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Effect of different release methods on the physical properties of the decompression process of nitrogen-containing supercritical CO2 pipelines

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ABSTRACT

CO2 transportation is an indispensable intermediate link in the CCUS industry chain. When transporting large capacity and long-distance CO2 with impurities, pipeline transportation is more safe and more efficient. In the event of accidental CO2 pipeline leakage or engineering venting process, the sudden phase change and expansion of CO2 in the pipeline will lead to a sudden drop in the temperature of the pipeline, which will increase the risk of pipeline rupture. The research on the change of temperature on the wall of the pipeline during the venting process and the heat transfer properties of phase change has essential significance in avoiding the cracking of cracks and reducing the risk of crack expansion. In order to conduct small-scale pipeline safety research, a 16m long, 100mm inner diameter pipeline test device is set up. The distribution of temperature in the pipeline, the temperature on the pipe wall and the change of pressure in the pipeline in the process of slow valve opening and instantaneous full-diameter venting of nitrogen-containing supercritical phase CO2 were measured by venting experiment with inner diameter of 25mm. The influence of different venting modes on the depressurization of the pipeline, the temperature change inside and outside the pipeline, and the influence of phase change on the heat transfer in the pipeline were analyzed. The pressure, temperature and wall temperature values at the front, middle and rear sections of the pipeline were measured. It can be seen from the results that at the same elevation, the wall temperature drop at the vent end is smaller than that at the medium injection end, and the trend is the same as that of the temperature change in the pipeline. On the same section, the wall temperature drop at the bottom of the pipeline is the largest, and it is much larger than the wall temperature drop at the top and middle of the pipeline. At the injection end of the pipeline, the wall temperature is lower than the bottom temperature of the pipeline due to the continuous phase change and heat absorption of the medium. Compared with instantaneous full-diameter venting, valve opening venting has a longer phase change heat transfer time, larger wall temperature drop, and greater brittle fracture risk.

Keywords: Pipeline transportation, Pressure drop, Temperature inside the pipe, Temperature on the pipe wall

1. INTRODUCTION

The safe and efficient CO2 transportation network is essential intermediate link in the CCUS industry chain [1]. High-pressure pipeline transportation of CO2, as the most cost-effective high-flow transportation method [2], will be applied as the main transportation method of CO2 in the CCUS industry chain [3,4], and therefore the safety of its transportation needs to be paid more extensive attention.

CO2 pipelines can be accidentally cracked and leaky and depressurized due to manufacturing defects, impurity corrosion, and mechanical damage during transport [5]. In addition the pipeline should be drained and depressurized through the valve to the main pipe when the pipeline is over pressurized or needs to be drained for maintenance. During the decompression of the main, the phase change and expansion heat absorption of carbon dioxide in the pipe can lead to a sudden drop in the temperature of the medium inside the pipe [6], which reduces the temperature of the pipe wall and its toughness increasing the risk of pipe ruptu-re [7,8]. Therefore, it is necessary to study the characteristics of pipe temperature change in different release

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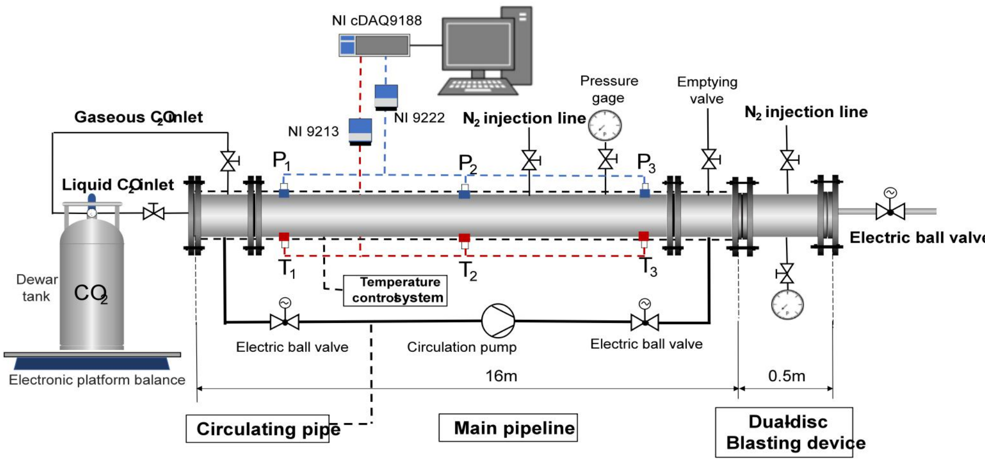

Fig. 1. Schematic diagram of the experimental apparatus

processes. In this study, a small-scale experimental pipeline of 16m length and DN100 was constructed, and the effects of two types of venting methods, namely rupture disc and valve, on the decompression of S-CO2 containing nitrogen in the pipe, the temperature inside the pipe and the change of temperature distribution pattern of the pipe wall were investigated by 25mm diameter venting experiments. The effect of different venting processes on the risk of pipe wall fracture was analyzed.

