance composite membrane has good compatibility with the liquid in Space Station, excellent heat-proof property, melted property, physical and mechanical properties, high gas-resistance and water-resistance property and great chemical corrosion-resistance property. The high impedance composite membrane material offers a new method for the design and application of inner-bag type water container in Space Station.

1. Introduction

The general water container of the Space Station is a general water storage container for the environmental control and life support subsystem (ECLSS). The storage or contact media in the water container include astronaut drinking water, condensed water, urine after adding pretreatment agent, urine residue after distillation, ultrapure water after purifying the urine treatment device, etc. The International Space Station (ISS) uses water storage tanks to transport and store liquid media. There are four commonly used tanks, Contingency Water Container(CWC), Payload Water Reservoir(PWR), Rodnik and EDV [1-12]. The first two are portable, collapsible structural soft storage tanks or water bags, the latter are hard shell and soft capsule tanks. In order to satisfy the compatibility requirement between the water storage vessel and the related media, the cystic structure in the soft body is adopted. The compatibility between the inner pocket and the media should be considered in the design.

CWC uses a thicker Combitherm membrane (VPCXX140) as the material of the capsule in the tank. It is compatible with the drinking water of astronauts containing silver ions. However, the caprolactam released from the material will increase the concentration of Total Organic Carbon(TOC) in drinking water. Long-term use of the water will have certain impact on health of astronauts, and this kind of membrane can not be used. PWR uses FEP membrane, which can not prevent carbon dioxide in the air from entering the storage water through the membrane, resulting in the PH value of the storage water tending to decrease under long-term storage conditions, and its poor air tightness can not prevent the filling liquid. For the PVDF membrane used in Russia, its compatibility with the drinking water of astronauts containing silver ions is poor, and the material performance is single, so it can not store all
kinds of liquid media. In summary, these tanks can only be used to store one or more types of water in Space Stations, not all liquid media in Space Stations.

In order to manage the liquid medium in the Space Station uniformly, all kinds of water in the Space Station of our country need a general water storage container for storage and transportation. The storage or contact media include astronaut drinking water with silver ion, condensate water, urine with pretreatment agent, urine residue after distillation pretreatment. Ultra-pure water and residual liquid after purification of the urine treatment unit put forward higher requirements for the materials of the water storage unit. Therefore, it is imperative to develop a high impedance composite membrane which can transport and store many kinds of solutions to meet the needs of our Space Station.

2. High impedance composite membrane material design
A new nine-layer high impedance composite membrane was developed for the Space Station's general water container. The composite membrane consists of nine layers of materials, metallocene polyethylene as the outermost layer, ethylene-vinyl alcohol copolymer as the innermost layer, and the proportions of each layer were designed by ourselves. The ethylene-vinyl alcohol copolymer layer can shield the nickel. The caprolactam produced by the Dragon prevents its infiltration and increases the TOC content. The new nine-layer high impedance composite membrane is different from the Combitherm membrane used by the International Space Station CWC. The composite membrane has excellent thermal sealing, melting properties, physical and mechanical properties, super water and gas resistance, excellent chemical stability, and can be compatible with five solutions. It is a new design. The new nine-layer high impedance composite membrane can be used to transport and store a variety of liquid media in Space Stations to meet the liquid storage requirements of China Space Stations, which is not available in the same type of tanks abroad. At present, similar formulations of composites have not been published publicly.

2.1. Function design
According to the requirements of high gas resistance, water resistance, compatibility, chemical stability and mechanical properties of liquid storage materials in Space Station, the functions of each layer of high impedance composite membrane were designed. The functions of each layer are as follows:
- Metallocene polyethylene has the properties of tensile resistance, penetration resistance, impact resistance and tear resistance, good thermal sealing and chemical stability, and good compatibility with five solutions.
- The nylon layer has high elongation, good air tightness, excellent mechanical properties, three times the tensile strength of polyethylene, and high puncture strength.
- Ethylene-vinyl alcohol copolymer is a new type of high impedance material with good transparency, high air tightness and strong gas barrier.
- The adhesive layer has a good adhesion to nylon and can fill the tiny holes in nylon membrane.
- Polyethylene adhesive layer and metallocene polyethylene have good adhesion, can effectively bond metallocene polyethylene and adhesive layer.

Through the reasonable selection of material function, it is ensured that the 9-layer high impedance composite membrane has the requirements of water resistance, gas resistance and compatibility, which surpasses the performance of Combitherm composite membrane and meets the requirements of Space Station for high performance water storage materials.

