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Experimental study of the influence of burst parameters on the initiation of CO_2 BLEVE

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ABSTRACT

A small-scale experimental system was constructed to simulate the initiation of CO_2 BLEVE process in different phase state. Dynamic pressure parameters after disc burst were analysed to supplement the influence rules of vent size and burst pressure to the intensity of CO_2 BLEVE. Comparisons between the supercritical phase state CO_2 and liquid CO_2 on the pressure parameters were made to reveal the phase state influence to the initiation of CO_2 BLEVE. The vent size of 8 mm and 15 mm were two critical parameters under different burst pressures. The changing of pressure became irregular when the vent size surpassed 8 mm, and the pressure rise value will never surpassed the pressure drop value when the vent size reached or surpassed 15 mm. The supercritical state CO_2 was unstable compared to the liquid state CO_2. A more complex phase transition in the discharge process caused the pressure parameters changing became irregular; especially when the inner pressure reached 10 MPa and CO_2 became a supercritical state fluid. After burst, the fluid releasing form the vessel instantly and limited space was reserved for the fluid to swell in the vessel, causing the inner pressure can't rebound in time, which eventually led the overpressure disappear.

1. Introduction

Carbon dioxide emissions are considered to be an important cause of global warming. As a promising method for CO_2 mitigation, carbon capture and storage (CCS) has been widely used in many countries, including in applications to enhance oil recovery (EOR). In both the processes of CCS and CCS-EOR, CO_2 would be compressed into high pressure vessels or pipelines. When the vessel or pipeline experiences a sudden rupture, a severe hazard called Boiling Liquid Expanding Vapour Explosion (BLEVE) may occur (Martynov et al., 2014). An explosion shock wave, fragments, asphyxiating gas, and frostbite caused by a BLEVE can cause injury and damage to people and the surrounding equipment (Connolly and Cusco, 2007; Minh and Rodica, 2011; Hulsbosch, 2012; Rian et al., 2014; Laboureur et al., 2015; Liu et al., 2018). To prevent the occurrence of these damaging events, many studies have been conducted to reveal the mechanism of the CO_2 BLEVE process. It was proposed that rapid depressurization of hot, saturated liquids may result in an explosion when the temperature of the hot liquid was above the superheat limit temperature and the drop in the tank pressure was very rapid (Reid, 1979). However, the superheat limit theory Reid proposed was based on homogeneous nucleation. Actually, homogeneous nucleation boiling is extremely difficult to achieve but heterogeneous nucleation boiling occurs much more easily and can also lead to explosion, even if the initial temperature was below the overheating limit (Prugh, 1991a,b; Birk and Cunningham, 2015, 1996; Lin, 2000). These studies indicate that it was not easy to predict and control the occurrence of the BLEVE through the liquid temperature. Generally, it would be much easier to control the hazard in its initial period. In a CO_2 BLEVE, the indication of initiation was the pressure rebound at the beginning. In the previous studies (Mcdevitt et al., 1990; Kim-E, 1981; Venart et al., 1993), the pressure rebound phenomenon that produces overpressure was considered a critical condition of the BLEVE, always leading to destruction of containers, and this pressure rebound value was influenced by operating parameters like the burst vent size and the initial vessel burst pressure. Few researches have been conducted to reveal the vent size and initial burst pressure influence to the BLEVE process systematically. Ahmad et al. studied the fluid thermodynamic regime in the vessel and jet behaviour

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during the release process at the opening had been studied under a different release vent size and initial vessel pressure (Ahmad et al., 2013). However, for the vent size was very small compared to the vessel, pressure rebound and explosion were not happen. In our previous research (Li et al., 2017), the parameter of the burst vent size was studied to reveal its influence on the CO_2 BLEVE intensity during the initial period under a pressure of 5 MPa. The study concluded that a critical burst vent size existed, which indicated that the initiation of the CO_2 BLEVE can be affected by the operating parameters, and its hazards can be controlled through manipulating these parameters. However, in that previous study, the burst pressure was only 5 MPa in maximum and CO_2 just reached liquid state, but what about the phenomenon of a higher burst pressure and supercritical state CO_2 sudden releasing from the tube and how the burst parameters will affect the BLEVE process have not been studied yet. So it is necessary to conduct these works to supplement the influence rules of vent size and burst pressure to the intensity of CO_2 BLEVE of the supercritical phase state CO_2 and liquid CO_2.

In the present study, CO_2 was supplied by a high-pressure injection system in which the fluid temperature, burst pressure, and vent size could be easily controlled and the liquid can be pressured to supercritical or dense state. The ejection and phase change process of CO_2 after the burst were studied, and the influence of vent size and the initial vessel burst pressure on the initiation of the CO_2 BLEVE were analysed and discussed. The conclusions can be used to guide the prevention of BLEVE accidents.

2. Description of the experiment

Fig. 1 shows the schematic diagram of the experimental apparatus that contain the CO_2 injection system, the visual two-phase flow monitoring vessel, and the data acquisition system.

In the injection process, CO_2 was supplied by a 40-litre high-pressure gas cylinder and refrigerated by a refrigerating machine and an ice chest. Afterwards, the cooling CO_2 was injected into a vessel using a high-pressure pump, which could raise the CO_2 pressure up to 80 MPa. The visual two-phase flow monitoring vessel was the main part of the experiment, whose designed pressure was 42 MPa with a maximum working pressure of 40 MPa. The total volume of the vessel was about 966 cm^3. Two KD2004 dynamic pressure transducers (PT 1 and PT 2) with the measuring range of 0.0001–20 MPa and the resonant frequency of 200 kHz were installed in the vessel wall, and the lower one (PT 2) was 11 cm away from the bottom of the vessel while the upper one (PT 1) was 62 cm away. Three MIK PT100 temperature transmitters—TT 1 TT 2 and TT 3 were installed from the top to the bottom along the side of the vessel wall to measure the temperature of the fluid in the vessel. The measurement range of the temperature transmitters was from 200 °C to 650 °C and the measurement accuracy was 0.15 °C.

