Effect of Impurities on Depressurization of CO₂ Pipeline Transport

Cheol Huh\textsuperscript{a,b,*}, Meang-Ik Cho\textsuperscript{b}, Sup Hong\textsuperscript{c}, Seong-Gil Kang\textsuperscript{d}

\textsuperscript{a}Ocean Science and Technology School, Korea Maritime and Ocean University, 727 Taejong-ro, Youngdo-gu, Busan, 606-791, Republic of Korea
\textsuperscript{b}Offshore CCS Research Unit, Korea Research Institute of Ships & Ocean Engineering, 32 1312beon-gil, Yuseong-daero, Yuseong-gu, Daejeon, 305-343, Republic of Korea
\textsuperscript{c}Technology Center for Offshore Plant Industries, Korea Research Institute of Ships & Ocean Engineering, 32 1312beon-gil, Yuseong-daero, Yuseong-gu, Daejeon, 305-343, Republic of Korea
\textsuperscript{d}Maritime Safety Research Division, Korea Research Institute of Ships & Ocean Engineering, 32 1312beon-gil, Yuseong-daero, Yuseong-gu, Daejeon, 305-343, Republic of Korea

Abstract

The objective of the present study is to gain an understanding on the effect of impurities during the depressurization of CO₂ pipeline transport. In this study, experimental apparatus was built to simulate the transient behavior of CO₂ pipeline transportation. The transient blowdown test was conducted at the initial conditions of 85 bar and 20 °C. To study the effect of impurities, N₂ was added from 2% to 8% on mass fraction basis. The blowdown of CO₂ pipeline transport system was numerically simulated. The dynamic multiphase flow simulator OLGA was used to model the depressurization of CO₂ pipeline system. Comparisons of experimental data and numerical simulation results were carried out. Initial severe pressure drops during few seconds were well estimated by numerical simulation for both pure and mixture cases. On the other hand, the numerical simulation did not provide reliable temperature drop predictions. As the amount of N₂ impurity increases the numerical simulation results showed better pressure drop predictions. But there were some difference between experimental data and numerical simulation results in gradual pressure drops as the amount of N₂ impurity decreases. In conclusion, it is required to improve the phase change model of numerical simulator.

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* Corresponding author. Tel.:+82-51-410-5247; fax: +82-51-404-3985.
E-mail address: cheolhuh@kmou.ac.kr
1. Introduction

To achieve safe and cost effective design of CO₂ transport, it is important to understand transient behavior such as start-up, shutdown, etc. Especially, the pipeline systems show severe pressure and temperature drops during the depressurization. Depressurization of dense CO₂ showed a two-phase transient phenomenon with Joule-Thomson cooling and phase change. Depressurization of CO₂ were studied by many researchers[1–4]. Clausen et. al[5] analyzed a large CO₂ pipeline depressurization experiment of an onshore 50 km long 24-inches buried pipeline from initially supercritical conditions. Sudden expansion of dense CO₂ trigger very rapid temperature drop. To ensure integrity of the pipeline, low temperature operations below the design condition should be avoided. Moreover, if the CO₂ reaches its triple point (518 kPa and −56.6 °C) dry ice will be formed, potentially causing blockages[6]. During the whole CCS value chain, there is a possibility of CO₂ venting to the atmosphere due to the unexpected accident, failure and planned maintenance.

In this study, experimental blowdown of CO₂ with impurity were carried out. The test was conducted at the initial conditions of 85 bar and 20 °C. To study the effect of impurities, N₂ was added from 2% to 8% (mass fraction). This blowdown of CO₂ pipeline transport system was numerically simulated with the dynamic multiphase flow simulator OLGA. Comparisons of experimental data and numerical simulation results were carried out.

Fig. 1. Schematic diagram of experimental apparatus [4].
2. Experiment of CO$_2$-N$_2$ Depressurization

The experimental apparatus consists of pressurizing part, liquefying part, mixing zone, and test section as shown in Fig. 1. The experimental facilities was designed to compress and liquefy gaseous CO$_2$ and then mix it with some impurities[4]. It is possible to supply various conditions of CO$_2$-impurity mixtures to test section. The booster discharge pressure was maintained at specific pressure value between 100–130 bar, varying at each test case. The test section consists of circularly winded tubes, temperature, and pressure sensors. The inner diameter of the test tube is 3.86 mm. At the inlet and outlet of test section 14 temperature and absolute pressure transducers are installed. Total length of flow test section is 51.96 m.