2.2. Composition and layout of material components
The high impedance composite membrane for Space Station water container consists of nine layers of materials, namely, Mao Linear Low Density Polyethylene (MLLDPE), Polyethylene tie layer, Adhesive layer, Nylon (PA nylon membrane), Ethylene-vinyl alcohol copolymer (EVAL), nylon (PA), Adhesive layer, Polyethylene adhesive layer (EVAL), MLLDPE. The composition of the nine layer high impedance composite membrane is shown in Table 1.
Table 1. Layer materials of the high impedance composite membrane.

| No. | Name of materials                        |
|-----|------------------------------------------|
| 1   | Mao Linear Low Density Polyethylene      |
| 2   | Polyethylene tie layer                   |
| 3   | Adhesive layer                           |
| 4   | Nylon                                    |
| 5   | Ethylene-vinyl alcohol copolymer          |
| 6   | Nylon                                    |
| 7   | Adhesive layer                           |
| 8   | Polyethylene tie layer                   |
| 9   | Mao Linear Low Density Polyethylene      |

The layouts of nine layers of composite membranes are shown in Figure 1.

![Figure 1. The layout of the 9 layer materials of the high impedance composite membrane.](image)

The new nine-layer high impedance composite membrane is symmetrically arranged with symmetrical distribution on both sides. The symmetrical structure is easy to realize three-dimensional heat sealing technology. Linear low density polyethylene (1st and 9th layers) is the outermost material, and the inner layer is Polyethylene Adhesive layer, Adhesive layer, Nylon, and the middle layer (5th layer) is Ethylene-vinyl Alcohol copolymer.

Considering the requirements of thermal sealing and compatibility, metallocene polyethylene is used as the outer layer, and caprolactam produced in nylon can be effectively prevented from infiltrating into the solution; the combination of the 4th and 6th layers can reduce the probability of gas penetrating through the tiny holes due to manufacturing defects, and the inner layer adopts the 2nd layer. Ethylene-vinyl alcohol copolymers can prevent carbon dioxide from entering the solution in the air and reduce the pH value. At the same time, they can prevent ammonia from urine and urine residue from penetrating into the external air and causing environmental pollution.

2.3. Design of material ratio for different layers

According to the actual functional requirements, it is the basis of ensuring the realization of the function to make a reasonable proportion of the composite membrane materials. Considering the requirements of high water resistance, gas resistance, chemical stability, compatibility and mechanical properties of nine-layer high impedance composite membrane, the thickness ratio of each layer of composite membrane was determined: Metallocene Polyethylene 52%, Polyethylene Adhesive 13%, Adhesive 5%, Nylon 18%, Ethylene-vinyl Alcohol copolymer 12%, among which Metallocene Polyethylene, Polyethylene tie layer, Adhesive layer and Nylon thickness are two layers of material thickness.
3. Experimental verification of the performance of high impedance composite membrane

3.1. Compatibility performance
In order to verify the reliability of the design, the compatibility and mechanical properties of the high impedance composite membrane were tested, including the compatibility of the high impedance composite membrane with astronaut drinking water, condensate water, urine after adding pretreatment agent, urine residue after distillation pretreatment, and ultrapure water after purification of urine treatment unit. The test results show that part of the test results of astronaut drinking water are shown in Figure 2.

(a) Change of TOC concentration  (b) The concentration change of Caprolactam

Figure 2. The experiment result of the astronaut drinking water and its comparison with NASA.

(a) Astronauts drinking water  (b) Condensate water

(c) Urine after pretreatment  (d) Concentrated urine added with pretreatment agent

Figure 3. A part of the compatibility experiment of liquid medium in Space Station.
The total amount of TOC released in one month was close to 1.5mg/L. Compared with the Combitherm membrane used in the CWC container of the International Space Station, the TOC and caprolactam released from the nine-layer high impedance composite membrane were lower than those from NASA, and were better than those from NASA. Test results of water bag Combitherm membrane for Space Station. The compatibility test kit with some Space Station liquid medium is shown in Figure 3.

Various compatibility tests showed that the high impedance composite membrane had good liquid compatibility in Space Station, especially in concentrated urine containing pretreatment. The results showed that the average thickness of the sample strip decreased very little after 180 days and had good chemical stability.

3.2. Mechanical property
The transverse tensile strength, longitudinal right-angle tearing strength, transverse right-angle tearing strength and thermal bonding strength of the test bags filled with various liquid media are measured periodically. Some of the test results are shown in Figure 4.

(a) After pretreatment (b) With pretreatment agent

Figure 4. The change of tensile strength with different keep time.

A large number of compatibility tests have been carried out on all kinds of media. From the tensile strength test results of two kinds of corrosive liquids, it can be seen that the overall strength of the test bags is slightly reduced, but the reduction is not significant. Because the material strength test can only be started once after a certain storage period, the difference of the bulk material of the bag will cause some fluctuations in the test results.

4. Conclusions
- The test results of the composite membrane and the astronauts' drinking water showed that the total TOC released in one month was close to 1.5mg/L, and the concentrations of TOC and caprolactam were lower.
- After 90 days, the transverse and longitudinal tensile strength of pretreated urine were reduced to 38 MPa and 35.25 MPa, respectively. The results of concentrated urine bag with pretreatment agent were similar.
- High impedance composite membrane for Space Station tank has good liquid compatibility, excellent heat sealing, melting and physical and mechanical properties, super water and gas resistance and excellent chemical stability, which can be widely used in Space Station aquatic products.
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