Burning Criteria of D-^{3}He ST Reactor

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Fusion reactors using D-^{3}He fuels are attractive because of significantly reduced neutron and the elimination of tritium fuel. In early works for D-^{3}He tokamak reactors, peaked the temperature and the density profiles have been considered. The plasma current with the bootstrap current fraction of 100 % is preferable for the steady state tokamak operation. So, it can be considered that the steady state tokamak reactor has internal transport barrier. This paper will present the criteria for D-^{3}He tokamak reactors using the energy and the particle balance equations. Considering recent improvements of tokamak research, new assumption of this paper are as follows: (1) the temperature and density profiles are ITB type; (2) the bootstrap current fraction is 100 %; (3) the confinement time (τ_E) is γ_{HH} times of IPB98(y,2) scaling; (4) the particle confinement time (τ_p) is τ_p~2 τ_E. Equations are solved numerically starting from the initial condition as n_{e0}~2x10^{20} m^{-3} and T_{e0}~80keV with give fueling rate of D and ^{3}He. When the system is stable, the density and the temperature settle down to steady state.

When the ^{3}He density is 25% of whole ion density the lowest T_i/T_e that is about unity can be obtained. In most cases the hot ion mode (T_i/T_e > 1) and the high central beta are required for the steady burning D-^{3}He reactor. As the impurity density increases the required T_i/T_e increases. The required T_i/T_e d is almost constant in the wide range of major radius (R). In a D-^{3}He reactor, the radiation loss (Bremsstrahlung and the synchrotron radiation) is the major energy loss mechanism. The alpha heating power increases as the T_i increases and the radiation loss power decreases as the T_e decreases. Therefore the hot ion mode is necessary to obtain the steady burning D-^{3}He reactor.

Traditionally, the beta value has been considered as the most important parameter for the D-^{3}He reactor. In order to increase the alpha heating power, the beta or the toroidal field (B_t) should be increased. In this calculation, as the B_t increases, the required central beta (β_0) reduces. As the radius of the ITB foot-point reduces with β_0=1, the required γ_{HH} increases to obtain burning plasma. In this case, the averaged beta decreases with the same β_0. Therefore the averaged beta is not important, but high β_0 is required to burn D-^{3}He plasma.

As the γ_{HH} increases, the required B_t and R are reduced. From the view point of reactor engineering, the coil field (B_{coil}) is more important than the B_t. The minimum coil field B_{coil} for a particular R is B_{coil} =21.2 $R_c^{-0.86}$ for the D-^{3}He reactor with γ_{HH}=3; B_{coil} =10.3$R_c^{-0.89}$ for the D-T reactor with γ_{HH} =1.5, where R_c is the core radius, as $R_c = R - a - d_s$, a is the minor radius, and d_s is the thickness of the shield. In this case the fusion power is 2.3GW for the D-^{3}He reactor, and 5GW for the D-T reactor. So, the D-^{3}He reactor requires two times higher coil field and γ_{HH} than the D-T reactor, but the output power is half.

In order to obtain ST D-^{3}He reactor, some improvements are required in the coil field, the confinement improvement factor and the central beta. The most critical condition is the hot ion mode (T_i/T_e > 1).