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Experiment of N_2O_4 Leakage and Diffusion in A Closed Space

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Abstract: The paper, by experiment of physical simulation, researched the leakage and diffusion law of N_2O_4 in a specific closed space. To simulate N_2O_4 leakage, the experiment pumped a certain amount of N_2O_4 gas into a specific space from a simulated leak point. And some electrochemical sensors were used to detect the concentration of N_2O_4 gas in some places in the space. The result showed that N_2O_4 diffused in the space, and the sensors facing to and near to the leak point sensed N_2O_4 gas at first. In the beginning, N_2O_4 diffused faster in the places below than above, and the bigger the leakage amount, the higher the concentration. After a while, N_2O_4 gas got even by diffusion, and the bigger the leaked amount was, the bigger the even concentration. If the environmental temperature was high, the even concentration in the lower part was higher a bit than that in the upper part. And the specific distribution of concentration was decided by the shape of the space.

Keywords: Closed space, N_2O_4, Leakage, Diffusion, Experiment.

1. Introduction

N_2O_4 is a common rocket engine fuel, which is decomposed into nitrogen dioxide in the air after volatilization, showing reddish brown color. It has medium toxicity and strong oxidization, and can support combustion. In case of leakage, nitrogen dioxide will spread rapidly, which will easily lead to bad consequences such as fire, burns and poisoning. Leakage in closed space is even more dangerous. Therefore, it is of great significance to study the leakage and diffusion law of N_2O_4 in closed space for accident early warning, monitoring, prevention and disposal.

Huang Zhiyong and Chen Xing studied the evaporation model of N_2O_4 under storage conditions [1], Feng Luo, Zachary Huang and others simulated the diffusion of N_2O_4 in confined space in brine [2]. Zhan Xiang and Cui Cunyan studied the ventilation optimization of propellant diffusion in closed space [3], Chen Jiazhao and Yu Wentao analyzed the diffusion safety of propellant in cylindrical space [4], and Liu Ningyuan and Cui Cunyan studied the leakage diffusion model of propellant in space launch site [5]. However, there are few reports on physical simulation tests of propellant leakage and diffusion in closed space. In this paper, the method of physical simulation test and electrochemical sensor are used to monitor the concentration of nitrogen dioxide vapor [6] [7] [8], and the law of N_2O_4 leakage and diffusion in a specific closed space is studied, which provides reference for rocket propellant leakage monitoring.

2. Test System

2.1. Closed space simulator

The closed space simulation is welded by cylinder, upper and lower half ellipsoidal concave bottom, pipeline, etc., as shown in Fig. 1. In order to test the leakage and diffusion law of N_2O_4 in the two-stage inter-tank section of a rocket, a special closed space is formed to simulate the two-stage inter-tank section of a rocket.

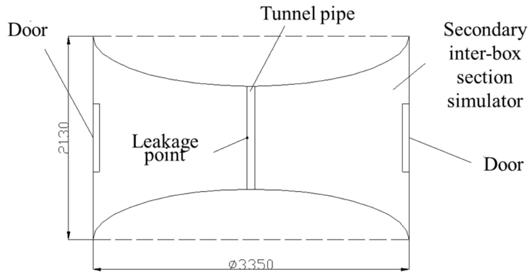


Figure 1. Dimension of Closed Space Simulator

The diameter of the cylinder is 3350mm and the height is 2130mm. There is an 800mm × 800mm gate in the middle of quadrant II and quadrant IV. The ratio of long radius to short radius of semi-ellipsoid bottom is 1.4. The pipe diameter is 100mm. A small hole with a diameter of 2mm is arranged at the middle of the pipeline facing quadrant II as a leakage point. The interior of the object is shown in Fig. 2.

Figure 2. Inside of Closed Space Simulator

2.2. Concentration acquisition system

The concentration acquisition system consists of nitrogen dioxide concentration sensor, data acquisition equipment, control equipment, etc. The physical object is shown in Fig. 3.

