Experimental study of self-pressurizing transfer system for cryogenic liquid

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A series of experiments have been made to investigate cryogenic liquid transfer performance by self-pressurizing method for liquid oxygen tank. The simulation propellant is liquid nitrogen and the pressurizing gas is N_2 gas containing CO_2. By varying the content of CO_2 in pressurizing gas, both "liquid oxygen gasified pressurization mode" and "abundant in oxygen pressurization mode" are simulated. The experiments show that the simulation arrangement is feasible.

INTRODUCTION

To choose an appropriate pressurizing method for achieving the pressurizing transfer process for liquid propellant is a very important problem for cryogenic rocket design. The way of self-pressurizing transportation is an essential factor, by which the deadweight of rocket can be reduced, and the delivery capability and reliability may also be improved.

In order to carry out the simulation experiment of self-pressurizing transfer of cryogenic propellant rocket, a special down-scale test-bed has been designed. It follows the principle that the content of the pressurize gas in the simulation experiment is the same as the self-pressurize gas in the liquid propellant rocket, and the mass flux of impurity (carbon dioxide and water vapor) passing the engine filter in the experiment is also the same as in flight state.

In the self-pressurizing transfer system, the pressurizing gas is oxygen gas containing some carbon dioxide and water vapor. Based on calculation and data analysis, it has been recognized that the contents of carbon dioxide [1] and water vapor [2] in the system are far higher than their saturation solubility in the oxygen, and solid particles may form at low temperatures. In order to simulate the floating state of the solid particles in liquid, liquid nitrogen is used as simulation propellant instead of liquid oxygen, and the content of water vapor is converted into a proper content of carbon dioxide. Thus nitrogen gas containing carbon dioxide is used as pressurizing gas, instead of the combustion product used in the liquid oxygen-kerosene rocket.

EXPERIMENTAL APPARATUS

The experimental apparatus shown in Figure 1 mainly consists of a gas distribution system, a liquid transfer system and the data acquisition and control system. According to the requirement of the simulation, the pressurized gases of 0.4MPa* are prepared in advance in the gas tank(left side in Figure 1), which will be regulated to 0.15MPa when passing the pressure regulator to transfer the cryogenic liquid in LN_2 tank right side in Figure 1. The tank filter, liquid flow meter and engine filter are installed in the pipe of the liquid transfer system.

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* The pressure readings in the paper all use gauge pressure.

In the experiment, the pressure difference between the two sides of the tank filter and the engine filter, the system temperatures, the flow rates of pressurized gas and liquid are measured by the measuring system. Whether the engine filter is jammed by solid particles formed in the transfer process can be observed accordingly.

The compositions of pressurized gases, which are validated by a GC112A gas chromatograph before experiments, are listed in Table 1.