The discharge pressure of the experiment was controlled by the pressure relief apparatus in which the bursting disc was installed on the connecting pipe with a bolt seat. LP/ZH bursting discs with different calibres and bolt seats were used in the experiments. When the pressure difference between the two sides of the bursting disc reached the pre-set value, the bursting disc ruptured and CO_2 discharged immediately.

The heating controller can monitor the temperature change of the temperature measuring points with time. The temperature control range was from ambient temperature to 150 °C, and the precision of temperature control was ± 1 °C. The electric heating tubes were located at the top and bottom of the outer wall of the container, and the heating mode together with the heating range can be selected. The power of each electric heating tube was 200 W and each group contained six parallel tubes.

The data acquisition system included a charge amplifier, a synchronizer trigger, a National Instruments (NI) data collector, with a data acquisition frequency of 1 MHz/s, and a displayer. The pressure signals of PT 1 and PT 2 were amplified by the charge amplifier and then transmitted to the NI data collector, while the temperature signals of TT 1, TT 2, and TT 3 were transmitted to the NI data collector directly and then showed on the displayer. A high-speed camera with a frequency of 1000 fps was used to record the phase state change in the process of the superheated CO_2 explosion.

In this experiment, air in the vessel was excluded by filling gaseous CO_2 into it before the disc was installed and then cooled CO_2 was injected into the vessel uninterruptedly until the disc burst. Different diameters and intensities of discs were used to control the vent sizes

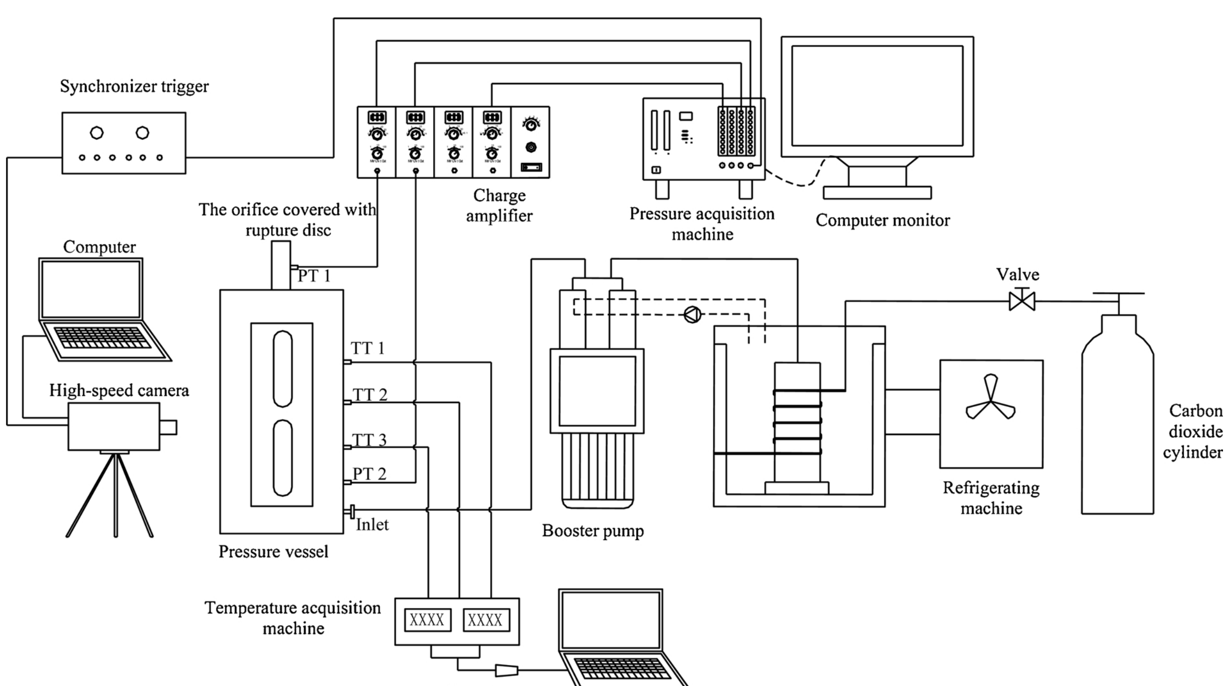


Fig. 1. The schematic diagram of the experimental apparatus.

Table 1
Experimental parameters in different tests.

Test number	Designed burst pressure P_m /MPa	Diameter of the disc D_m /mm	Acreage of the disc A_m /mm^2	Liquid temperature before burst T_0 /°C	Actual burst pressure P_r /MPa	Liquid filling rate φ /%
T1	7	3	7.070	25.10	6.97	70
T2		5	19.63	24.51	6.85	
T3		10	78.54	24.30	7.13	
T4		15	176.7	29.01	7.01	
T5		20	314.2	28.00	7.06	
T6	8	3	7.070	21.50	7.82	–
T7		8	50.27	28.42	8.26	
T8		10	78.54	37.90	8.15	
T9		15	176.7	30.80	8.54	
T10	3	8	50.27	15.83	2.82	30
T11	5			14.53	4.85	50
T12	10			26.60	10.07	–

"-" refers to no data is available.

and the initial burst pressures, which were the two main parameters to be studied in this research.