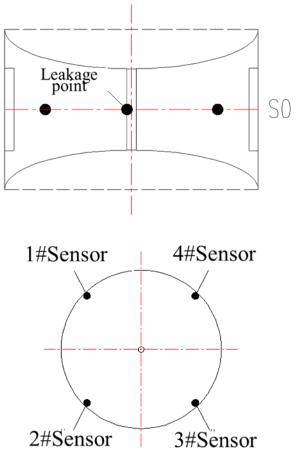
Figure 3. Picture of Real Product of Concentration Data Collection System

2.2.1. Technical indicators of the system

(1) Sensor measurement range: 0.1 ~ 100ppm
(2) Sensor resolution: 0.1 ppm
(3) Sensor output: 4 ~ 20mA
(4) Sensor response time: ≤ 30s
(5) Explosion-proof grade of sensor: Ex iaIIB T4
(6) Use temperature range:-20℃ ~ + 40℃;
(7) Data acquisition frequency: ≮1Hz
(8) Number of channels: 4

2.2.2. Sensor distribution

4 electrochemical nitrogen dioxide gas concentration sensors were used to monitor the nitrogen dioxide gas concentration in the closed space in real time. Four sensors are arranged on the inner wall of the cylinder at 45 degrees between four quadrants. In order to analyze the influence of sensors at different heights on the detection results, 3 height sections are respectively set: S_0 section with the same height as the leakage point (i.e., the middle of the cylinder height), S_1 section 330mm above the leakage point and S_2 section 330mm below the leakage point, as shown in Fig. 4 (a). In order to save money, four sensors are fixed at one height section at three heights at a time. The actual sensor is shown in Fig. 4 (b) (located at S_0 section).



(a) Schematic layout of sensors

(b) Physical diagram of sensor

Figure 4. Diagram of Sensors Distribution

2.3. N_2O_4 leakage simulation system

N_2O_4 leakage simulation system is composed of a N_2O_4 bag, a quantitative pump, a gas pipeline, etc. The N_2O_4 bag contains quantitative N_2O_4 gas (nitrogen dioxide), which is connected to the quantitative pump through the pipeline, and the outlet of the quantitative pump is connected to the preset leakage point on the pipeline. The real object is shown in Fig. 5.

Figure 5. Picture of Real Product of N_2O_4 Leakage Simulator

3. Test Process

The test was carried out in the shed of a factory in Beijing, which can shade the sun and has good ventilation conditions.

3.1. Test preparation

3.1.1. Preparation of quantitative N_2O_4 gas

0.2 ml, 0.5 ml and 0.7 ml of N_2O_4 liquid were injected into three sampling bottles, respectively, and frozen in the freezer for 2 hours, then the frozen sampling bottles were put into air bags and sealed.

3.1.2. Installation and calibration of sensors

The nitrogen dioxide gas sensor was installed and calibrated.

3.1.3. Debugging concentration acquisition system

The concentration acquisition system was turned on and debugged to ensure correct data acquisition.

3.2. The sensor is tested at the same height as the leakage point

(1) Install the sensor in S_0 section, close the door of the closed space simulation box, and seal the door crack of the box with rubber strip;

(2) Connect the air bag containing 0.2 ml N_2O_4 sampling bottle with the test pipeline and seal the interface;

(3) Open the cap of the sampling bottle, wait for the liquid to completely volatilize into gas, and mix evenly in the air bag;

(4) Open the propellant gas concentration monitoring system, check whether the wiring of sensors 1 ~ 4 corresponds to channels 1 ~ 4 on the control host, and check whether the display on the control host is correct;

(5) Turn on the quantitative air pump, start the test, record the test start time, the concentration acquisition system automatically records the data of four sensors in the closed space simulation, the tester observes the reading of the host, and shut down the air pump after the gas in the air bag is completely pumped out;

(6) After the readings of the four sensors are consistent, the test is terminated, the test termination time is recorded, and

the tank door is opened to completely disperse the N_2O_4 gas inside the tank;

(7) Replace the sampling bottle in the air bag, and carry out leakage and diffusion simulation tests of 0.5 ml and 0.7 ml quantitative N_2O_4 respectively according to the above methods. Each dosage was done 3 times, and the corresponding N_2O_4 gas concentration data was collected.

