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REVIEW OF PELLET FUELING OF TOKAMAKS*

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Recent experiments on the Alcator-C[1], D-III[2], TFTR[3,4], and ASDEX[5] tokamaks have demonstrated the importance of the plasma fueling mechanism on the performance of tokamak plasmas operating in the density regime of 5×10^{13}-1×10^{15} cm^{-3} and with plasma heating in the 2-8 MW range. Although the mechanism of edge fueling as embodied by gas injection and recycle[6] has been generally understood for many years, its limitations have only recently been recognized. Pellet fueling[6,7] presents an alternative to the broad plasma density profiles that result from edge heating in that the centrally peaked fuel deposition profiles lead naturally to more peaked density profiles, higher central densities, increased particle confinement times and reduced mantle densities and recycling[2]. In many cases, the altered density profiles result in an increase in plasma stored energy and a concomitant increase in the gross energy confinement time, τ_E.

These characteristics of pellet fueling are illustrated in Fig. 1 where we compare plasma density and temperature profiles and the resulting plasma energies for gas fueled (G) and pellet fueled (P) TFTR ohmic discharges[4]. Plasma energy increases continuously during the density

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buildup phase and reaches a peak value of 0.9 MJ at 0.2 s after the pellet fueling pulse (5 pellets of 2.7 mm diameter injected at 1300 m/s). The density profile is centrally peaked owing to the fact that the third and subsequent pellets penetrate to the magnetic axis. In contrast, the gas profile is broad as a consequence of the absence of central particle sources; and, the magnitude of the density is substantially lower. The P discharge exhibits a 70% improvement in energy confinement time.

The scaling of confinement time with plasma density for G and P type TFTR ohmic discharges is shown in Fig. 2. While the strong saturation of τ_E with density for G type discharges is typical of tokamak confinement results in the L-regime[8], pellet fueled discharges exhibit superior confinement properties (H-mode levels) at densities that are well into the region where the neoclassical ion heat conduction losses are predicted to contribute significantly to the power balance. A similar trend was observed on Alcator-C by Greenwald[1] who concluded that the improved confinement was due to a reduction in the ion thermal conductivity anomaly. It has been proposed that the steep density gradients that are produced during pellet injection prevent the onset of ion-temperature-gradient driven turbulence that might be responsible for the degradation in confinement observed in gas fueling experiments.

The general improvement in energy confinement resulting from pellet injection in ohmic discharges is not universally observed in auxiliary heated plasmas. Although an enhanced confinement regime was observed in limiter discharges on D-III at up to 2.4 MW of neutral injection, at higher beam power, the confinement was found to degrade to levels comparable to gas fueled plasmas[2]. As pointed out by Sengoku[2], the confinement degradation could be due in part to a broadening of the plasma density profile that results from reduced penetration at higher temperature. On TFTR[3,4], no significant improvement was observed at up to 7 MW of beam power. However these experiments were characterized by unfavorable plasma heating profiles resulting from poor beam penetration at the elevated densities associated with pellet injection.

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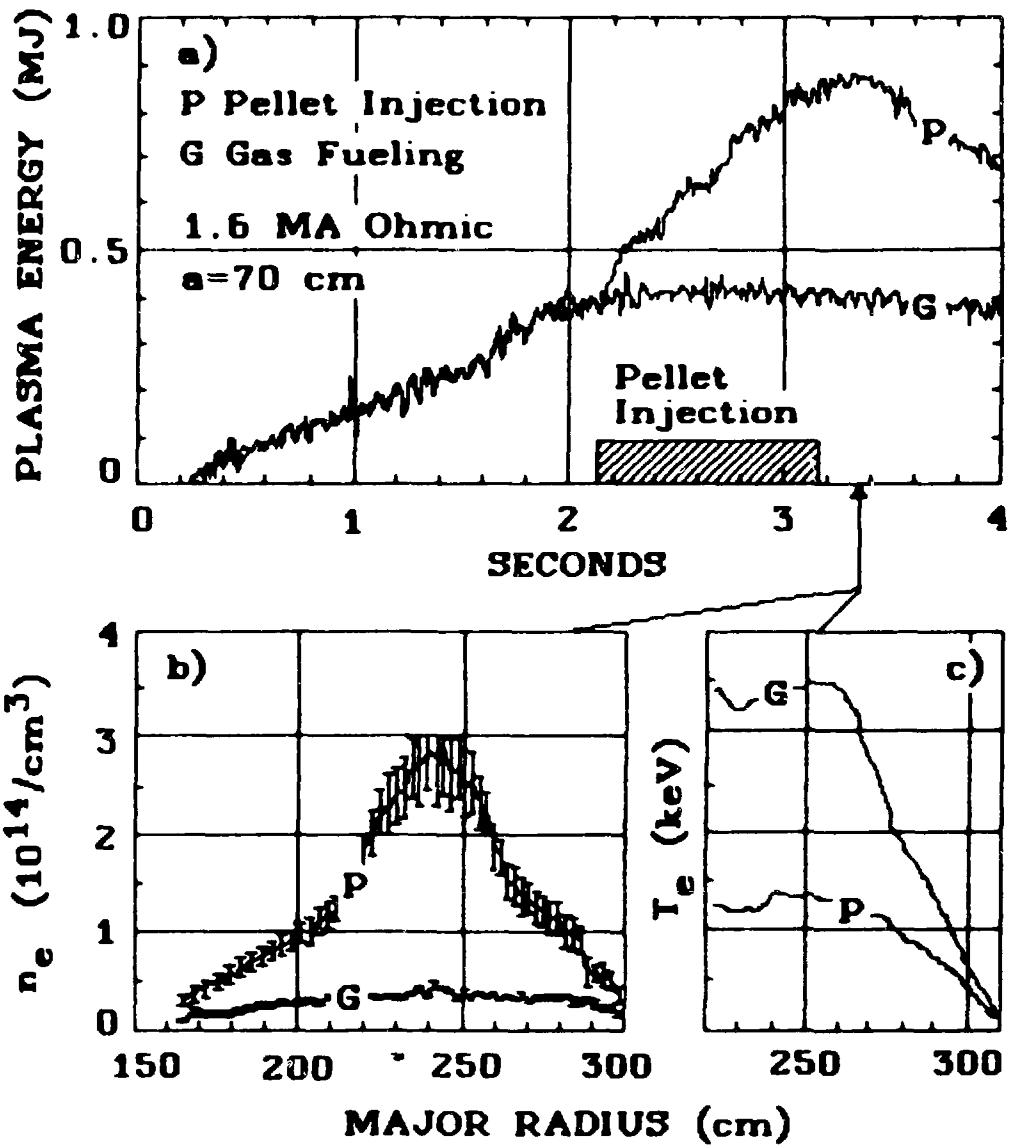
FIGURE CAPTIONS:

