Research Inventy: International Journal of Engineering And Science
Issn (e): 2278-4721, Issn (p):2319-6483, PP: 06-09
www.researchinventy.com

Study of plasma density and diffusivity effect on fluctuationand transport in boundary region in Aditya tokamak

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Abstract. *Nuclear fusion is the natural process that occurs in sun, stars and Magnetically confined tokamak are the machines to obtain nuclear fusion by confining plasma to harness fusion energy, which will be a source of clean energy in future. Many machines are developed and many research is going on to achive the controlable fusion process worldwide including a machine called Aditya tokamak in India. The boundary region in tokamak called the Edge and Scrape-Off Layer (SOL) region which has very complex physics and engineering issues and depends on many plasma parameters like plasma density, plasma temperature, input power, plasma diffusivity and many others [16]. In this article the edge and SOL plasma fluctuation and stability is discussed in Aditya tokamak and it's effect on some of these parameters and the importance of plasma transport and plasma recycling is discussed. The role of plasma diffusivity, plasma density in edge and SOL plasma fluctuations is discussed for Aditya tokamak configuration, and its role in confinement and stability. Some of these discussions are based on previous simulation and experiments on Aditya tokamak boundary region and its importance to other fusion grade Machines [6, 8].*

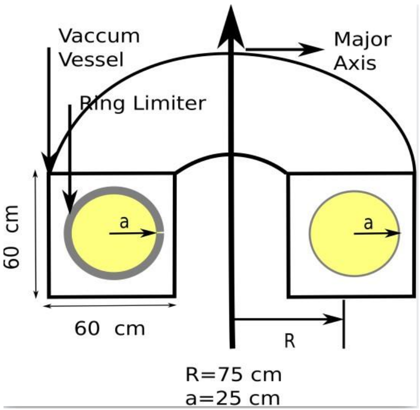
I. Introduction

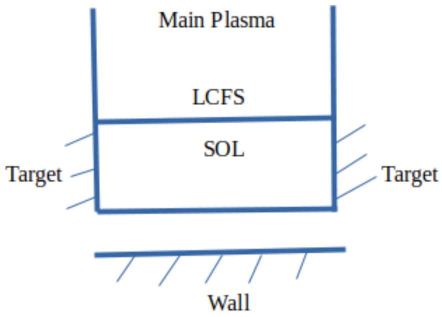
Nuclear fusion process in stars, sun are due to high gravitational force when two atomic nuclei combine with strong nuclear force, but to obtain fusion process in earth machines are needed in which mixture of deuterium and tritium is fused in the form of a plasma, and required to control the plasma to sufficient time to obtain power from fusion. Generally three factors are necessary to have a sustained fusion i. e plasma density, plasma temperature and energy confinement time commonly known as Lawson's criteria. There are many machines under operation and construction worldwide to achieve this natural process, but most advanced machine in fusion is called tokamak, and many such machines are in operation in many developed and developing counties including India [1, 9, 15, 16].

The tokamaks use high magnetic fields to achieve improved plasma confinement and are generally 2D symmetric toroidal magnetic field configuration, but due to some plasma facing components the plasma sometimes become 3-D in nature [1, 3]. Aditya tokamak present at Institute for Plasma Research, Gujarat, India has a machine with rectangular wall and circular plasma due to presence of a plasma facing component called limiter initially now upgraded to a machine having circular wall and circular plasma to reduce plasma recycling and better control of plasma and to improve plasma confinement duration. The boundary region in these machine call Scrape Off Layer (SOL) and has open magnetic field line, but the magnetic field line pattern varies from one machine to another due to which the SOL region is very complex physics and engineering issues [4, 12, 16]. 3-D character of Edge and Scrape-off Layer plasma transport properties is seen and observed in Aditya tokamak [7, 15]. In the machine the plasma is not controlled and for this many efforts and dedicated experiments and simulations are going on parallel to understand the plasma properties. SOL width is a region formed in boundary are strong indicator of plasma diffusivity and plasma density and also helps to control the heat and particle flux on wall and limiter as reported in ITER tokamak simulations [1, 2, 11].

