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Preliminary Study on S-CO_2 Leakage to High Pressure Water

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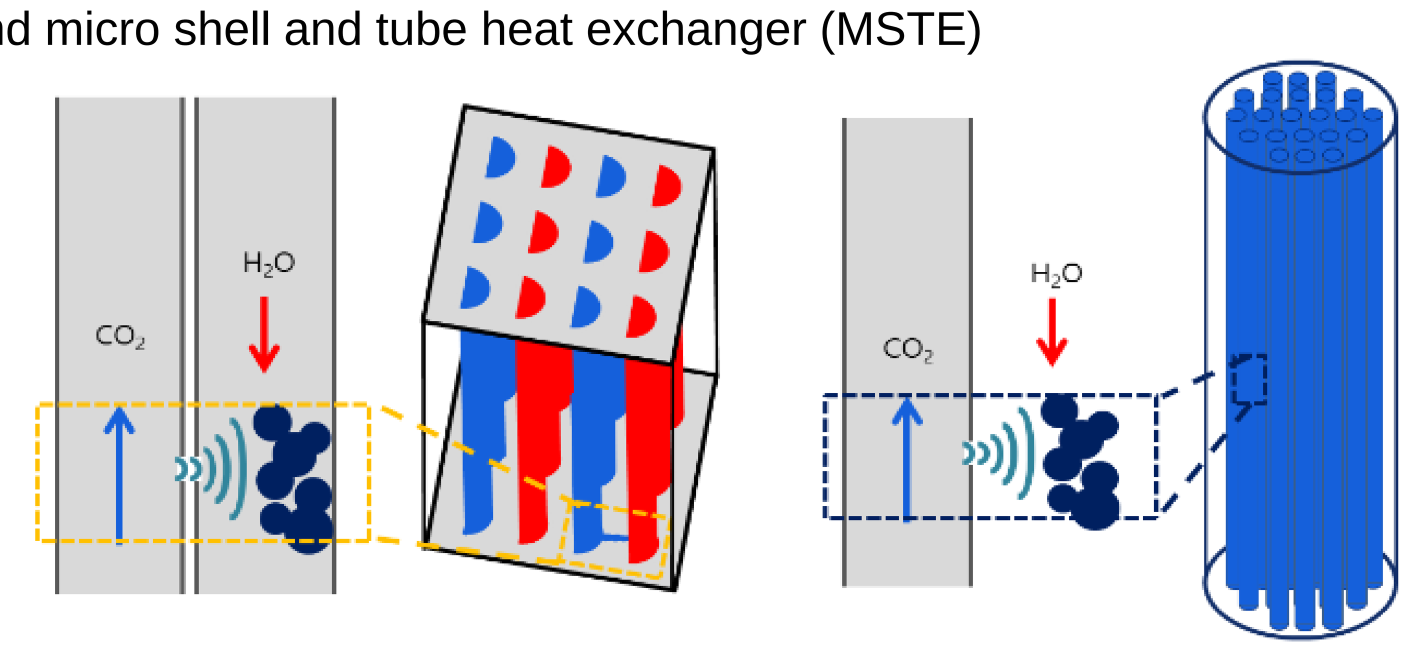
Introduction

- A supercritical CO_2 (S-CO_2) cycle can be a good alternative of a steam Rankine cycle because the S-CO_2 cycle offers many advantages in a practical application due to high thermal efficiency, high power density, and mild environmental requirement for keeping integrity of turbomachinery blade.

- Thermodynamically, higher operating pressure in the S-CO_2 cycle leads to higher efficiency of the cycle. However, the operating pressure should be determined with regard to operational and safety issues. When using the S-CO_2 cycle as an indirect cycle coupled to the traditional PWR concept, in a case of leakage in the intermediate heat exchanger (IHX), the situation where the pressure on the S-CO_2 cycle is higher than the pressure on the primary side's water could be inappropriate considering conventional safety system.