3. Result and discussion

Twelve groups of tests with different parameters were conducted to study the effects of burst parameters on the CO_2 BLEVE using the experimental apparatus mentioned above. Details of the parameters in these experiments are listed in Table 1.

3.1. The pressure changing character and description of typical parameters

A typical test, T8, is chosen to explain the pressure changing process and the testing parameters of supercritical CO_2. The parameters of T8 can be seen in Table 1, and CO_2 was injected in the tube consistently until the vessel inner pressure surpassed 8.26 MPa and the disc burst.

Fig. 2 shows the phase change, heterogeneous nucleation, and swelling process of liquid CO_2 after the bursting of the disc. The gas phase fluid on the top of the vessel ejected first. Following ejection, the inner pressure on the top decreased to the ambient pressure immediately, and the decompression wave propagated down to the vessel, causing the supercritical CO_2 to be superheated and boiling. The decompression wave propagated speed can be calculated through the pressure drop time difference between the top dynamic pressure and the bottom dynamic pressure, which can be seen in Fig. 3. The pressure drop time difference was about 2.3 ms and the distance was 510 mm, so the decompression wave speed was about 221.7 m/s. A ruler was installed to test the gas-liquid two phase layer propagation speed, and within 64 ms this layer propagated down for about 22 mm, so the layer propagation speed was about 0.34 m/s, shown in Fig. 2. This slow propagation speed indicated that the bottom pressure change may be relatively weak. Thousands of bubbles formed and constant swelling

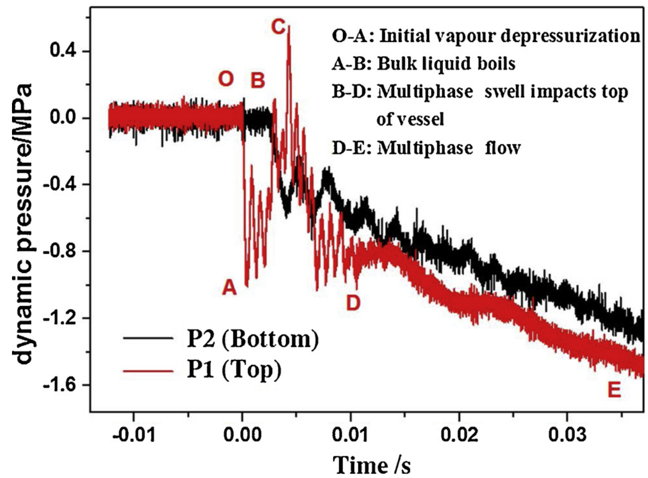


Fig. 3. Dynamic pressure changes during the initial period of burst disc rupture of T8.

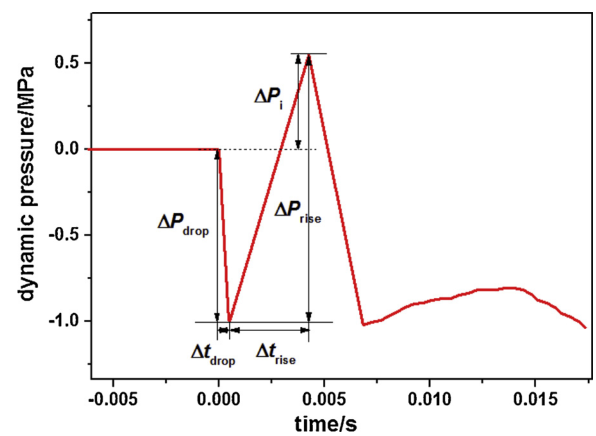


Fig. 4. Parameters contrast.

occurred, which led the inner pressure to rebound. The rebound of the inner pressure accelerated the ejection speed, and the inner pressure decreased again, causing the superheated liquid to continuously boil.

Fig. 3 shows the inner dynamic pressure change on the top and bottom of the vessel after the bursting of the disc. The dynamic pressure shown in Figs. 3 and 5 indicates that only in the initial period of 10 ms after the disc burst did a rapid pressure change occur, and on the top side of the vessel, the inner pressure surpassed the initial value right after the bursting of the disc, which was resulted from the initiation of CO_2 BLEVE. The initiation of CO_2 BLEVE has been studied and proved by some researchers (Mcdevitt et al., 1990; Li et al., 2017), and the pressure rebound was the sign of the degree of the liquid superheat and the intensity of BLEVE initiation.