2. EXPERIMENTS

2.1 Experimental setup

To study the effects of different release methods and N2 on the physical properties during the decompression in the tube, an experimental setup was built as shown in Figure 1. The experimental setup consists of a 16 m long main pipe, CO2 injection system, circulating pipe section, heating and insulation system, release equipment, and acquisition system. The experimental pipeline is made of 304 stainless steel with a maximum working pressure of 16 MPa, an inner diameter of 233 mm, and a wall thickness of 8 mm. In order to make the medium in the pipe mixed evenly, a circulation section controlled by two electric ball valves is set up, and a differential pressure circulation pump is used to circulate the medium in the pipe.

The release equipment includes electronically controlled ball valve, 0.5m double film burst pipe section and 25mm inner diameter release pipe section. Electric control ball valve nominal pressure 16MPa, full open need 15s. Dual-disc blasting device section structure as shown in Figure 2, Two bursting discs form a double membrane chamber at the end of the main channel and two sub-chambers in the release chamber for instantaneous release of the pipe.

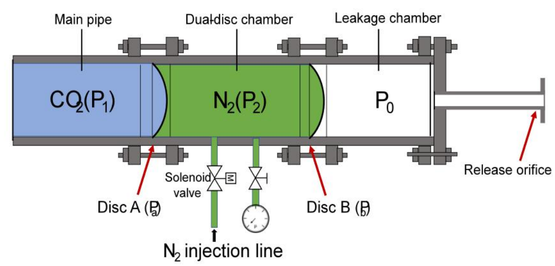

Fig. 2. Schematic of dual-disc blasting device

2.2 Instrumentation

In order to collect the transient pressure and temperature changes during the pressure drop of different release methods in the main pipe, three test points were set up in the main pipe as shown in Table 1. The acquisition system consisted of three multilayer thermocouples, nine pipe wall surface thermocouples, and three high frequency pressure sensors. The multilayer thermocouple is a T-type thermocouple with a response time of 100ms and a measurement range of -200-350°C, which is used to measure temperature variations at different heights inside the pipe. The pipe wall surface thermocouple is also a T-type thermocouple and is used to measure the temperature distribution at the top, middle and bottom of the pipe wall. The pressure transients inside the pipe during the pressure drop are measured by a high frequency pressure transducer with a range of 0-16 MPa, a response frequency of 100 kHz and an accuracy of 0.25% FS. The sensor arrangement at the test point is shown in Figure 3.

Tab. 1. Experimental measurement point locations.

Distance (m)	Temperature of internal pipeline	Temperature of pipeline wall	Pressure of internal pipeline
15.5	T_{1d1-3}	T_{1w1-3}	P_1
9	T_{2d1-3}	T_{2w1-3}	P_2
1.75	T_{3d1-3}	T_{3w1-3}	P_3

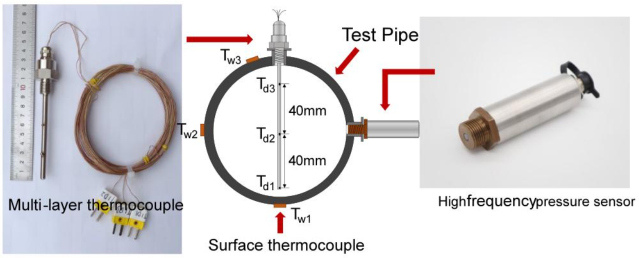

Fig. 3. Schematic of dual-disc blasting device

2.3 *Experimental conditions and Experimental procedure*

In order to avoid the high critical pressure and to ensure the initial phase state of the mixture is in the critical zone, the initial condition of N2 injection is chosen as 1.5%. Figure 4 shows the phase diagram of nitrogen-containing carbon dioxide. The experimental conditions and the initial state of the medium in the pipe are shown in Table 2.

