Self-breathing Technology for Spacecraft Packaging Container Gas Drying Method

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Abstract. The self-balancing method of packing container is to connect the packing container with the outside world to achieve pressure balance. The gas entering the packing container has been filtered and dried, and the technology of gas filtration has been mature. Under the open environment, the hygroscopicity of hygroscopicity agent needs to be tested. This paper introduces the requirement of hygroscopicant and the test of hygroscopicity under restraint condition, which is used in the design of self-balancing packaging equipment.

1. Introduction
The spacecraft is transported to the destination in the packing container. During the transportation, the spacecraft must be kept in a clean, dry and pressurized environment [1-2]. In this method, packing container pressure balance is proposed, the communication channel between the packing container and the external environment is a self-balance filter container. A moisture absorption agent and an air filter are installed in the filter box. The air entering the box must be filtered and dried by the filter container. In this method, air filtration is a relatively mature technology, but in the open environment, the moisture absorption capacity of the moisture absorbent needs further verification to assess whether it can meet the moisture absorption requirements. Therefore, this method focuses on the selection and verification of the moisture absorbent.

2. Calculation Condition
The requirements are as follow:
- (1) The volume of the purified packing box is about 240m³;
- (2) Purification time [3] is not less than 12 hours;
- (3) In the external temperature for -10 °C ~ 40 °C environment (temperature range can be distinguished between summer and winter), Internal the container to maintain the temperature is 5 ~ 35 °C;
- (4) The cleanliness in the container: 100,000 grade [4];
- (5) The humidity [5] of the container: < 55%.

3. Principle and calculation
3.1. Principle
The amount of moisture absorbed should be calculated according to 95% of the maximum humidity of air. According to formula (1), the humidity of 12 hours is reduced from 95% to 55%, and the moisture
absorbed by temperature change is calculated.

\[ H = V_1 \times m_3 \times \rho \]  

(1)

\( H \) —— The humidity of 12 hours decreased from 95% to 55%, and the water content needed to be absorbed by temperature change;

\( V_1 \) —— Intake Volume of 240 m³ container with 12 hours temperature Change;

\( m_3 \) —— Air humidity per cubic metre dropped from 95% to 55% of the water needed to be absorbed;

\( \rho \) —— Air density (1.2kg/m³);

Calculate the required moisture absorbent capacity as shown in Figure 1.

3.2. Gas Expansion Coefficient

According to Gay-Lussak's law (Uoseph Lollis Gay-lusses). When the pressure is constant, the volume of a certain mass of gas is proportional to the thermodynamic temperature. That is \( V_1/T_1=V_2/T_2=...=C \) constant. The expansion coefficient of the gas is 100/26666 (currently recognized as 1/273.15). When the altitude is fixed, the coefficient of thermal expansion of air volume can be found to be 1/273.15 (according to the law of thermal expansion of gas), that is, Air Volume (Abbreviation: AV) increases by 0.366% (av) for every degree of temperature rise.

3.3. Computation of Gas Volume Intake

The maximum range of temperature variation during transportation is 5~35°C, according to the record of temperature change curve in actual transportation, it is known that the temperature in the container rises at the fastest rate of 2°C per hour and 24°C at the most in 12 hours, so the air intake is calculated by the temperature difference of 30°C. Calculating gas volume according to formula (2)

\[ V_1 = V_2 \times (T_1-T_2) \times AV \]  

(2)

\( V_2 \) —— cabin volume 240 m³;

\( T_1=35°C \);

\( T_2=5°C \);

AV = 0.366%;

Data Substitution Formula (2);

\[ V_1 = 240 \times 30 \times 0.366\% = 26.35 \text{ m}^3 \].

3.4. Moisture Content

Packing container are transported between Beijing and Tianjin. The weather and climate conditions between Beijing and Tianjin are inquired. The highest temperature in summer is about 40°C, and the maximum humidity is 95%.

According to the dredging map, we can find that the moisture content of air is 46.26 g/kg when the temperature is 40°C and the humidity is 95%. That is, the moisture content of air is 46.26 g/kg when the temperature is 40°C and the humidity is 95%. The moisture content of air is 46.26 g (h1). According to the dredging map, we can find that the moisture content of air is 25.97 g/kg when the temperature is 40°C and the humidity is 55%. That is, the moisture content of air is 25.97 g/kg when the temperature is 40°C and the humidity is 55%. The moisture content of air is 25.97g (h2). The weight
of water absorbed per cubic meter of air from 95% The moisture content of air in 40°C and humidity is 55% humidity to 55% humidity at 40°C is calculated according to formula (3).

\[ m_3 = m_1 - m_2 \]  

\( m_1 \) —— Water content in air per cubic metre at 40°C and 95% humidity (46.26g);
\( m_2 \) —— Water content in air per cubic metre at 40°C and 55% humidity (25.97g);

Data Substitution Formula
\( m_3 = m_1 - m_2 = 20.29 \text{(g).} \)

3.5. Calculation of Moisture Absorption
Calculating Formula (1) Results Using Moisture Content and Intake data

\[ H = V_1 \times m_3 \times \rho = 26.35 \times 20.29 \times 1.2 = 642 \text{g} \]

That is to say, during 12 hours of continuous transportation, under the most disadvantageous conditions, the moisture absorbed by the transport compartment is 642 g, which decreases from 95% to 55%.