✓ Schematic of leakage situations for printed circuit heat exchanger (PCHE) and micro shell and tube heat exchanger (MSTE)

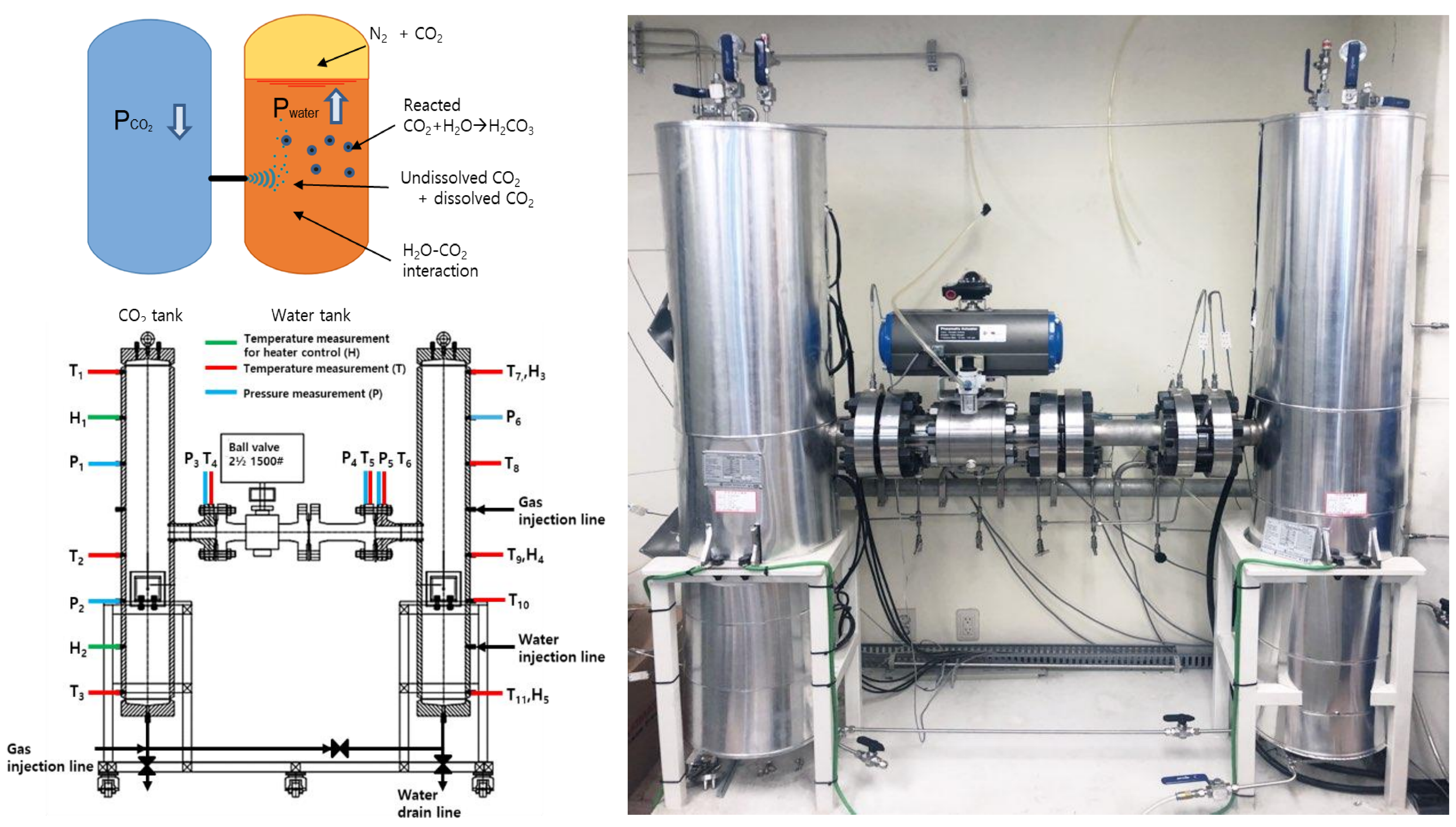


- Therefore, it is necessary to understand the dissolution phenomenon that can occur due to the IHX failure when adopting high pressure S-CO_2 cycle before devising a proper concept of safety system.