3.3. Sensor above leak point and below leak point test

The sensor is installed in S_1 section and S_2 section respectively, and the simulated leakage diffusion test is completed according to the above method, and the corresponding N_2O_4 gas concentration data is collected.

4. Test Data

The time-N_2O_4 concentration curve is plotted with the data collected by the system, in which the abscissa is time (recorded as hours: minutes: seconds), the ordinate is N_2O_4 concentration (unit: ppm), and channels 1 to 4 correspond to sensors 1 to 4, respectively.

Fig. 6-8 show the results of three tests with the sensor located in S_0 section and N_2O_4 dosages of 0.2 ml, 0.5 ml and 0.7 ml, respectively. The test conditions are shown in Table 1.

Table 1. Experimental Condition of Cross Section S_0

N_2O_4 dosage/ ml	Start time (filled with N_2O_4)	End time (open tank door)	Ambient temperature/°C	Ambient humidity/%	Fe
0.2	Day 1 11: 03	Day 1 11: 39	37	55	7.54
0.5	Day 2 8: 42	Day 2 10: 03	30	51	SiO2
0.7	Day 3 10: 18	Day 3 11: 08	32	42	35.78

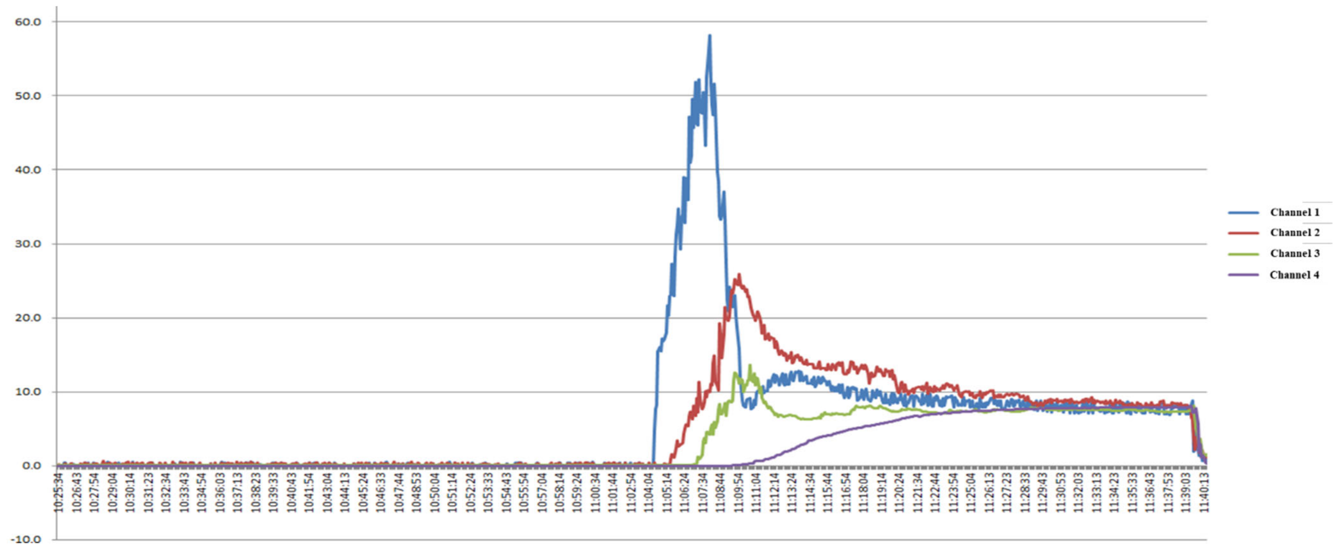


Figure 6. Experimental Data of Cross Section S_0 (Dosage of N_2O_4 is 0.2ml)