The test section was filled with controlled CO$_2$-N$_2$ mixture at specified pressure condition, and meanwhile the temperature of test section was reached at test condition. As test condition was achieved, the inlet and outlet valves were closed. After 1 minute the outlet valve opened and transient flow test initiated for each test case. The experimental measurement errors of mass flow of CO$_2$ and N$_2$ are ±0.14% and ±1.0% of readings, respectively. The uncertainty of temperature sensor, pt100 RTD, is ±0.1°C. The pressure gage’s error is about 0.064 bar.

3. Numerical Simulation of CO$_2$-N$_2$ Depressurization

The dynamic multiphase flow simulator OLGA 7.0.1 (Schlumberger) was used to model the depressurization of CO$_2$ pipeline system. A recent single component module of OLGA makes it possible to model pure CO$_2$ depressurization using the Span–Wagner equation of state. On the other hand, single component module does not take into account the presence of some impurities. The properties of CO$_2$-N$_2$ mixture were modelled using PVTsim (Calsep). Before going to depressurization calculation, steady state and shut-in simulations were carried out. Shut-in operation was performed by closing the outlet valve and the CO$_2$ feed was terminated simultaneously.

4. Comparison of Experiment and Numerical Simulation

Comparisons of experimental data and numerical simulation results were conducted. During the blow-down, temperature and pressure of CO$_2$ suddenly decreased. As the CO$_2$ in the flow line was released to the atmosphere, the volume of the CO$_2$ suddenly expanded due to pressure difference between flow line and atmosphere. This volume expansion triggered very fast heat transfer and then resulted in severe temperature drop of the flow line and the working fluid.

Figures 2(a) and 2(b) show the comparison of pressure and temperature variations during the pure CO$_2$ depressurization event, respectively. The symbolic data represents the experimental data and the line data mean the numerical simulation results. The locations of measured data are described in the legend. That is the distance from the exit of the test section. Therefore, 7.93m is the nearest measured point from the exit.

![Fig. 2. Comparison of experimental data and numerical simulation of pure CO$_2$ depressurization.](image-url)
Fig. 3. Comparison of experimental data and numerical simulation of 98% CO\textsubscript{2} and 2% N\textsubscript{2} depressurization.

Fig. 4. Comparison of experimental data and numerical simulation of 96% CO\textsubscript{2} and 4% N\textsubscript{2} depressurization.

Fig. 5. Comparison of experimental data and numerical simulation of 92% CO\textsubscript{2} and 8% N\textsubscript{2} depressurization.
After the initiation of the blowout, the pressures rapidly drop. More pressure drops were shown as the locations of the measured points close to the exit. For an instant, the pressures gradually decreased following the first rapid drops and then decreased very fast again. The numerical calculation showed very good predictions of initial pressure drop. But the second rapid pressure drops were not predicted. The differences between the experiment and numerical calculation mean that the dynamic multiphase flow simulator did not provide a reliable prediction for departing the saturation condition during the depressurization.

Figures 3-5 show the comparison of pressure and temperature variations during the CO$_2$-N$_2$ mixture depressurization. The mass fraction of N$_2$ was controlled from 2 to 8%. As the amount of N$_2$ impurity increases the numerical simulation results showed better pressure drop predictions. Because the dynamic multiphase flow simulator OLGA was originally built to simulate the multicomponent and multiphase flow, CO$_2$-N$_2$ mixture depressurization were relatively well predicted compared with pure CO$_2$ case.

The numerical simulation shows reasonable agreement for the pressure drops but do not provide reliable temperature drop predictions. A similar numerical simulation results were shown in the previous studies[1,6].

5. Conclusion

Experimental and numerical studies on the effect of impurities during the depressurization of CO$_2$ pipeline transport were carried out. The experimental data and numerical simulation results were compared. Initial severe pressure drops during few seconds were well estimated by numerical simulation for both pure and mixture cases. On the other hand, the numerical simulation did not provide reliable temperature drop predictions. As the amount of N$_2$ impurity increases the numerical simulation results showed better pressure drop predictions. But there were some difference between experimental data and numerical simulation results in gradual pressure drops as the amount of N$_2$ impurity decreases. In conclusion, it is required to improve the phase change model of numerical simulation.

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