- In this paper, the experimental and numerical methods for simulating and analyzing the case of PWR are introduced.

Description of the facility

✓ Schematic of leakage process and Photograph of the experimental facility



- The main process of the experiment.

1) CO_2 flows from high-pressure tank (CO_2, Left tank) to low-pressure tank (Water, Right tank) through a nozzle.
2) The leaked CO_2 is dissolved into the water non-dissolved CO_2 collects at the top of the low-pressure tank.
3) Estimate the dissolved mass of CO_2 and non-dissolved mass using measured pressure and temperature.

* N_2 gas is injected for pressurization of the low-pressure tank.

✓ Design specifications of the experimental facility.

	Design parameter	
High/Low pressure tank	Pressure (MPa)	22
	Temperature (°C)	150
	Volume (L)	47 (I.D : 200 mm, H : 1600 mm)
Pipe connecting two pressure tanks	Internal diameter (mm)	57
	Length (mm)	1090
High pressure tank heater (jacket-type)	Electric capacity (kW)	5
Low pressure tank heater (jacket-type)	Electric capacity (kW)	12
Valve type	Ball valve	

Numerical model for analyzing experimental results

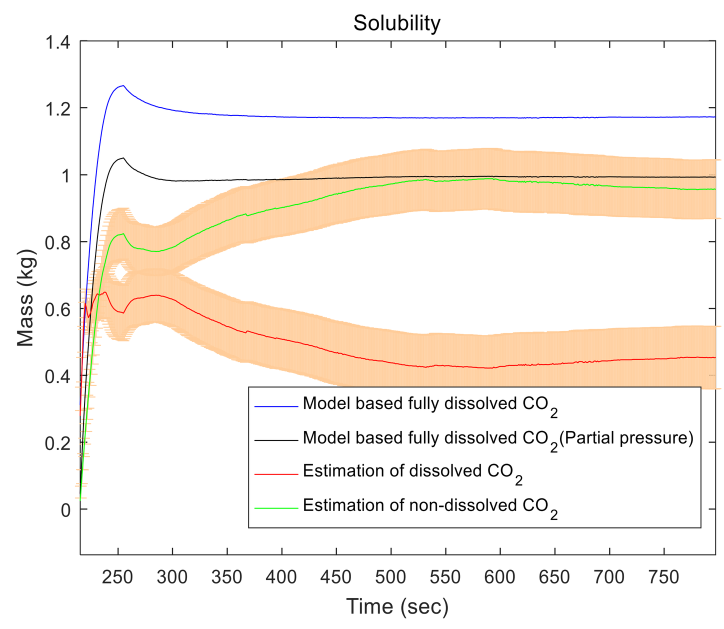
- The mass flow rate of leakage can be calculated using the measured pressure and temperature data of the high pressure tank.

$$\dot{m} = \frac{V_{tank}(\rho_{t+\Delta t} - \rho_t)}{\Delta t}$$

- In this experiment, dissolved mass of CO_2 in the water system is an object to be identified. Dissolved mass can be calculated with assumptions that N_2 dissolution is neglected, the dissolved CO_2 reaches thermal equilibrium with water and the system pressure is equal to stagnant.

$$\frac{M_{water}}{\rho_{water}} + \frac{M_{N_2}}{\rho_{N_2}} + \frac{M_{dissolved\ co_2}}{\rho_{apparent}} + \frac{M_{gas\ co_2}}{\rho_{co_2}} = V_{tank}$$

✓ Example of the result



- The experimental results show the dissolved mass using the above equations. But, the final goal of the study is modeling the dissolution process model for safety analysis code.

- For this reason, the authors try to estimating the bubble size using the measured data.