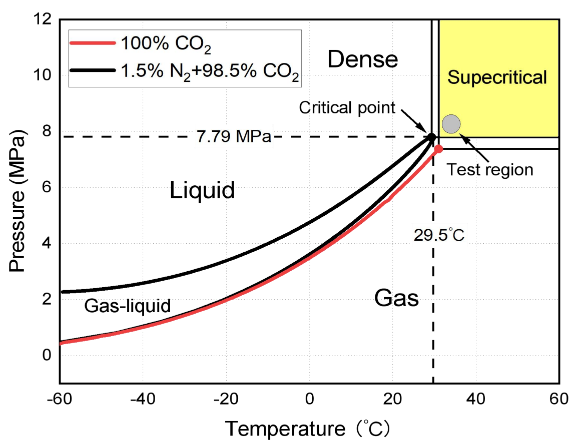

Fig. 4. The phase diagram of nitrogen-containing carbon dioxide

Tab. 1. Experimental conditions.

Number	Pressure (MPa)	Temperature (℃)	Orifice (mm)	N_2 content	Release Method
Test 1	7.85	32.2	25	1.5%	Valve
Test 2	7.82	31.6	25	1.5%	Rupture discs

3. ***EXPERIMENTAL RESULTS AND DISCUSSIONS***

3.1 *Instrumentation*

As shown in Figure 5, the evolution of pressure in the pipe during the valve release process of nitrogen-containing CO2 pipeline is shown. The pressure inside the pipe drops to atmospheric pressure at the beginning of 37.71s. 4.15s after the start of the release, the pipe pressure drops to the critical pressure, when the phase change volume expansion occurs, the pressure drop rate slows down. With the increase of valve opening, the rate of pressure drop in the pipe also increases, and rises to the maximum at the beginning of the release

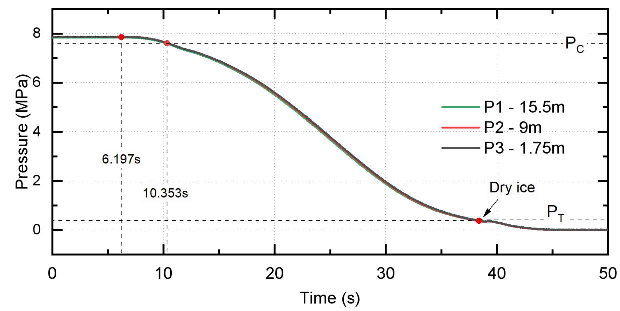

Fig. 5. Pressure evolution during valve release of nitrogen-containing CO2 pipeline

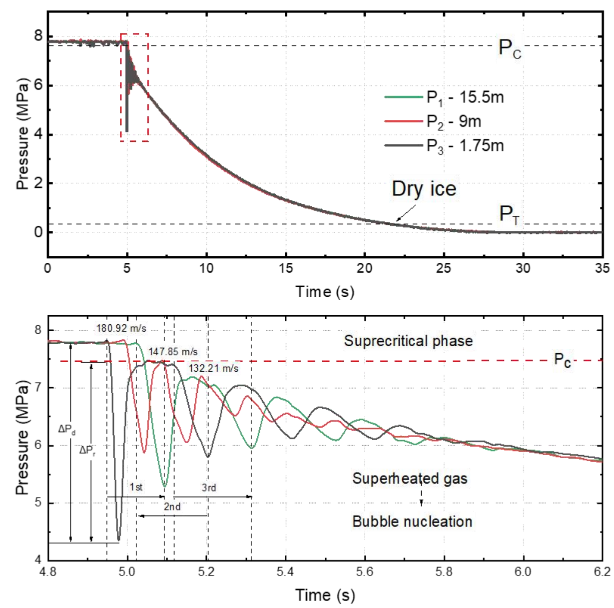

Fig. 6. Pressure Evolution during Rupture Disc Release of Nitrogen-Containing CO2 Pipeline

18.65s. And as the pressure decreases in 32.01s the pressure in the pipe reaches near the three-phase point.

As shown in Figure 6, the evolution of pressure in the pipe during the rupture disc release process of nitrogen-containing CO2 pipeline. The total pressure drop time in the pipe is 23.96. Compared with the valve venting process, the overall pressure drop in the rupture disc venting process is divided into a fluctuating drop process and a smooth drop process, with the fluctuating drop process lasting about 1.9 s. The fluctuating drop process generates a decompression wave with a decompression wave speed of about 180.92 m/s. The overall pressure in the pipe drops below the critical pressure in about 0.07 s at the beginning of the venting process. Compared with the valve release process, the rupture disc release process has a larger pressure drop rate and a more complex phase change process. And the generation of decompression wave will increase the risk of fracture.

3.2 Temperature evolution of the pipeline

The evolution of the temperature inside the pipe and the wall temperature during valve release is shown in Figure 7. The overall temperature drop rate increases and then decreases as shown in the figure. The temperature drop in the injection port section of the pipe is smaller than the temperature drop in the discharge port. The temperature drop in the middle section of the pipe is the largest, and the bottom temperature is the lowest. The lower the temperature, the higher the density, the lower the temperature at the bottom. The distribution of wall temperature at the top and middle of the pipe is similar, the closer to the vent the stronger the heat transfer efficiency and the lower the lowest temperature. The wall temperature at the bottom of the pipe is farther away from the release port, the greater the temperature drop, the most distal wall temperature drop to -26.31 ℃.