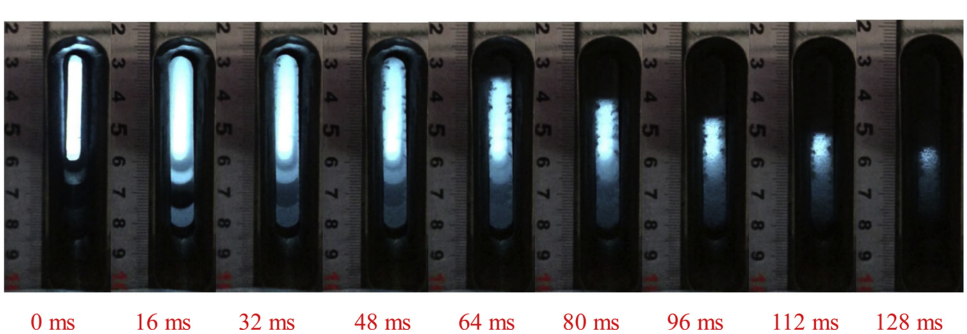
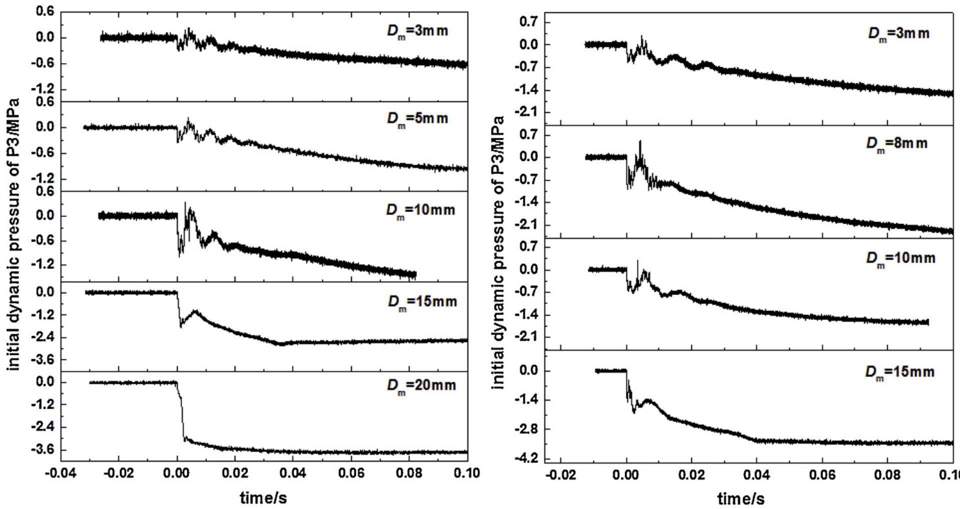


Fig. 2. The heterogeneous nucleation and swelling process of CO_2 after the burst disc rupture.



(a) P_m =7MPa (b) P_m=8MPa

Fig. 5. Dynamic pressure changes over time under different relief vent sizes.

Table 2

Typical experimental parameters for the dynamic pressure at top of the vessel in the initial period of BLEVE under different relief sizes.

Test number	ΔP_{drop} /MPa	Δt_{drop} /ms	v_{drop} /(MPa·ms^{-1})	$\Delta P_{rise/MPa}$	$\Delta t_{rise/ms}$	$v_{rise/(MPa{\cdot}ms-}$$^{1)}$	ΔP_i /MPa	T_0 /°C	T_{min} /°C	$\Delta T = T_0$-T_{min} /°C
T1	0.286	0.528	0.541	0.525	3.415	0.154	0.239	25.10	−58.63	83.73
T2	0.341	0.348	0.980	0.571	3.408	0.168	0.230	24.51	−59.86	84.37
T3	1.004	0.874	1.149	1.317	1.211	1.088	0.313	24.30	−54.63	78.93
T4	1.830	1.228	1.490	0.872	4.667	0.187	−0.958	29.01	−69.30	98.31
T5	3.146	2.646	1.189	0	–	–	–	28.00	−53.12	81.12
T6	0.5101	0.6639	0.7683	0.8006	4.0429	0.1980	0.2905	21.50	−69.92	91.42
T7	1.0078	0.2926	3.444	1.5472	3.9382	0.3929	0.5394	28.42	−67.83	94.70
T8	0.6896	2.0904	0.3299	0.7011	3.2093	0.2185	0.0115	37.90	−57.77	95.67
T9	1.9927	2.4200	0.8234	0.6119	3.8452	0.1591	−1.3808	30.80	−61.39	92.19

"-" refers to no data is available.

To explain the parameters' influence clearly, Fig. 4 displays the typical parameters corresponding to the pressure-time curve in the initial period.

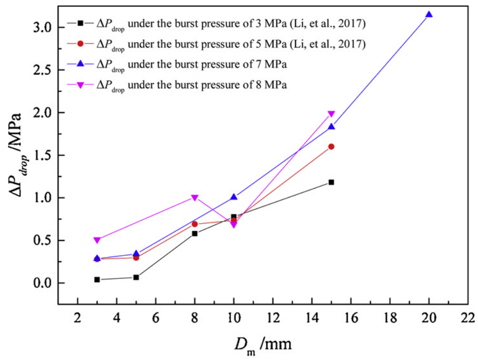
ΔP_{drop} is the initial pressure drop value after disc burst (MPa), ΔP_{rise} is the pressure rebound value (MPa), $\Delta P_i = \Delta P_{rise} - \Delta P_{drop}$ is the overpressure (MPa), Δt_{drop} is the time segment when the pressure disc ruptures until the inner pressure decreases to the lowest pressure point, Δt_{rise} is the pressure rebound time, $v_{drop} = (\Delta P_{drop})/(\Delta t_{drop})$ is the pressure drop rate (MPa/ms), and $v_{rise} = (\Delta P_{rise})/(\Delta t_{rise})$ is the pressure rebound rate (MPa/ms).

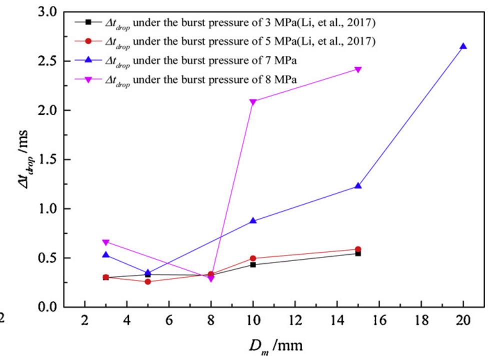
3.2. Effects of vent size

The vent size was one of the critical parameters affecting the burst results. Different vent sizes led to different pressure drop rates and degrees of superheat, which can be reflected in the character of the pressure drop and rebound.