In this article we will first discuss briefly about Aditya tokamak and complex SOL in Aditya machine present in India, following effect of plasma density and plasma diffusivity on plasma transport in Aditya SOL region based on previous experiment and simulations in the device following summary and conclusions.

1. Aditya tokamak and complex SOL



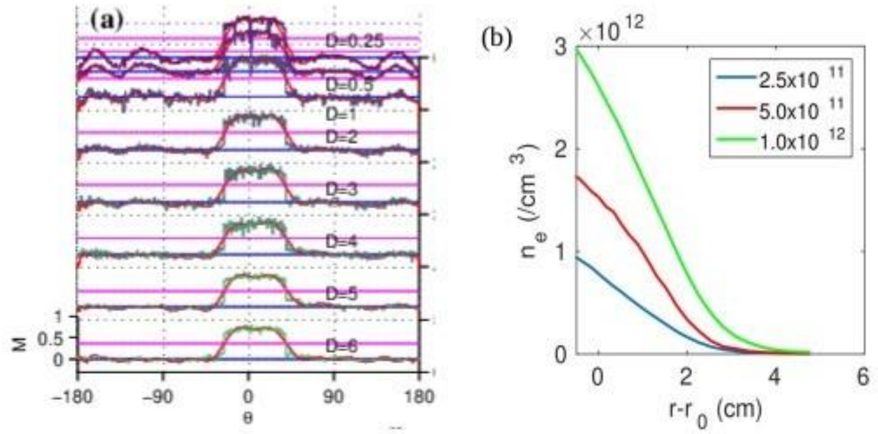


[Left hand side Fig.1 is the Schematic of Aditya ring limiter tokamak, Right hand side Fig.2 is the simple 1D slab model of SOL region]

Aditya is a medium size tokamak having major and minor radii of 75 cm and 25 cm, with a maximum toroidal magnetic field of 0.7-0.8 T at the center called magnetic axis and poloidal magnetic field one tenth of toroidal magnetic field [7]. In Aditya discharges a slight shift of the plasma strike-point from the exact $\theta = 0$ (mid-plane) location is generally seen depending on the orientation of the toroidal magnetic field and plasma current [7, 16]. Many important physics and engineering conclusions to National and International fusion research community is given and now recently the machine is upgraded to Aditya-UG. Initially the machine has a rectangular vessel in whole 360 degree and a circular plasma facing component limiter is placed at one toroidal location, due to which a circular plasma is generated in the vessel. Toroidal magnetic field is generated by rectangular copper coils surrounding the vessel and a plasma current is generated by transformer action in the machine. The working gas Hydrogen is used in the machine in all the plasma discharges. Many diagnostics facilities are used to measure different plasma parameter like plasma density, electron temperature, Mach number, and others. Many important experiments like intermittence of plasma turbulence and gas puff induced plasma suppression and many others [6–8, 16] are already reported. The discharge duration is some 300-400 milliseconds and all the diagnostics measure all the plasma parameters within this time period. The boundary region in this machine due to presence of rectangular wall and limiter is very complex as already discussed in Bibhu. et. al Nucl. Fusion (2015) [15]. The 1D simple slab SOL region is shown in Fig.2. Previous analysis is done considering this slab model which gave many important results but it was not complete due to complexity of Aditya SOL, So a detailed 3D simulation study is done later on as reported [4, 5]. Different types of plasma flow in the machine is shown such as ExB flow, Grad P, PS flows are reported in the machine by Sangwan. et.al Physics. Plasmas (2012, 2013, 2014).

The transport of plasma from center of machine called core region to wall region depends on various factors at edge region such as edge density, power crossing the LCFS (Last close flux surface), diffusivity and many other parameters. The effect of plasma density and diffusivity on plasma transport in Aditya SOL region due this this complex field line patterns is discussed in Bibhu. et. al Phys. Plasmas (2017). The density asymmetry in Aditya cross- section is observed experimentally and also shown from 3D simulation study and related SOL-Width variation is presented in Bibhu. et. al JPCS (2017). In this article some important points are discussed based on our previous simulation results from a 3D model which is a fluid plasma neutral model for Aditya tokamak to give support to some of previous experimental results measured for the machine Aditya and gave some predictions for Aditya- UG and other machines.