4. Experiment

4.1 Experiment Principle
The air volume is regulated by a supply air equipment. The normal temperature and humidity air is fed into a sealed container to simulate the transportation environment of the equipment. The air volume is regulated at the inlet end and the temperature and humidity are measured. A certain amount of moisture absorbent is placed in the sealed container, and the temperature and humidity of dehumidified air are detected by another temperature and humidity detector at the outlet, thus the moisture absorption performance of raw materials is calculated. At the same time, a recorder, record the change of temperature and humidity time uninterrupted and after moisture absorption moisture. The test prototype is shown in Figure 2. The water content at the inlet minus the water content at the outlet is the water absorbed by the desiccant. The water content in each state is calculated according to formula (4).

\[ H_n = V \times \rho \times d n \]  

\( H_n \) —— Absorbed water
\( V_2 \) —— Intake volume (7.2 m³/h);
\( \rho \) —— Density of air (1.2g/ m³);
\( d \) —— Moisture content;

![Figure 2. Test device](image)

4.2. Test Conditions
Laboratory environment: Temperature: 5 - 35 C, humidity: 30% - 70%.
According to the conditions, the air intake of the packing container for 12 hours is \( v = 26.35 \text{ m}^3 \), while the air intake per hour is \( v = 26.35 \text{ m}^3 \).
26.35 m³/12h = 2.2 m³/h; Input gas should be more than 2.2 m³/h. At present, the input gas volume is 7.2 m³/h, which meets the requirements.

4.3. Experimental Data
Calculating data by taking hygroscopic material silica gel as an example,

- W——Hygroscopic material weight (18.64 kg);
- T——Test time (m);
- RH₁——Inlet relative humidity (59.6%);
- d₁——Moisture content of inlet air (=9.77 g/kg);
- V₁——Inlet air volume (7.2 m³/h);

The above data substitution formula (4),

\[ H_1 = V_1 \times \rho \times d_1 \]
\[ H_1 = 7.2 \times 1.2 \times 9.77 = 84.41 \text{g}; \]

- RH₂——Outlet relative humidity (34.3%);
- d₂——Moisture content of outlet air (=5.87 g/kg);
- V₂——Outlet air volume (7.2 m³/h);

The above data substitution formula (4),

\[ H_2 = V_2 \times \rho \times d_2 \]
\[ H_2 = 7.2 \times 1.2 \times 5.87 = 50.71 \text{g}; \]

According to the formula (5) calculation of water absorbent absorption,

\[ H_3 = H_1 - H_2 \]
\[ H_3 = 84.41 - 50.71 = 33.7 \text{g}; \]

The maximum rheumatism rate was 34.3% within 35 minutes of the test and remained stable for several hours. The moisture absorption was calculated every 12 hours according to formula (6)

\[ H_4 = H/T \times 60 \times 12 \]

- H₄——12-hour water absorption (g);
- H₄=694 (g)

694 > 642, Therefore, the hygroscopicant meets the requirements.

The hygroscopicity of each substance is shown in Table 1.

| Table 1. Water absorption capacity |
|-----------------------------------|
| Weight (kg) | Silica gel | CaCl₂ | montmorillonite | mineral |
| 18.64 | 19.67 | 23.35 | 22.56 |
| T (m) | 35 | 60 | 85 | 48 |
| RH₁ (%) | 59.6% | 66% | 63.6% | 34% |
| d₁ (g/kg) | 9.77 | 9.99 | 9.21 | 4.53 |
| H₁ (g) | 84.4 | 86.3 | 79.6 | 39.1 |
| RH₂ (%) | 34.3% | 34.6% | 33.2% | 16.5% |
| d₂ (g/kg) | 5.87 | 5.46 | 5.08 | 2.25 |
| H₂ (g) | 50.7 | 47.2 | 43.9 | 19.4 |
| H (g) | 33.7 | 47.2 | 35.7 | 19.7 |
| H₄ (g) | 694 | 470 | 302 | 295 |
| conclusion | Yes | No | No | No |
The experimental results of several moisture absorbents show that silica gel can meet the requirements of open environment.

5. Concluding Remarks
The key technology of drying air in the self-balancing technology of packing container was tested through calculation and test analysis. The moisture absorbent and weight meeting the requirements were determined through the test results. However, this scheme only considers the gas exchange caused by temperature change, and the air pressure change transportation caused by altitude also needs to be considered. Therefore, this method is suitable for the transportation with little change in altitude. In the future, when this technology is widely used, the change of air pressure along the transport route should also be fully considered. The elevation of the transport route should be measured in detail to calculate the air exchange capacity. The weight of the hygroscopicant needed can be calculated by adding the air exchange capacity caused by the temperature change.

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