# §22. Hydrogen Isotope Circulation for Burning Plasma Sustainment

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Hydrogen isotope (DT) circulation which is required to maintain a burning plasma has been investigated by extrapolating from the pellet injection experiment on LHD. Burning rate of DT fuel which is defined by the ratio of the burnup to fuel is less than 1%. This result implies that more than 100 kg DT fuel per day is required. Additionally, since the pneumatic pellet acceleration concept is employed, large amount of propellant gas is required in the pellet injector. However, it is possible to suppress the DT inventory within tolerance level by circulating the DT fuel in a pellet injector.

Let us suppose that the target plasma size is four times as large as LHD and the central plasma temperature is 10 keV with parabolic profile. The pellet injection condition that is required to sustain $n_\mathrm{e}(0) = 2.5 \times 10^{20}$ /m$^3$ ($\sim$ 3 GW fusion output) is calculated. Pellet fueling property is estimated by using the Neutral Gas Shielding (NGS) model. A simple diffusion model which consider spatially uniform diffusion coefficient and no convection velocity are applied to estimate the density change after the pellet deposition because a particle transport of the LHD plasmas in high-density regime can be described by such a simple diffusion model. Here the diffusion coefficient; D is approximately expressed by the following equation.

$$D = 0.05 P_\mathrm{heat}^{0.6} B_\mathrm{T}^{-0.8}$$

The injection frequency which is required to sustain $n_\mathrm{e}(0) = 2.5 \times 10^{20}$ /m$^3$ is shown in Fig. 1 as open circle. Since the pellet penetration depth and supplied particle number increase as the pellet size become large, the required injection frequency decreases as the pellet size become large. The fuel rate which is defined by the product of the injection frequency and particle number per pellet takes at least $3.0 \times 10^{23}$ atoms/s. Since the DT burning rate at 3 GW fusion output is $2.2 \times 10^{21}$ atoms/s, the burning efficiency which is defined by the ratio of the fuel burning to the fuel supplying is less than 1%.

In order to secure a reliability of the pellet injection, pneumatic pellet acceleration is employed. The choice lead to a disadvantage due to a propellant gas consumption which require about 3 times larger than a pellet mass. It is reasonable to use a fuel gas as a propellant gas to prevent an impurity mixing and the pumped propellant gas at a differential pumping system is directly reusable as the propellant gas and/or fuel gas as shown by broken line in Fig. 2. The DT fuel flow rates which are estimated by assuming that the pellet cutting loss ratio and propellant gas consumption ratio are 35% and 333% is shown in Fig. 2. The DT fuel consumption as a propellant gas is $12.0 \times 10^{23}$ atoms/s and this amount is equivalent to 432 kg/day. However, the DT fuel inventory is estimated to be around 5 g considering that the time constant of the pumping and compression is 1 s. The largest DT fuel storage is a cryo-cylinder to solidify the DT fuel. A time constant of the hydrogen solidification is no more than 40 s based on the repetitive pellet injector operation on LHD. Since the pellet fuel rate is assumed $4.83 \times 10^{23}$ atoms/s including 35 % pellet cutting loss ratio, the DT fuel inventory at the cryo-cylinder is estimated to be 80 g. The total DT fuel inventory in the pellet injector is estimated to be about 85 g.

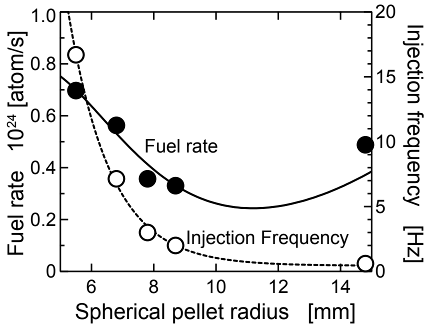


Fig. 1: Pellet size dependence of the injection frequency and fuel rate to sustain $n_\mathrm{e}(0) = 2.5 \times 10^{20}$ /m$^3$.

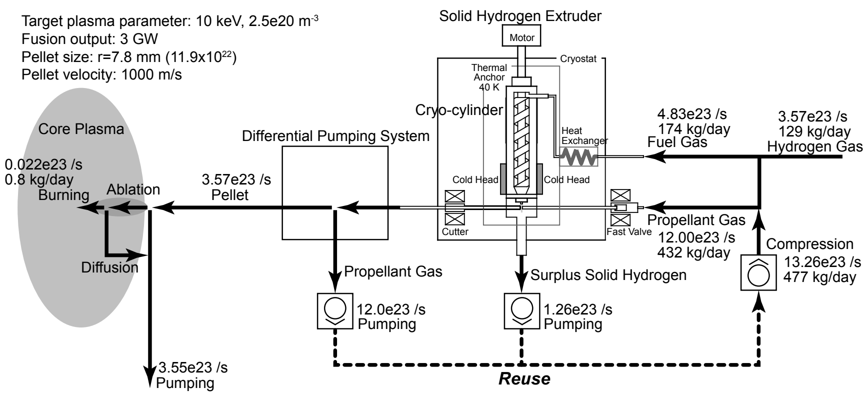


Fig. 2: DT fuel gas flow in a pellet injector.