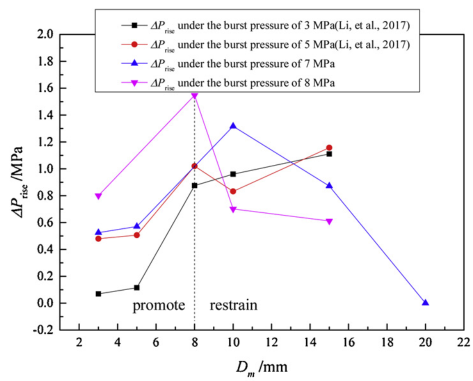
Fig. 5 shows the vessel top dynamic pressures under different vent sizes both under the vessel inner pressures of 7 MPa and 8 MPa. It can be seen that the increase in the vent size caused the overpressure to decrease and even disappear. To reveal the effect of the vent size on the pressure parameters, the parameter values of the pressure are listed in Table 2 and the variation tendencies including the reference data are displayed in Fig. 6. It is shown that for the burst pressure, both the initial pressure drop value ΔP_{drop} and the pressure drop time Δt_{drop} were positively correlated to the vent size, which was obvious for the burst pressure of 3 MPa, 5 MPa and 7 MPa. However, when the burst pressure reached 8 MPa, at which CO_2 can become to supercritical phase state, this positive correlation became unsteady and the pressure rise time at 10 mm vent size experienced an obvious enlargement. What's more, the changing of pressure rise value ΔP_{rise} and Δt_{rise} were consistent under different burst pressures before 8 mm-vent size, but once the vent size surpassed 8 mm, the changing of pressure rise became irregular especially for the burst pressure of 8 MPa experiments. These tendencies indicated that the supercritical state CO_2 was not stable compared to the liquid state CO_2, and a more complex phase transition in the discharge process may be the reason that the pressure parameters changing became irregular.

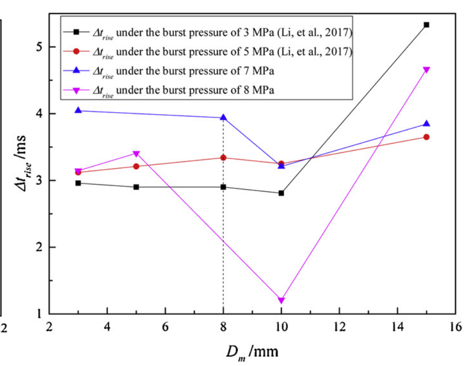
The pressure rise value ΔP_{rise} showed a tendency to increase first and then decrease while the pressure rise time Δt_{rise} showed an inverse tendency. The pressure drop rate v_{drop} and rise rate v_{rise} both showed a tendency to increase first then decrease. Furthermore, the overpressure ΔP_i showed a maximum value of 0.313 MPa at a vent size of 10 mm when the vessel inner pressure was 7 MPa and 0.539 MPa at a vent size of 8 mm when the vessel inner pressure was 8 MPa. This overpressure was a signal of the initiation of the CO_2 BLEVE, and it also was the cause of the vessel break increase and even tearing. What's more, when the vent size was smaller than 8 mm, the overpressure was proportional to the initial burst pressure, but it reversed when the vent size surpassed 8 mm. Once the vent size reached or surpassed 15 mm, the pressure rise value will never surpassed the pressure drop value, which made the vessel be safe enough to discharge. All the above tendencies indicate that 8 mm and 15 mm of vent sizes were two critical diameter sizes in this BLEVE process. When the vent size is larger than 8 mm, the boiling and expanding effects of CO_2 fluid will be weakened by the ejection, which made the explosion intensity decay. This result indicates that the



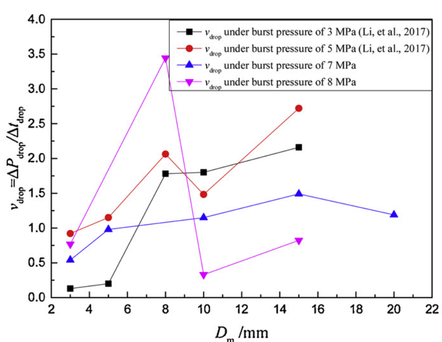


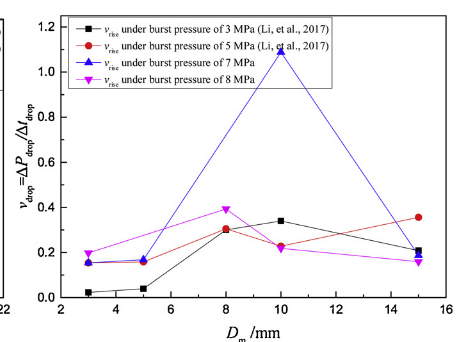
(a) Changing rules of pressure drop with vent size. (b) Changing rules of pressure drop time with vent size.



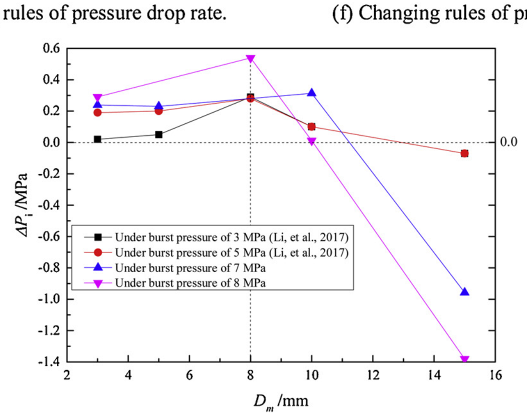


(c) Changing rules of pressure rise with vent size. (d) Changing rules of pressure rise time with vent size.