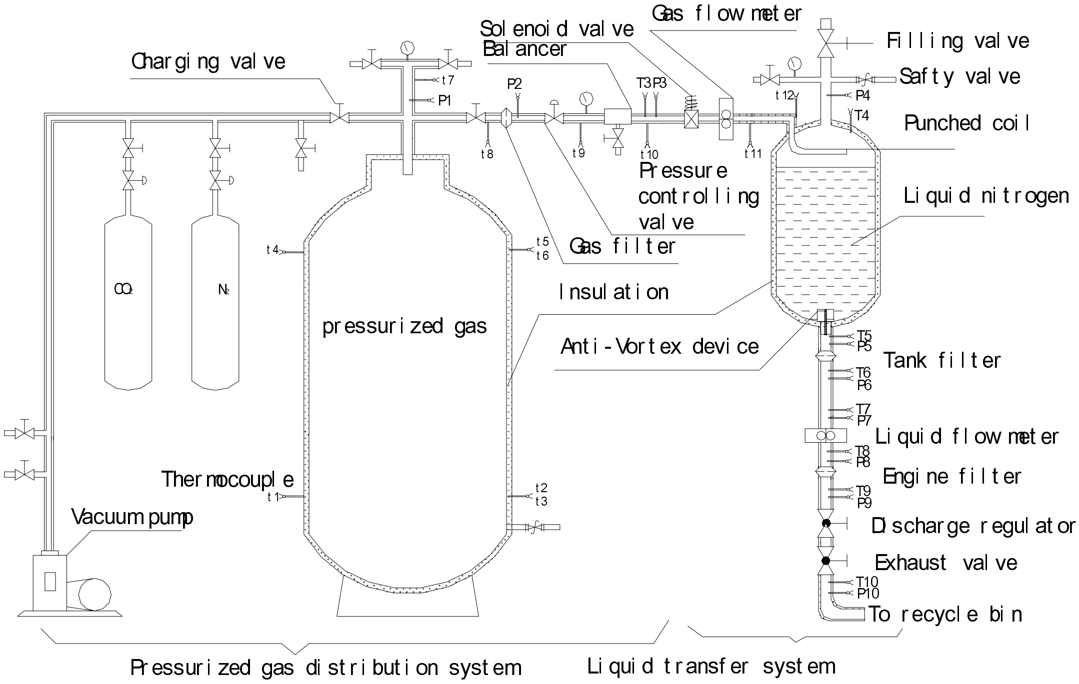

Figure 1 Schematic of experimental apparatus

Table 1 Composition of pressurized gases (Volume percent)

Mode	Required composition			Composition used in experiment	
	H_2O	CO_2	O_2	CO_2	N_2
Abundant in oxygen pressurization	7.08	3.10	89.82	7.346	92.654
Liquid oxygen gasified pressurization	0.142	0.063	99.795	0.1429	99.8571

EXPERIMENTAL RESULT AND DISSCUSSION

<u>Liquid oxygen gasified pressurization mode</u>

The pressurized gas is N_2 gas containing 0.143% CO_2. The engine filter installed is a stainless steel screen (150 μm，960 mm^2). The opening of the discharge regulator is about 1/3 of the total flow area. Detailed experimental results are shown in Fig.2.

The experimental system must be well precooled in advance. At 29s after data acquisition and control system start, the experiment begins with both the exhaust and solenoid valves open. T5~T9 retain at LN_2 temperature and T10 drops down to LN_2 temperature dramatically (see Fig. 2(a)). At the same time, P3 to P7 drop down at the beginning, and then go back quickly (see Fig. 2(b)). 47s later, P3~P7 begin to be stable, that means the liquid transfers stably. In Figure 2(c), the pressure difference between the two sides of the engine filter (P8-P9) is about 2kPa in the transfer period. After 263s, all the pressure readings begin to drop down to zero as the liquid was emptied in the pipe.

In Fig. 2(d), the liquid flow rate is quite stable in the transfer period. The maximum value is 1.5L/s, and the integral value is 339.21L. At the beginning of the experiment, the pressurized gas flow reaches a peak value, and then drops down quickly. Then it gradually increases, and has a reading about 0.0172 kg/s at 262s. The integral gas flow is 3.94kg.

