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Physics Studies of Cryogenic Pellet and Tracer-loaded Pellet (TESPEL) Injections in the Stellarator TJ-II

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Core fuelling is a critical issue on the pathway to the development of steady-state operational scenarios in magnetically confined plasma devices. Although gas puffing has been the established tool for creating and maintaining plasmas in small and medium sized tokamaks and stellarators, its location at the plasma periphery portends that it will become inefficient for larger reactor-type devices. Hence, cryogenic pellet injection (PI) has become the prime candidate for core fuelling. Although PI technology is now well developed 1, a comprehensive understanding of all aspects of pellet/plasma interaction is still to be achieved, i.e., pellet ablation, plasmoid expansion and drift, particle deposition, or enhanced ablation by fast particles. Indeed, understanding these topics is crucial if deep penetration, core deposition, and high fuelling efficiencies are to be achieved, an aspect additionally important for helical devices to avoid the core particle depletion predicted by neoclassical theory for on-axis microwave heating [2]. For instance, the benefit of high-field side (HFS) injection over low-field injection for achieving improved efficiency is well known for tokamaks [3]. In contrast, for stellarators the advantage of HFS injection remains unclear [4]. Similarly, new understanding is also needed to refine simulation codes such as the Hydrogen Pellet Injection 2 (HPI2) codes used for predicting optimized fuelling conditions [5].
A second key topic for steady-state operation of helical-type reactors is increased impurity confinement at high electron densities that can lead to impurity accumulation and subsequent radiative collapse of the plasma [6]. A pellet method for performing impurity studies is the Tracer-Encapsulated Solid-Pellet technique in which a hollow polystyrene sphere, (-CH(C6H5)CH2-)n, filled with a known quantity of a suitable tracer element, is injected into a plasma [7]. Using this technique, the tracer element is deposited in the plasma core.
Although the raison d'être of these pellet injection methods is distinct, both pellet types should experience the same physics processes as they penetrate through magnetic confined plasma. Ablated particles in the partially ionized cloud (plasmoid) that surrounds a pellet should experience the same effect(s) thus they should undergo similar expansion and post-detachment processes, e.g., drift and diffusion. However, few systematic comparisons exist due to the limited number of devices equipped with both systems. Even if both are available, they tend to have different injection geometries or to be located in different machine sectors. In the stellarator TJ-II, a pipe-gun type cryogenic PI, that injects pellets from the low-field side (LFS) of the magnetic-axis, has been operated since 2014 [9]. Also, a TESPEL injector has been piggy-backed on various occasions onto its up-stream end [10], thereby making it a unique as both pellet types are injected along adjoining guide tubes into the same TJ-II sector. In addition, the same diagnostics are used to evaluate ablation and penetration depth (fast-frame camera) whilst other diagnostics (Thomson Scattering, ⊠wave interferometer, etc) provide data on pellet particle transport and deposition and plasma perturbation.

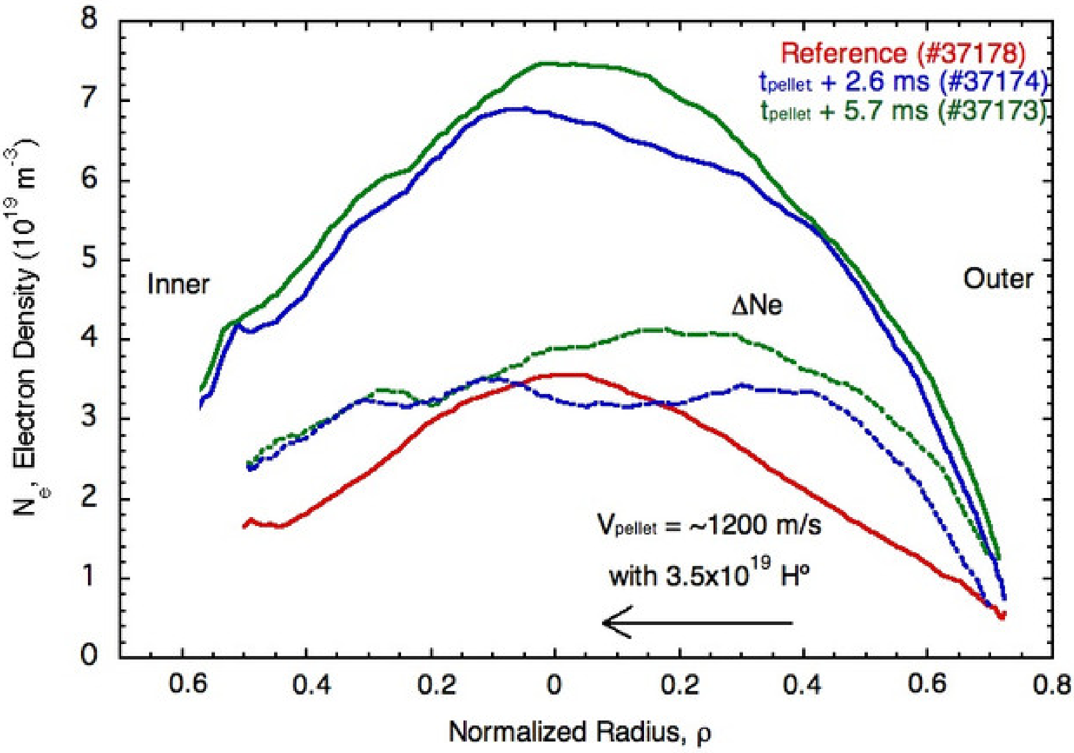

Figure 1:

Since pellet injection began on TJ-II, a large pellet database has been built up for both microwave and neutral beam heated plasma (hydrogen has been the primary working gas). In parallel, a stellarator version of the HPI2 code was benchmarked using TJ-II and since then it has been adapted for the W7-X and Heliotron-J devices [11]. As part of TJ-II PI studies, fast-frame imaging of the ablation process has observed outward plasmoid drift velocities that concur with simulations. In addition, comparative studies made with TESPEL pellets have substantiated the influence of pellet particle mass on plasmoid drift, deposition profile peaking and deposition efficiency [12]. Moreover, studies, which reveal a strong penetration depth/fuelling efficiency relationship, show improved fuelling when a fast particle population resides within the plasma core of TJ-II [13]. However, while the physics behind the contribution of fast-particle associated effects to fuelling continues to be studied it has been possible to simulate the effect by including semi-empirical parameters. Nonetheless, the location of such a population can be identified from enhanced ablation in the TJ-II while a recently upgraded fast-frame camera (double-bundle) has facilitated such studies. In addition, a small precursor pellet or a small pre-injection gas puff has been used to pre-cool the plasma edge in order to enhance the pellet penetration depth, and hence improve fuelling efficiency. It is found that the former leads to a small increase in fuelling while the latter can result in high post-injection densities (Fig. 1). In parallel, changes in the plasma potential and radial electric field have been investigated using a dual Heavy Ion Beam Probe system and a Doppler reflectometer. For instance, immediately after an injection the density fluctuation level is strongly reduced for a short time period (1 ms), followed by a slow increase as plasma density evolves and the electron temperature recovers [8]. Finally, detailed studies of the neutral cloud that surrounds a pellet have been undertaken using a narrowband filter based light detection system in order to determine obtain density and temperature values for use in the TJ-II version of the HPI2 code.

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