(e) Changing rules of pressure drop rate. (f) Changing rules of pressure rise rate.



(g) Changing rules of overpressure with vent size.

Fig. 6. Effects of vent size on the top dynamic pressure parameters with different burst pressures.

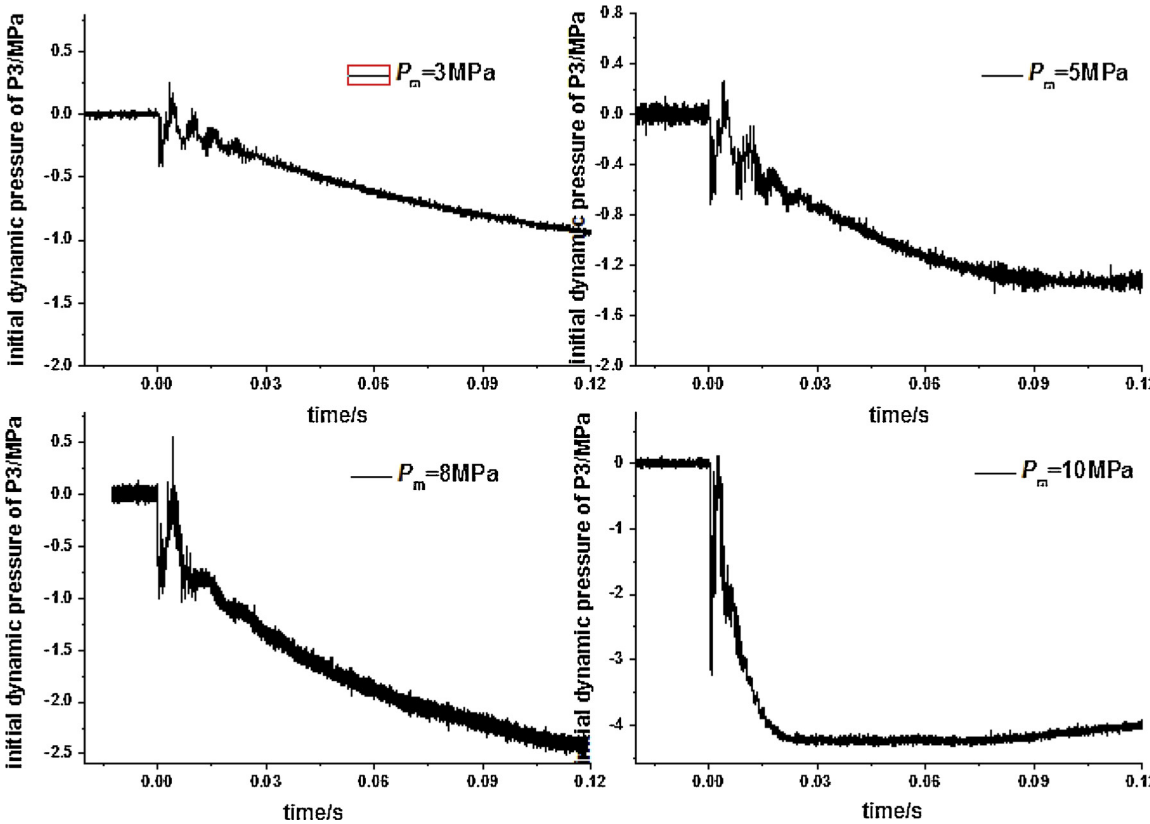


Fig. 7. Top dynamic pressure-time curves at the initial period of BLEVE under different burst pressures.

Table 3
Experimental results of the dynamic pressure at the top of the vessel.

Test number	ΔP_{drop}/ MPa	Δt_{drop}/ ms	v_{drop}/ (MPa·ms^{-1})	ΔP_{rise}/ MPa	Δt_{rise}/ ms	v_{rise}/ (MPa·ms^{-1})	ΔP_i/ MPa	T_0/ °C	T_{min}/ °C	$\Delta T = T_0\text{-}T_{min}$/ °C
T10	0.418	0.417	1.003	0.665	2.773	0.240	0.248	15.83	−0.30	16.13
T11	0.710	0.471	1.508	0.958	3.336	1.003	0.248	14.53	−9.87	24.40
T7	1.008	0.293	3.444	1.547	3.938	0.393	0.539	28.40	−66.28	94.68
T12	3.197	0.795	4.023	3.278	1.324	2.476	0.021	26.60	−64.45	91.05

