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# Experimental study of the flow characteristics and impact of dense-phase $CO_2$ jet releases

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ABSTRACT

High-pressure dense-phase $CO_2$ transportation is the main approach for transportation of $CO_2$ in China. During the transportation process, $CO_2$ is in a high-pressure dense phase. If $CO_2$ leakage occurs in such a case owing to line equipment damage, the low-temperature high-speed jet flow will be hazardous for human lives and property. To study $CO_2$ leakage, an experiment was conducted to examine the impact of a dense-liquid $CO_2$ jet during accidental releases. The impact value was measured for different nozzle sizes, inner pressures, and distances. Therefore, studying the mechanism and effectively evaluating the consequences and impact of the accidental leakage of high-pressure dense-phase $CO_2$ are important for ensuring the security of its transportation.



**Contents**



## 1. Introduction

Carbon capture and storage (CCS) (Wilday et al., 2011) is a new technology that could reduce the carbon dioxide ($CO_2$) emissions from fossil fuel-fired power plants and industrial sources (Tapia et al., 2016). It is considered a technology alternative that could contribute to reducing the global $CO_2$ emissions by approximately six billion tons per year in 2050 (Munkejord et al., 2016). It is an efficient technology that depends not only on sound technical and engineering practices but also on societal, political, and economic factors (Chen et al., 2015). CCS involves the capture and separation of $CO_2$ from the industrial emission sources or other energy sources. Following this, $CO_2$ is transported to the storage site, and sealed from the atmosphere (Doe, 2007). The technology of $CO_2$-enhanced oil recovery ($CO_2$-EOR) that combines the displacement of reservoir oil and $CO_2$ storage, can provide both social and eco-

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**Table 1**
Accidents caused by high pressure $CO_2$ (Ccps, 2011; Clayton and Griffin, 1994; Li et al., 2011; Zhang et al., 2013).

| Date | Location | Capacity | Reason | Casualties |
|---|---|---|---|---|
| 1969.01.02 | Repcelak, Hungary (Ccps, 2011) | 35 t | Overcharge | Nine people dead, and four $CO_2$ storage tanks and laboratory equipment destroyed. |
| 1969.03.01 | Fukushima, Japan (Zhang et al., 2013) | | Overpressure | The workshops built by slates were destroyed within 50m, and the glass in the workshops was broken within 500m. |
| 1972.11.27 | San Antonio, TX, USA | 10 kg | Corrosion | |
| 1976.09.02 | Haltern, Germany (Ccps, 2011) | 23 t | Brittle fracture | One person dead, and the fragments were thrown to 360 m away. |
| 1988.11.21 | Worms, Germany (Clayton and Griffin, 1994) | 30 t | Overpressure | Eight people were injured, and the tanks were broke into pieces. Parts of the fragments were thrown to the Rhine river which is 300 meters away. |
| 2008.11.13 | Yuhang, China (Li et al., 2011) | 130 m3 | Brittle fracture | Two people dead and three people injured. The $CO_2$ carriers, H2SO4 carrier and H2O2 carrier were destroyed. The fragments spread to the villages nearby. |

nomic benefits, and therefore, it is the most widely used and mature form of technology in recent years.

Certain environmental, health, and safety risks arise when a new technology such as the CCS-EOR technology is expected to be extensively used. $CO_2$ transportation plays an important role that links its capture and storage. The preferred mode of $CO_2$ transportation in CCS is through pipelines because it is considered as the most economical method for this purpose over land. $CO_2$ can be transported through pipelines in gas, liquid, supercritical, and dense phases, which in turn depends on the temperature and pressure of the pipeline. A $CO_2$ phase can transform easily under the effect of the variation in the temperature (31.1 °C) and pressure (7.38 MPa) when the conditions reach the critical temperature and pressure, as shown in Fig. 1. If $CO_2$ is transported in a liquid phase, gas-phase $CO_2$ will exist because of the variations in the temperature and pressure. Then the emergence of a two-phase fluid can make the working condition unstable and result in various difficulties in transportation (Zhao et al., 2015). Usually, it is safe to transport $CO_2$ at a pressure exceeding 8 MPa because its increased density prevents the two-phase fluid from forming. A lower temperature will make it easier and safer to achieve the high-pressure conditions. Therefore, the necessity to keep the pipelines at a low

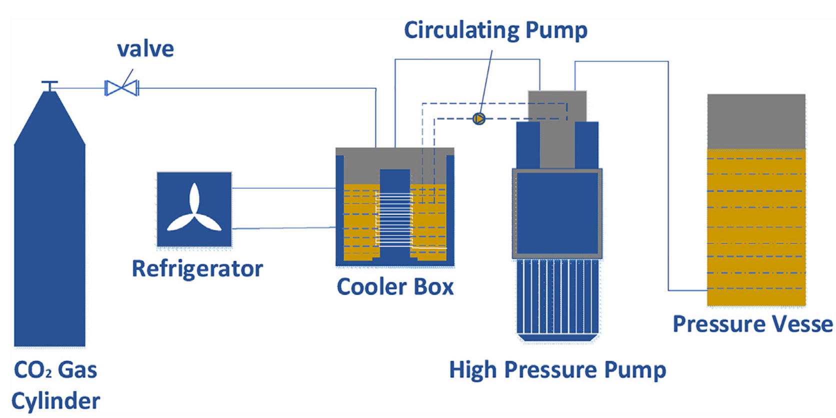


**Fig. 1.** Sketch of the $CO_2$ injection device.

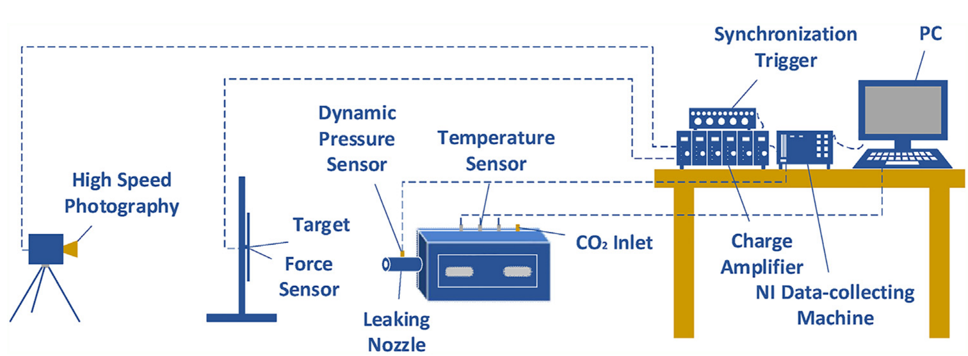


**Fig. 2.** Schematic diagram of the experiment system.