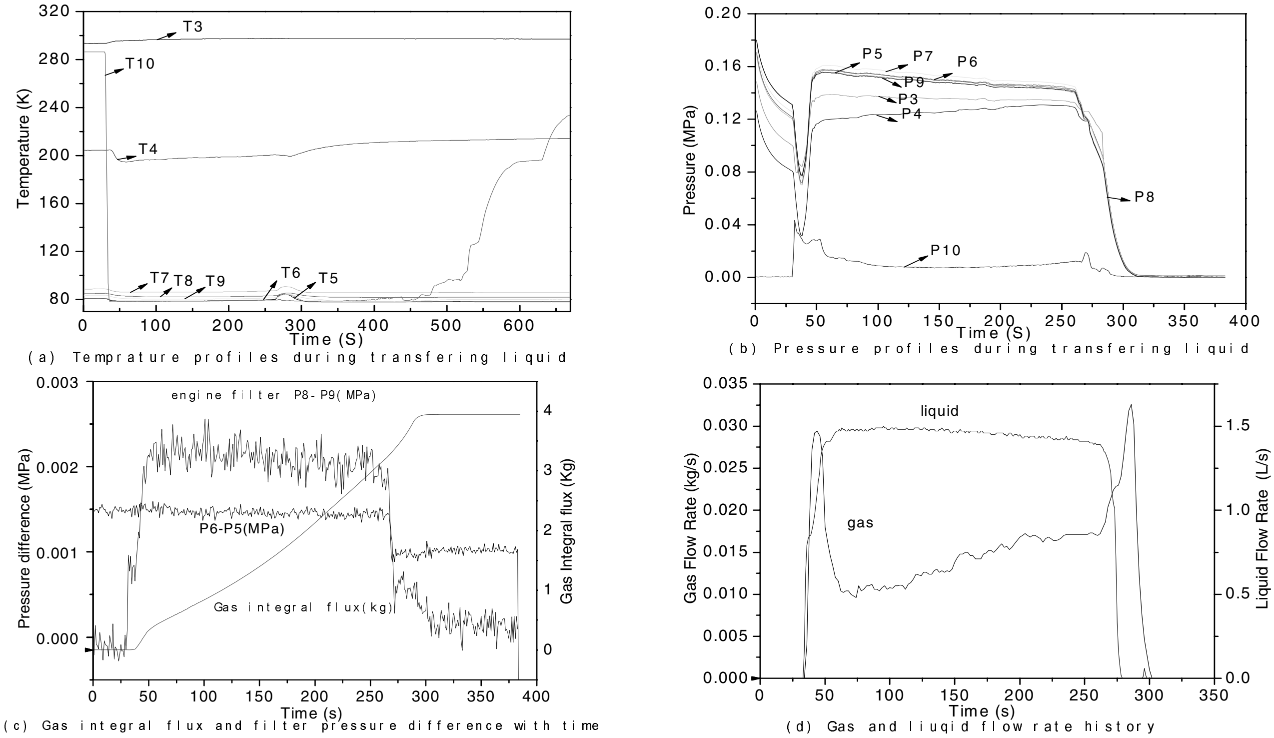

Figure 2 Temperature, pressure and flux profiles of gasified pressurization

Figure 3 Surface status of engine filter

The engine filter is dismantled as soon as the experiment stopped. As shown in Fig. 3, at the bottom of the tapered filter there are a few white crystal particles adhered to other impurity. The GC112A gas chromatograph says the particles are CO_2.

In summary, the liquid flux in pressurized transfer process is stable, and the engine filter has not been jammed by CO_2 crystal particles piled on the bottom of the filter.

Abundant in oxygen pressurization mode

The pressurized gas used in this experiment is N_2 gas containing 11% CO_2. Both engine filter(150 μm，960 mm^2) and tank filter(150 μm，5000 mm^2) installed are stainless steel screens. The opening of discharge regulator holds about 1/3 of the total flow area. The experimental results are shown in Fig.4.

From Fig. 4(a) we can see that T5~T9 remain at LN_2 temperature and T10 drops down to LN_2 temperature dramatically. At the same time, P3~P7 drop down at the beginning, and then go back quickly, see Fig. 4(b). After about 34s, P3~P7 begin to be stable. It means that the liquid transfers stably. In liquid transfer period, the pressure difference between two sides of the engine filter (P8-P9) is about 1.5kPa, and that of the tank filter (P6-P5) is also 1.5kPa, and the pressure reading drops down to zero in 243s (Fig. 4(c)).

As shown in Figure 4(d), the liquid flow is quite stable in the transfer period. The maximum liquid flux is1.5L/s and the integral is 321.76 L. The integral of gas flow is 3.29kg.

The engine filter is dismantled after experiment and a few crystal particles under a layer of frost are found on the screen, see Fig. 5(b). It is certified by a GC112A gas chromatograph that the particles are CO_2. The frost on the screen came from air (see Fig. 5(b)).

The result shows that the solid particles may be kept back by the tank filter in the transfer pipe. It means that the particles have not jammed the engine filter and this additional tank filter has no obvious effect on the liquid transfer process.

Crystallization experiment

A simple crystallizing experiment is carried out to observe the real condensation state of CO_2 in liquid nitrogen.