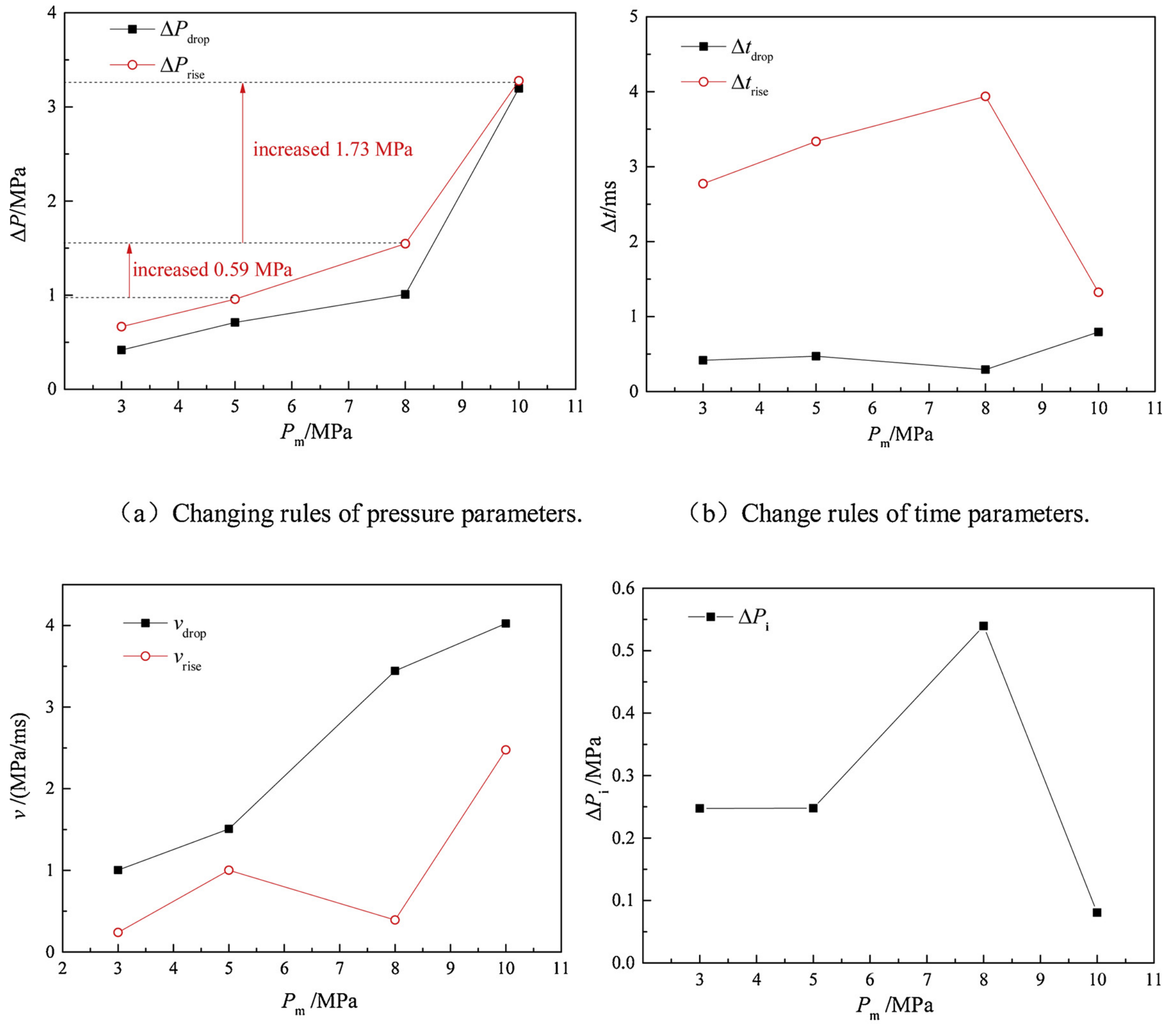
occurrence of CO_2 BLEVE needed a suitable pressure relief area; an area too large or too small would mitigate the liquid boiling process, which presents an important factor for the prevention of a BLEVE accident.

3.3. Effects of initial vessel burst pressure

It was evident that the burst vent size affected the BLEVE process after the disc burst; however, the initial conditions of CO_2 before the occurrence of the burst may also have influenced the boiling and swelling effects. So, the influence of initial vessel inner pressure before the burst on the BLEVE parameters was studied. From the results of the previous section we can see that the vent size of 8 mm diameter was the critical size where the BLEVE effect was the intense. So the vent size of 8 mm was selected and fixed in the following analysis.

The experimental conditions from test 10 to test 12 and together with test 7 can be seen in Table 1. Fig. 7 shows the top dynamic pressure-time curves in the initial process of the BLEVE, and the corresponding parameters were measured and listed in Table 3. When the burst pressures were 3 MPa, 5 MPa, and 8 MPa respectively, for which the pressure rise (ΔP_{rise}) significantly surpassed the pressure drop (ΔP_{drop}). However, when the burst pressure reached 10 MPa, the pressure rise was almost the same as the pressure drop, indicating that the initiation of the CO_2 BLEVE could not occur and, under these circumstances, the vessels would not be destroyed further. It has been revealed that the pressure rise was a result of the swelling of the gas-liquid two-phase flow layer and of the thousands of bubbles produced by the superheated liquid compressing the top space of the vessel. However, the CO_2 fluid at the pressure of 10 MPa was supercritical state and the two-phase layer will be disappear and the fluid density was approximated to liquid and the viscosity was approximated to gas and the diffusion coefficient was almost 100 times the liquid. Under this circumstance, it can be considered that the liquid filling rate was almost 100%, and after releasing, the fluid releasing form the vessel instantly, and limited space was reserved for the fluid to swell, so that the inner pressure could not rebound in time.

Fig. 8 shows the effects of the initial burst pressure on the top dynamic pressure in the initial BLEVE process. Fig. 8 indicates that both the dynamic pressure drop and rise were positively related to the initial vessel burst pressure. What's more, when the burst pressure increased form 8 MPa to 10 MPa, the pressure drop and rise value increased much more quickly than from 5 MPa to 8 MPa, which was owing to the phase change of CO_2 at 10 MPa. The overpressure (ΔP_i) rose first and then decreased from 3 MPa to 10 MPa, and the maximum value was produced at a burst pressure of 8 MPa. When the initial burst pressure was lower than 8 MPa, the top gas space was larger, which provided enough space for the swelling and expanding of the gas-liquid two phase layer. While, the burst pressure was relatively lower, which led to a slower discharge rate (seeFig. 8(c)) and less discharge volume, so the liquid



（a）Changing rules of pressure parameters. （b）Change rules of time parameters.

（c）Changing rules of pressure drop and rise rates. （d）Changing rules of overpressure.

