§7. Investigation of the Clustering Condition for the Supersonic Cluster Beam Injection

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The supersonic cluster beam (SSCB) injection method is being developed as a new fueling method for the Large Helical Devise (LHD) experiment. SSCB is an improved version of cluster jet injection (CJI) developed for HL-2A, where liquid nitrogen of 77 K is used for gas cooling [1], or the supersonic gas injector (SGI) developed for NSTX, where a Laval nozzle is used to generate supersonic gas jet.[2] In SSCB, high-pressure hydrogen gas cooled to less than 77 K by a GM refrigerator will be injected to vacuum through a fast solenoid valve with a Laval nozzle. Before applying SSCB to LHD, a solenoid valve for SSCB has been tested at a room temperature in a test vacuum chamber.

The experimental setup is shown in Fig. 1. A solenoid valve of Parker-Hannifin Pulse Valve Series 99B07 with a 500 µm diameter orifice has been tested. This valve is equipped with a tapered nozzle. This valve is set inside the vacuum chamber. The pressure in the vacuum chamber is measured by a pressure gauge of MKS Baratron capacitance manometer (MODEL#617A) set at the opposite side of the valve. When the valve is open, the gas flows from left to right in Fig. 1. Various gasses of H_2, He, CH_4, N_2, Ne, and Ar have been used in the experiment. A semiconductor laser of NEOARK LDP2-6535A with 650 nm standard wavelength and 35 mW power is set inside the chamber to perpendicularly intersect the gas flow. A beam dump is set at the opposite side of the laser and the valve is rolled by black tape in such a way that the stray light is decreased. The distance between the valve exit and the laser chord is variable from 3.5 mm to 4.0 mm. A fast charge coupled device (CCD) camera of 1280 × 1024 pixels is arranged in the direction perpendicular to both the gas flow and the laser beam. An example CCD image is shown in Fig. 2.

Rayleigh scattering of laser light by the cluster is measured by the CCD camera. In the case of CH_4, N_2, and Ar, clear scattering signals are observed at high valve backing pressure of more than 3 – 4 MPa. In the case of H_2, He, and Ne, on the other hand, no scattering signal is detected at < 8 MPa. The maximum of the scattering signal as a function of the backing pressure is plotted in Fig. 3, where the working gas is CH_4. The scattering signal increases with $\sim P_0^{2.8}$ for Ar and $\sim P_0^{3.2}$ for N_2. These results are similar to the results in Ref. 3). However, in the case of CH_4 (Fig. 3), it is found that the backing pressure dependence is stronger than expected, i.e., $S_{RS} \propto P_0^{4.8}$ at $P_0 < 7$ MPa and $S_{RS} \propto P_0^{8.6}$ at $P_0 > 7$ MPa. This result is different from $S_{RS} \propto P_0^{2.8\text{-}3.1}$ reported in Ref. 4), where Farges et al. estimated this relation assuming a multilayer icosahedral model for an Ar cluster. This model seems to be reasonable also for N_2, which shows similar pressure dependence as Ar. However, a new structure model would be necessary to determine the cluster size of CH_4, which shows stronger backing pressure dependence than Ar or N_2.

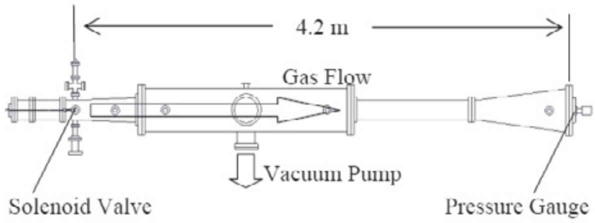

Fig. 1. Schematic of the experimental setup. The distance from the solenoid valve to the baratron pressure gauge is 4.2 m. Inside the chamber is pumped to less than 10^{-4} Pa. The laser is set inside the chamber.

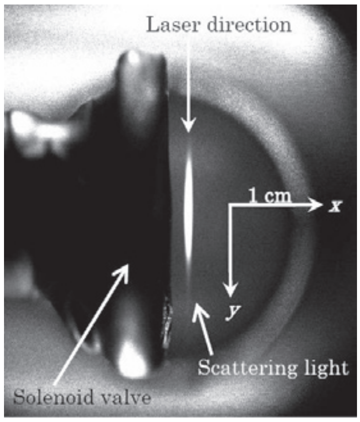

Fig. 2. The scattering light image detected by the CCD camera in the case of CH_4. The backing pressure is 8.0 MPa, and the exposure time is 10 ms. The laser beam direction (*y*) is perpendicular to the gas flow (*x*).

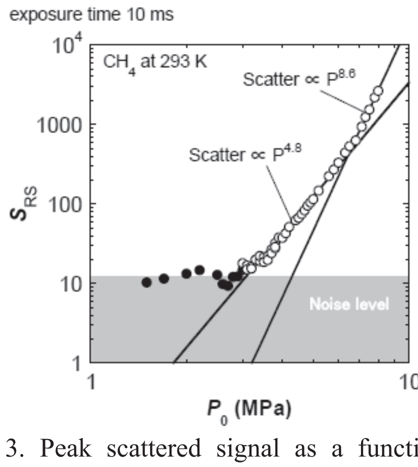

Fig. 3. Peak scattered signal as a function of the backing pressure in the cases of CH_4. Closed circles denote the signals under the noise level. Regression analysis has been done using the data points denoted by open circles.

1) Yao, L. et al. :Nucl. Fusion **47**, (2007) 139
2) Soukhanovskii, V.A. et al. :Rev Sci Instrum.**75**, (2004) 4320
3) Smith, R. A. et al. :Rev Sci Instrum. **69**, (1988) 3798.
4) Farges, J. et al. : J. Chem. Phys. **84**, (1986) 3491