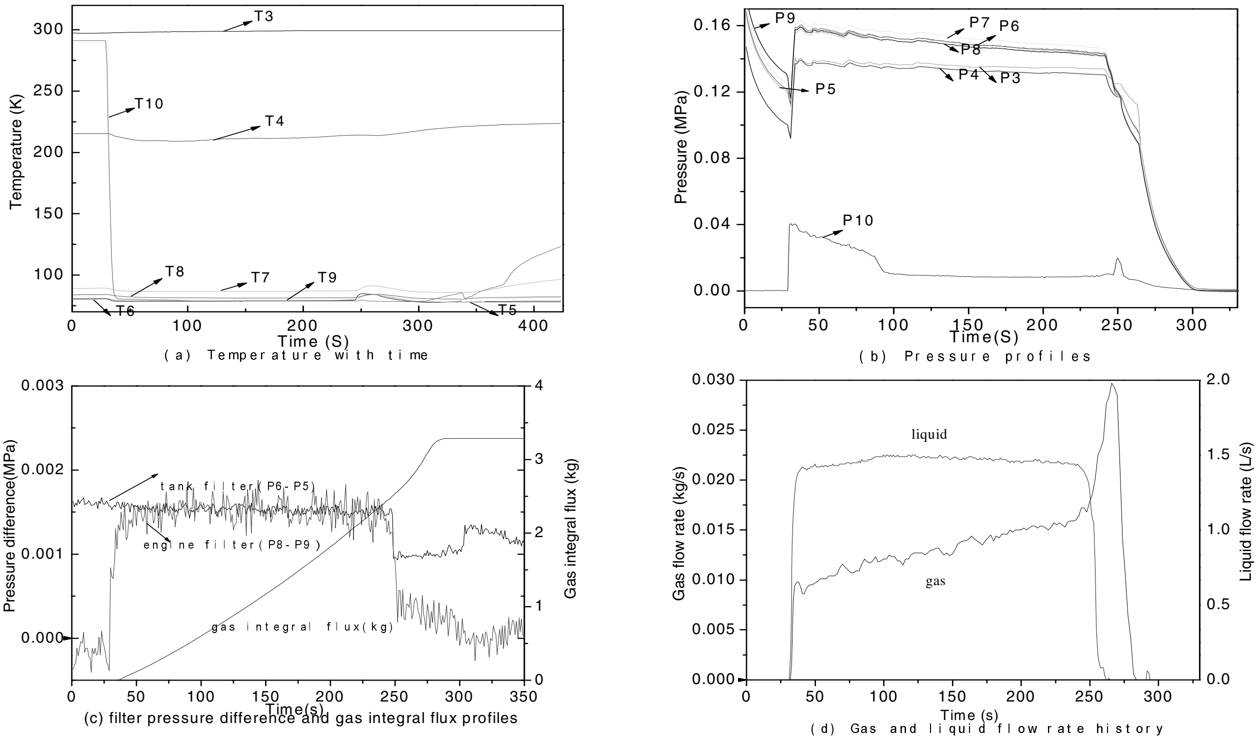

Figure 4 Temperature, pressure and flux profiles of abundant in oxygen pressurization

(a) Dismantled engine filter (b) Dismantled tank filter

Figure 5 Filter surface statuses

The experiment shows that liquid nitrogen filled with CO_2 becomes an emulsion. It is a highly dispersive and unstable system, in which CO_2 solid particles about 1~10 μm diameter [3] are dispersed in liquid nitrogen. The emulsion may possibly be delaminated, distorted, and demulsified along with the time.

CONCLUSION

The experiments show that the simulation test-bed works effectively. In the transfer pipe, the pressure difference between the two sides of the filter shows no obvious change along with the time and the variation of the flow flux. That means the filter has not been obviously jammed, and the pressurized gas containing carbon dioxide can be used to transfer the cryogenic liquid.

The simple crystallizing experiment illuminates that the feasibility of two modes of the self-pressurizing experiment depends on the solution character of carbon dioxide and water vapor in the liquid nitrogen or oxygen, especially on their crystallizing rate.

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