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Introduction to flow visualization system in SPARC test facility

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1. Introduction

Severe accident shows danger of hydrogen released into a closed containment building. The thermal-hydraulic process of hydrogen affects the integrity of a containment. The released hydrogen can be accumulated and mixed by steam and air depending on containment conditions under severe accident, which generates flammable mixture. Hydrogen explosion induced by ignition source cause severe damage to a structure or facility. Hydrogen risk regarding mixing, distribution, and combustion has been identified by several expert groups and studied actively since TMI accident [1]. A large-scale thermal-hydraulic experimental facility is required to simulate the complex severe accident phenomena in the containment building.

We have prepared the test facility, called the SPARC (Spray, Aerosol, Recombiner, Combustion), to resolve the international open issues regarding hydrogen risk [2].

Gas mixing and stratification test using helium instead of hydrogen and estimation of a stratification surface erosion of helium owing to the vertical jet flow will be performed in SPARC. The measurement system is need to observe the gas flow in the large scale test facility such as SPARC. The PIV (particle image velocimetry) system have been installed to visualize gas flow. The jet flow impinging on to helium stratification and erosion of a stratification will be evaluated by measuring 2D velocity field. The following chapters introduce instrumentation of PIV system.

2. Methods and Results

2.1 Test Facility

Figure 1 shows test facility called SPARC [2]. The vessel is a cylindrical pressure vessel made of stainless steel 316L and has a 3.4 m and diameter 9.5 m height. It is designed to observe the convection flow and gas distribution induced by the natural convection in a containment building. The total volume of vessel is 80 m^3 and the design pressure is 1.5 MPa at 180 °C [2].

2.2 Test Matrix

Figure 2 shows the experimental schematic of gas mixing and stratification test. The helium stable stratification (30 vol. %) is eroded by air jet flow at 8150 mm elevation. The initial mean velocity of air jet is 3.14 m/s which is released through jet nozzle of 100 mm diameter. The experimental condition is depicted in detail as Table 1.

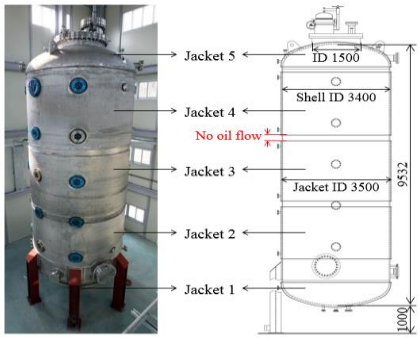

Fig. 1. SPARC vessel and jackets [2]

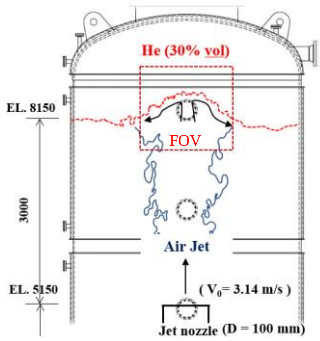

Fig. 2.The experimental schematic of gas mixing and stratification test

Table 1. The experimental condition of gas mixing and stratification test

Stratification condition	
Stratification fluid	Helium
Concentration	30 Vol. %
Jet condition	
Jet fluid	Air
Jet nozzle diameter (D_j)	100 mm
Initial mean velocity (V_j)	3.14 m/s
Temperature (T_j)	20 ºC
Reynolds No. (Re)	20000
Ambient condition	
Ambient fluid	Air
Pressure (P_a)	101.3 kPa
Temperature (T_a)	20 ºC

2.3 Camera and Laser of PIV

For the 2D velocity measurements a particle image velocimetry (PIV) system is used as Figure 3. CCD camera (FlowSense EO 4M, Dantec) of 2048 × 2048 pixels resolution records particle images and operated under double exposure mode. Canon lens (EF 35 mm f/1.4L II USM, Canon) is mounted in camera with 532 nm band pass filter. The expected FOV size will be 750 × 750 mm^2 and a resolution of 0.37 × 0.37 μm^2 /pixel will be achieved at 8150 mm elevation. Camera is synchronized with Nd:Yag double cavity laser (Dual Power 425-10, Dantec) of peak energy 425mJ/pulse at 532 wavelength. Laser sheet of 2.5 mm thickness and 1100 mm height will be illuminated into SPARC vessel through groups of sheet optics. The details of CCD camera and Nd:Yag double cavity laser is depicted in detail as Table 2 and Table 3 respectively.

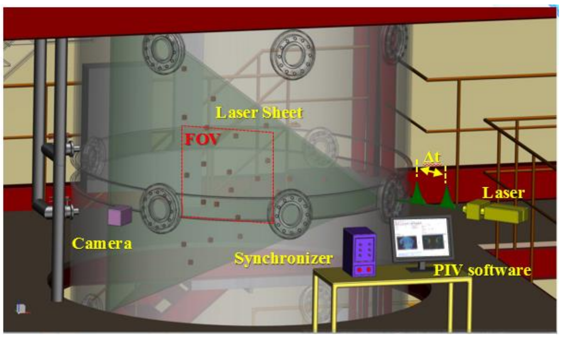

Fig. 3. PIV system for measuring 2D velocity field in SPARC vessel

Table 2. Specifications of CCD camera

CCD camera	
Resolution	2048 x 2048 pixels
Frame rate (at full resolution)	16 Hz
Interframe time	200 ns
Peak quantum efficiency	56 %
Lens mount	C – mount

Table 3. Specifications of Nd:Yag double cavity laser

Nd:Yag double cavity laser	
Configuration	Dual cavity
Pulse Energy at 1kHz	2 x 425 mJ
Wavelength	532 nm
Repetition Rate (each cavity)	10 Hz
Pulse Stability	± 2 %
Divergence	< 3 mrad
Beam diameter	9.5 mm
Polarization	Horizontal
Cooling system	Water cooling
Voltage	220 V, 60 Hz

2.4 Tracer particles

The jet fluids are uniformly seeded with tracer particle for PIV measurement. Two tracer particles are used differently depending on the purpose. One is liquid particle made of DEHS (Di-Ethyl-Hexyl-Sebacic-Acid-Ester, Dantec). The mean diameter of particle is about 1.5 μm and specific gravity is 0.91. It has advantages that its life time is longer than olive oil generally used and it can be used at high temperature. It does not also have a weak influence on test facility, because its residues is evaporated completely after long times (6 ~ 8 hours). The other is solid particle, dry expanded microsphere (Expancel 461 DET 20 d40, AkzoNobel), made of a copolymer and enclosed in each plastic shell is a gas such as isopentane. The mean particle diameter ranges from 15 um to 25 um and the specific gravity is 0.04. 2D velocity vectors are analyzed by processing particle image pairs using PIV software (DynamicStudio 4.10, Dantec).

3. Conclusions

We are preparing the test facility, called the SPARC, for estimation the thermal-hydraulic process of hydrogen in a closed containment building and the PIV system for quantitative assessment of gas flow. In particular, we will perform gas mixing and erosion of stratification surface test using helium which is the replacement of hydrogen. It will be evaluated by measuring 2D velocity field using the PIV system. The PIV system mainly consists of camera, laser and tracer particle. Expected maximum size of FOV is 750 × 750 mm^2 limited by focal length of lens and high power laser corresponding to 425mJ/pulse at 532 wavelength is required due to large FOV. Different type of tracer particle, DEHS particle and Expancel particle, will be used depending on the test purpose.

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