2. Density and diffusivity effect on Plasma transport in Aditya



[Fig.3 (a) shows the variation of Mach number with increase in diffusivity in SOL region
(b) Radial density profile with increase in input density, obtained from EMC3 simulation]

Plasma fluctuations and turbulence in edge and SOL region in tokamak are common observations in large number of tokamaks including Aditya tokamak. The origin of these fluctuations and their effect on plasma transport in not clear in many fusion grade machines including tokamak Aditya. In Aditya to reduce these plasma fluctuations gas-puff is inserted and fluctuation is reduced and is reported by Rjha. et. al PPCF (2009). There are other methods like Electrode biased experiments, pellet injection and many other methods also used to reduce these fluctuations and already used in the machine [6-8]. The physics behind these fluctuation suppression is not clear in many machines. In this section we try to explain fluctuation suppression based on simulation results as done in a 3D model EMC3 for Aditya tokamak [3–5, 10, 11, 13, 14].

In Aditya experiments as gas puff is increased at the edge region then actually a increase in density is seen in edge region which reduces the perpendicular particle flux and increases the particle confinement time as published and reported Rjha. et. al PPCF (2009). A reduction of fluctuations and increase of particle confinement time from experiments is observed in Aditya as explained but is not clear. The simulated poloidal variation of Mach number with diffusivity is shown in Fig. 3 (a) and this clearly shows that as diffusivity is increased the Mach number amplitude decreases due to high parallel flow shear and in Fig. 3(b) Radial density profile in SOL with rise in input density which shows density gradient decreases with rise in input density, which is a indication of fluctuation suppression as measured during gas- puff experiments. In experiments from Aditya from its edge plasma fluctuation profiles which are measured using different probe arrangements, the diffusivity and viscosity are determined using fick's law and some simple mathematical relations. But in simulations we vary diffusivity and will see the effect on plasma fluctuations on radial and poloidal direction [8]. Similarly the gas-puff experiments where gas-puff is located at one or two location but in simulation we vary the density at whole region.

The radial density profiles from simulations available used to determine the analytic relation between diffusivity and Particle flux by the mathematical relation obtained from 1D plasma

equation as $\Gamma_r = -D_\perp (\partial n/\partial \theta)$ where diffusivity is $D_\perp$. From this equation if the density

gradient becomes flat as obtained from 3D model results and keeping diffusivity constant, then the plasma particle flux will reduce accordingly. Similarly particle confinement time increases as density gradient decreases. This is what is observed and measured from spectroscopic and probe measurements in Aditya tokamak, if we put gaspuff in edge of tokamak plasma as reported by rjha. et. al PPCF 2009, but simulations are done considering many approximations, but still results are relevant.

II. Summary and conclusions

Plasma fluctuations in SOL region in tokamak plasma is common observation from probe measurements and spectroscopic observations in many fusion grade devices including Aditya tokamak in India. Plasma fluctuations and transport analysis in the Boundary region of non- axisymmetric toroidally discontinuous poloidal ring-limiter configuration of Aditya tokamak plasma are discussed with support from previous 3D simulations and experimental observations in the device as reported by rjha. et. al PPCF (2009). The current analysis is with increase in density and diffusivity parameter at the SOL boundary of fusion device

Aditya for old configuration and it's predictions for upgraded version with simple plasma equations. From these analysis as density at edge region rises, then density gradient decreases as a result the overall perpendicular plasma flux decrease towards wall and increase particle transport time, but plasma transport and recycling flux increases near limiter location. This discussion and analysis based on 1D fluid plasma equations validate to some extend to the understanding of previous experimental and simulation done for Aditya tokamak.

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