Fig. 1. Comparison of plasma stored energy and electron density and temperature profiles for pellet injection and gas fueling cases on TFTR.

Fig. 2. Scaling of energy confinement time with line average density for pellet and gas fueled ohmic TFTR discharges and comparison with Goldston scaling[8].



PLASMA ENERGY (MJ)
1.0
0.5
0
a)
P Pellet Injection
G Gas Fueling
1.6 MA Ohmic
a=70 cm
P
G
Pellet Injection
0
1
2
3
4
SECONDS
b)
n_e (10^{14}/cm^3)
4
3
2
1
0
P
G
150
200
250
300
c)
T_e (keV)
G
P
250
300
MAJOR RADIUS (cm)

Fig 1

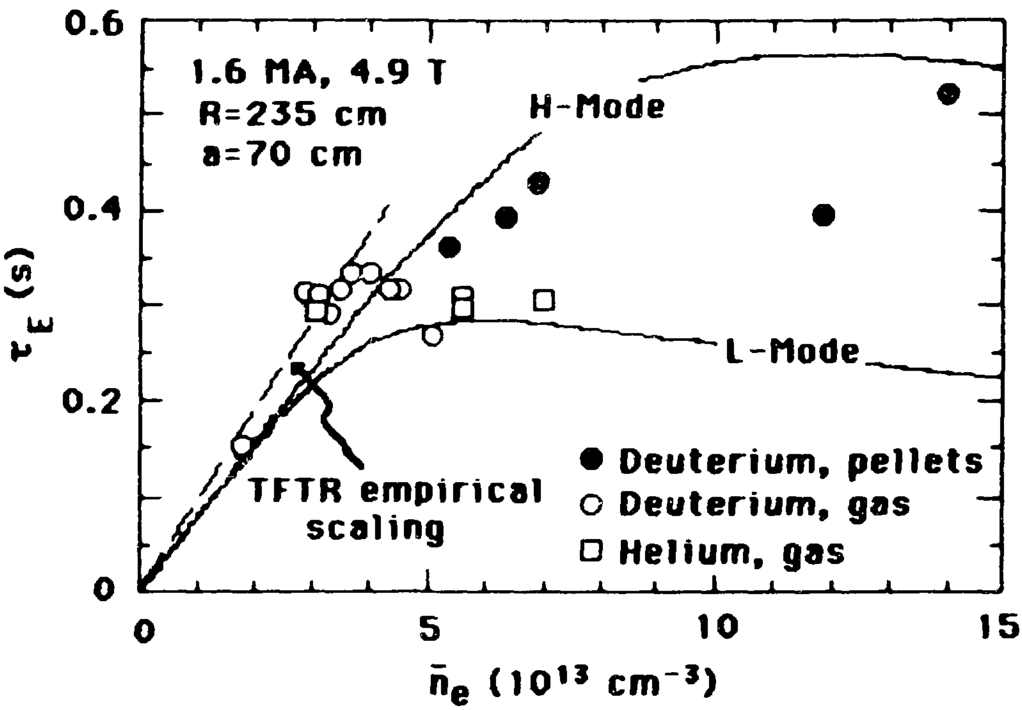

0.6
0.4
0.2
0
τ_E (s)
1.6 MA, 4.9 T
R=235 cm
a=70 cm
H-Mode
L-Mode
TFTR empirical scaling
Deuterium, pellets
Deuterium, gas
Helium, gas
0
5
10
15
$\bar{n}_e$ (10^{13} cm^{-3})

Fig 2