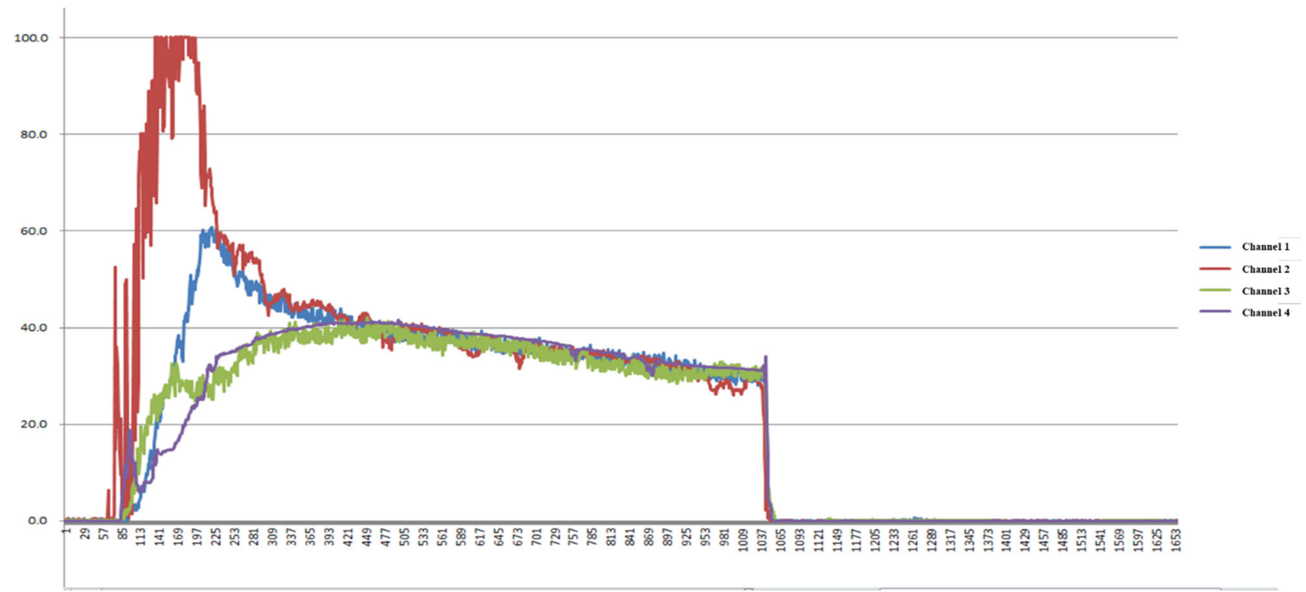


Figure 7. Experimental Data of Cross Section S_0 (Dosage of N_2O_4 is 0.5ml)