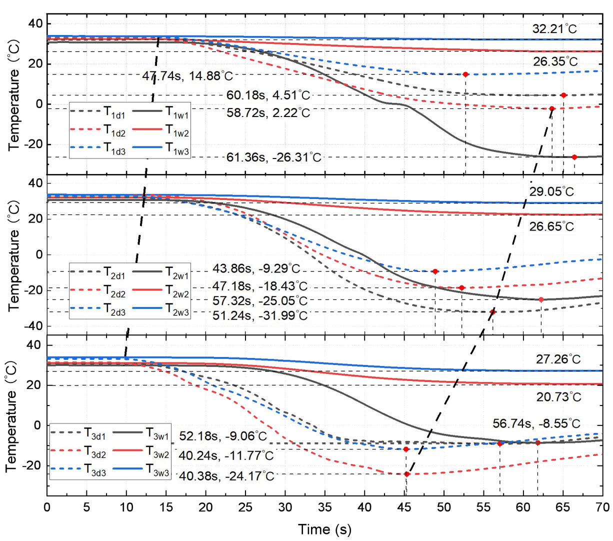

Fig. 7. Temperature evolution inside and on the wall of the nitrogen-containing CO2 pipeline during valve release

The evolution of temperature and wall temperature in the pipe during rupture disc discharge is shown in Figure 8. The overall temperature in the pipe is the fastest rate of temperature drop at the beginning of the release, when the phase change and expansion of the medium in the pipe are the most intense. Compared with the valve release process, the rupture disc release temperature drop rate is faster, and the temperature reaches the lowest point in less time. The overall heat exchange in the pipeline is similar to that of the valve release, and the lowest temperature in the tube reaches -31.70 ℃ in the middle section, which is not much different from the lowest temperature of -31.99 ℃ in the valve release. The wall temperature distribution is similar to that of the valve release, and the lowest point is also at the bottom of the section farthest from the release port, reaching -16.74℃. It can be seen that the minimum temperature that can be reached by the pipe wall is also higher due to the shorter heat exchange time of the rupture disc release process under the same release volume. Valve release compared to the rupture disc pressure drop process pipe by the threat of low temperature is greater, more likely to occur brittle fracture.

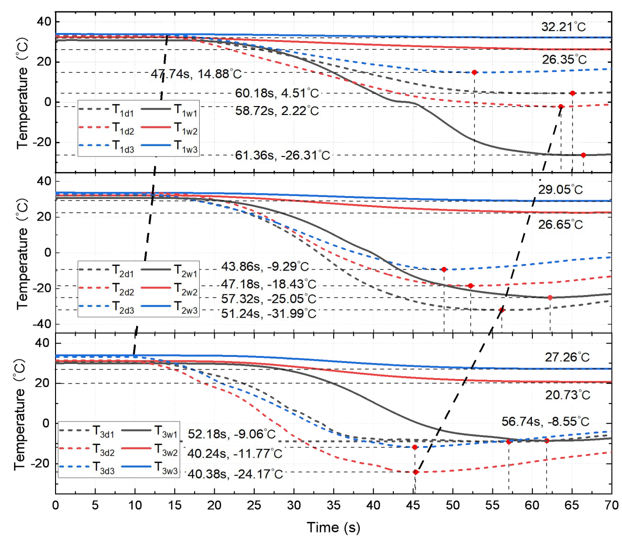

Fig. 8. Temperature evolution inside and on the wall of the nitrogen-containing CO2 pipeline during rupture-disc release

4. CONCLUSIONS

This thesis introduces the change law of pressure and pipe temperature in the pipe of two types of venting methods, valve venting and rupture disc venting, under 25mm caliber, and the conclusions obtained are as follows:

(1) Valve relief pressure drop rate is slower, but the phase state inside the pipe is more stable and the density changes smoothly. And avoid the threat of decompression wave.

(2) Valve relief temperature drop rate is slower, but the temperature drop inside the tube is greater, and the heat transfer time is longer. And the same volume of the tube wall temperature drop is greater, the risk of brittle fracture is greater.
(3) In the overpressure engineering relief and emptying maintenance, you need to pay attention to the temperature drop inside the pipe, the temperature drop of the pipe wall, to avoid excessive temperature drop leading to a reduction in the toughness of the pipe, affecting the safety of pipeline operation.

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