Fig. 8. Effects of initial vessel burst pressure on the top dynamic pressure parameters.

superheat degree was lower. These reasons eventually led to a lower overpressure and BLEVE intensity. The pressure rise (Δt_{rise}) time showed the same tendency as the overpressure, indicating that 8 MPa was an ideal condition for the occurrence of the BLEVE when the burst vent size was 8 mm.

4. Conclusions

The initial inner dynamic pressure changing process of the CO_2 BLEVE was revealed through a series of small-scale experiments, and the influence rules of different parameters on the BLEVE intensity were analysed. Some conclusions are presented as follows:

(1) The vent size of 8 mm and 15 mm were two critical parameters. Once the vent size surpassed 8 mm, the changing of pressure rise became irregular especially for the burst pressure of 8 MPa experiments. Once the vent size reached or surpassed 15 mm, the pressure rise value will never surpassed the pressure drop value, which made the vessel be safe enough to discharge under 8 MPa.
(2) The supercritical state CO_2 was not stable compared to the liquid state CO_2, and a more complex phase transition in the discharge process causing the pressure parameters changing became irregular.
(3) The initial burst pressure of 8 MPa was an ideal condition for the occurrence of the BLEVE when the burst vent size was 8 mm. when the burst pressure increased form 8 MPa to 10 MPa, the pressure drop and rise value increased about three time much more quickly than from 5 MPa to 8 MPa, which was owing to the phase change of CO_2 before 10 MPa.
(4) At the pressure of 10 MPa, gaseous CO_2 in the top space of the vessel liquefied gradually, making the gas-liquid interface disappear. At that time, fluid in the vessel was the mixture of supercritical state and liquid state CO_2, and the liquid filling rate can be considered as 100%. After burst, the fluid releasing from the vessel instantly but limited space was reserved for the liquid to swell, so that the inner pressure could not rebound in time, which eventually led the overpressure to disappear.
(5) Actually, the influence rules of temperature on the initiation of CO_2 BLEVE were also important, and this parameter which related to superheat limit theory was so complex that we should pay more attention on it in the future researches.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Ahmad, M., Osch, B.V., Buit, L., Florisson, O., Hulsbosch-Dam, C., Spruijt, M., et al., 2013. Study of the thermohydraulics of co2, discharge from a high pressure reservoir. Int. J. Greenh. Gas Control. 19 (19), 63–73.

Birk, A.M., Cunningham, M.H., 1996. Liquid temperature stratification and its effect on Bleves and their hazards. J. Hazard. Mater. 48, 219–237.

Birk, A.M., Cunningham, M.H., 2015. The boiling liquid expanding vapor explosion. J. Loss Prev. Process Ind. 7 (6), 474–480.

Connolly, S., Cusco, L., 2007. Hazards from high pressure carbon dioxide releases during carbon dioxide sequestration processes. IChemE Symp. Ser. 153, 1–5.

Hulsbosch, C., 2012. Assessment of particle size distribution in co2 accidental releases. J. Loss Prev. Process Ind. 25 (2), 254–262.

Kim-E, M.E., 1981. The Possible Consequences of Rapidly Depressurizing a Fluid. Massachusetts Institute of Technology, Pasadena.

Laboureur, D., Birk, A.M., Buchlin, J.M., et al., 2015. A closer look at bleve overpressure. Process. Saf. Environ. Prot. 95, 159–171.

Li, M., Liu, Z., Zhou, Y., Zhao, Y., Li, X., Zhang, D., 2017. A small-scale experimental study on the initial burst and the heterogeneous evolution process before CO2 BLEVE. J. Hazard. Mater. 342, 634–642.

Lin, W., 2000. Study on Thermal Process of Liquefied Petroleum Gas Explosion. Shang Hai Jiao Tong University, Shanghai.

Liu, Z., Zhao, Y., Ren, T., Qian, X., Zhou, Y., Sun, R., et al., 2018. Experimental study of the flow characteristics and impact of dense-phase co 2, jet releases. Process. Saf. Environ. Prot.

Martynov, S., Brown, S., Mahgerefteh, H., Sundara, V., Chen, S., Zhang, Y., 2014. Modelling three-phase releases of carbon dioxide from high-pressure pipelines. Process. Saf. Environ. Prot. 92 (1), 36–46.

Mcdevitt, C.A., Chan, C.K., Steward, F.R., Tennankore, K.N., 1990. Initiation step of boiling liquid expanding vapour explosions. J. Hazard. Mater. 25 (1–2), 169–180.

Minh, H.D., Rodica, L., 2011. Actuarial risk assessment of expected fatalities attributable to carbon capture and storage in 2050. Int. J. Greenh. Gas Control. 5, 1346–1358.

Prugh, R.W., 1991a. Quantitative evaluation of bleve hazards. J. Fire Prot. Eng. 3 (1), 9–24.

Prugh, R.W., 1991b. Quantify Bleve hazards. Chem. Eng. Prog. 87 (2), 66–71.

Reid, R.C., 1979. Possible mechanism for pressurized-liquid tank explosions or BLEVE's. Science 203 (4386), 1263.

Rian, K.E., Grimsmo, B., Lakså, B., Vembe, B.E., Lilleheie, N.I., Brox, E., et al., 2014. Advanced co 2, dispersion simulation technology for improved ccs safety. Energy Procedia 63, 2596–2609.

Venart, J.E.S., Rutledge, G.A., Sumathipala, K., Sollows, K., 1993. To bleve or not to bleve: anatomy of a boiling liquid expanding vapor explosion. Process. Saf. Prog. 12 (2), 67–70.