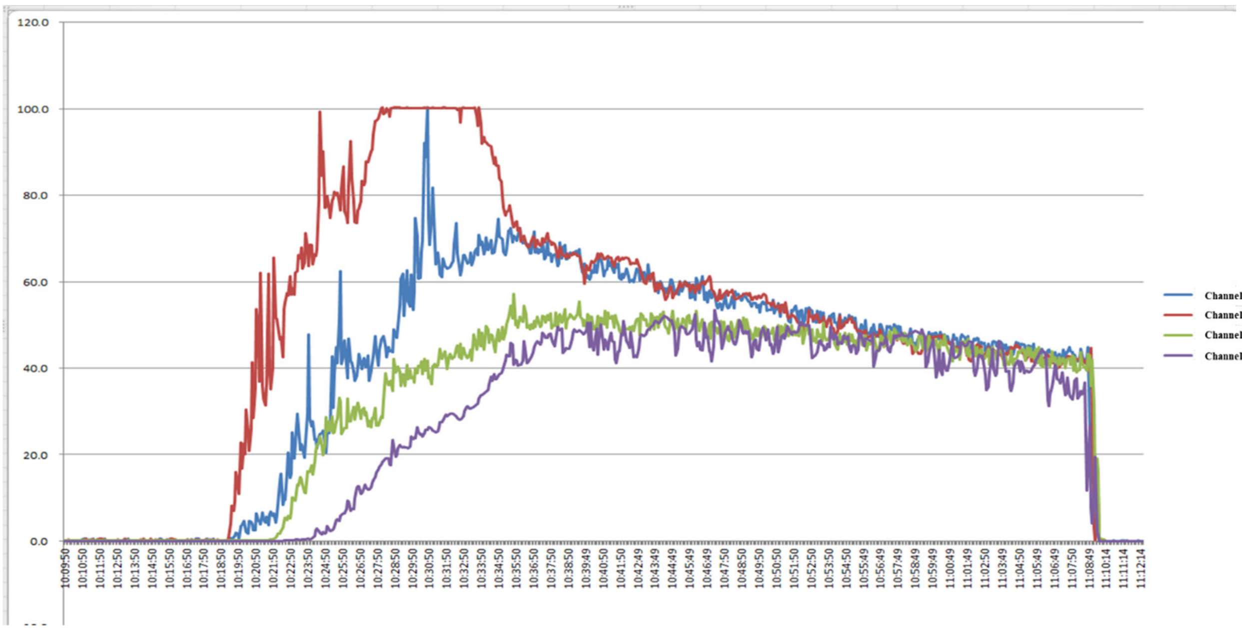


Figure 8. Experimental Data of Cross Section S0 (Dosage of N_2O_4 is 0.7ml)

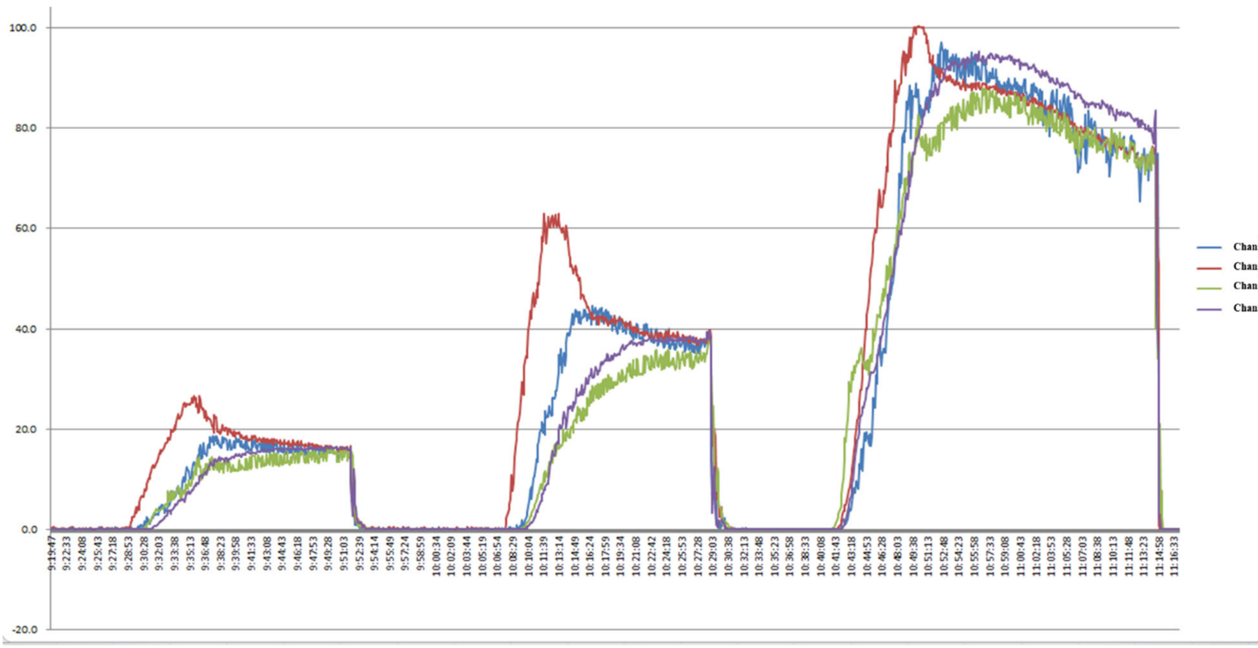


Figure 9. Experimental Data of Cross Section S_1 (Dosage of N_2O_4 is 0.2ml, 0.5ml and 0.7ml)