- When CO_2 is injected into water, the CO_2 jet collapses into fine bubbles. Thus, the authors used the numerical model for calculation of CO_2 dissolution and estimating the bubble size based on mass transfer from a single bubble rising in stagnant water.

$$\frac{dM}{dz} = -\frac{KA(C_s - C)}{U}$$

M : mass of CO_2 bubble

z : axial length

K : mass transfer coefficient

A : bubble suface area

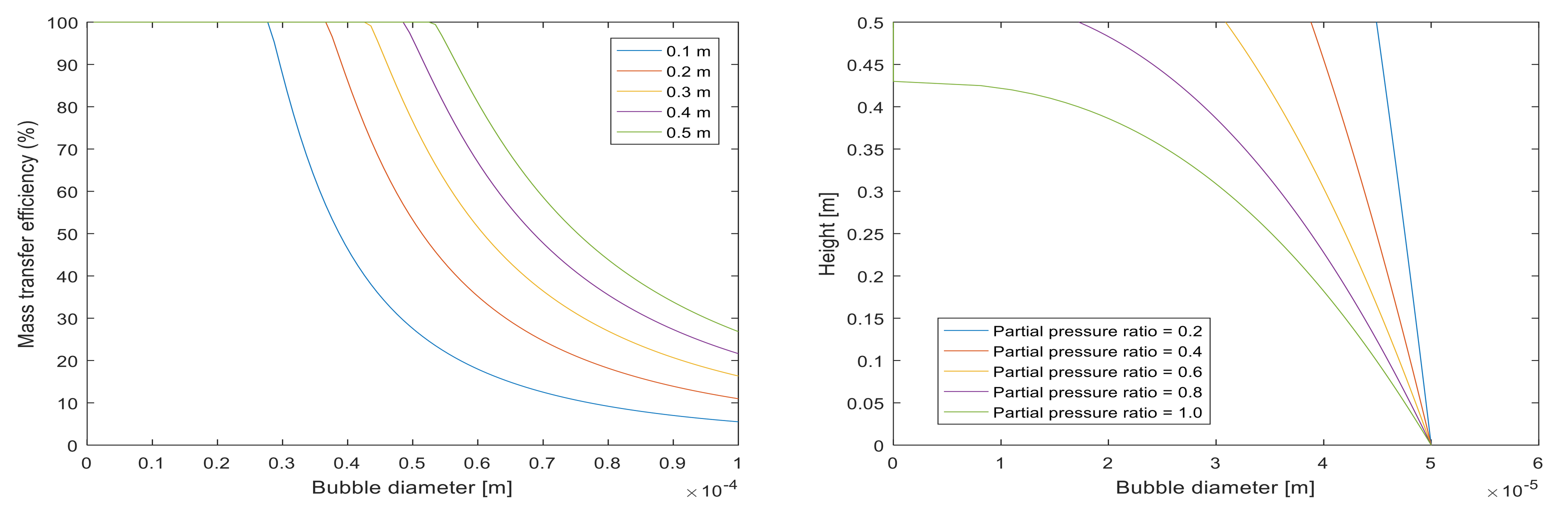
C_s : equilibrium concentration

C : dissolved concentration

U : bubble rising velocity

✓ Mass transfer efficiency as a function of bubble size (Left)

✓ Bubble diameter as a function of partial pressure (Right)



Summary, Conclusion and Further works

- The experimental facility and numerical method for simulating and analyzing the case of PWR coupled with the S-CO_2 power system are introduced in this paper.

- The purpose of the experiment is identifying the phenomenon of supercritical CO_2 leaking into high pressure water. Using the measured pressure and temperature data, the dissolved mass of CO_2 is calculated.

- The numerical method is based on the mass transfer from the bubble and it is used to calculate the dissolution according to the bubble size. The bubble size is thought as a key parameter because it is judged appropriate to be used as a model for safety analysis code later.

- The above equation does not consider the transient situation. Thus, the model is being developed by considering the variation with time. The model is a combination of the developed models by other researchers. Thus, the results could vary significantly depending on the models. The sensitivity of the model should be studied.

Acknowledgement

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