Fig. 9 shows the results of three tests with the sensor located in S_1 section and N_2O4 dosages of 0.2 ml, 0.5 ml and 0.7 ml respectively. The test conditions are shown in Table 2.

Table 2. Experimental Condition of Cross Section S_1

N_2O_4 dosage/ ml	Start time (filled with N_2O_4)	End time (open tank door)	Ambient temperature/℃	Ambient humidity/%
0.2	9: 27	9: 50	30	51
0.5	10: 06	10: 28	32	48
0.7	10: 40	11: 14	34	42

Fig. 10 and 11 show the results of four tests with the sensor located in S2 section and N_2O_4 dosages of 0.2 ml, 0.4 ml, 0.5 ml and 0.7 ml, respectively. The test conditions are shown in Table 3.

Table 3. Experimental Condition of Cross Section S_2

N_2O_4 dosage/ ml	Start time (filled with N_2O_4)	End time (open tank door)	Ambient temperature/℃	Ambient humidity/%
0.2	Day 1 9: 25	Day 1 9: 52	29	52
0.4	Day 1 9: 58	Day 1 10: 19	30	50
0.5	Day 2 9: 09	Day 2 9: 53	28	60
0.7	Day 2 10: 11	Day 2 10: 42	30	40

5. Conclusion

It can be seen from the above test data that:

(1) Generally speaking, Sensors 1 and 2 detect N_2O_4 gas before sensors 3 and 4, and reach a higher concentration peak, which indicates that the leakage and diffusion of N_2O_4 on the side facing the leakage point is faster and the concentration is higher. However, because it is a closed space, the concentration of N_2O_4 in the whole space will reach equilibrium after a period of time.

(2) From the point of view of diffusion velocity, the reaction time of sensor located in section S_0 is the shortest, followed by section S_2 and section S_1 is the longest, but the time difference is not big. This shows that N_2O_4 gas is heavier than air, and its diffusion velocity downward is slightly greater than that upward. The peak time of sensors located in different cross sections has little difference, but the greater the leakage dosage, the longer the peak time.

(3) From the concentration point of view, the greater the leakage dosage, the greater the peak value of the sensor at the same position; The sensor is located in different sections, the peak value is the largest in S_0 section, and the peak value is the smallest in S_1 section. This shows that the nearest sensor is easier to detect the leaked gas. The equilibrium concentration increases with the increase of leakage dosage, but the equilibrium concentration at S_0 section is the lowest and the equilibrium concentration at S_1 section is the highest. This is because the ambient temperature is high outdoors during the test, and it tends to rise with the heating of N_2O_4 gas. At the same time, the closed space is a special space with upper and lower concave bottoms, so it is easy to form a phenomenon that more N_2O_4 gas is accumulated in the upper and lower wedge-shaped areas than in the middle space.

6. Conclusion

In a special closed space, when N_2O_4 leaks, nitrogen dioxide gas diffuses, and the gas diffuses quickly towards the monitoring point on one side of the leakage point; The closer the monitoring point is to the leakage point, the faster the gas diffusion arrives; At the beginning, the lower monitoring point diffuses slightly faster than the upper monitoring point; The greater the leakage, the greater the concentration. However, after a period of time, the gas diffusion will reach equilibrium, and the greater the leakage dosage, the greater the equilibrium concentration; If the ambient temperature is high, the upper equilibrium concentration will be slightly higher than the lower equilibrium concentration. However, the concentration distribution is related to the shape of the closed space.

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