G Model
FUSION-8460; No. of Pages 5
ARTICLE IN PRESS
Fusion Engineering and Design xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Fusion Engineering and Design
journal homepage: www.elsevier.com/locate/fusengdes

Development of wall conditioning and impurity monitoring systems in Versatile Experiment Spherical Torus (VEST)

H.Y. Lee [a], J. Yang [a], Y.G. Kim [a], S.M. Yang [a], Y.S. Kim [a], K.H. Lee [a], Y.H. An [b], K.J. Chung [a], Y.S. Na [a], Y.S. Hwang [a,*]

[a] Seoul National University, Seoul, South Korea
[b] National Fusion Research Institute, Daejon, South Korea

HIGHLIGHTS

- The baking for partial wall heating and H_2/He GDC systems are developed in VEST.
- The RGA and OES systems for monitoring impurities are constructed in VEST.
- The partial baking and He GDC show limited effects on plasma characteristics.
- H_2 GDC above 4 h enables the longer plasma current duration up to ∼15 ms.
- After H_2 GDC, the discharge should be conducted within 3 h from treatment.

ARTICLE INFO

Article history:
Received 13 September 2015
Received in revised form
17 December 2015
Accepted 15 January 2016
Available online xxx

Keywords:
Wall conditioning
Impurity monitoring
Glow discharge cleaning
Baking
VEST

ABSTRACT

Wall conditioning and impurity monitoring systems are developed in Versatile Experiment Spherical Torus (VEST). As a wall conditioning system, a baking system covering the vacuum vessel wall partially and a glow discharge cleaning (GDC) system using two electrodes with dc and 50 kHz power supplies are installed. The GDC system operates with hydrogen and helium gases for both chemical and physical desorption. The impurity monitoring system with residual gas analyzer (RGA), operating at <10^{-5} Torr with a differential pumping system, is installed along with the optical emission spectroscopy (OES) system to monitor the hydrogen and impurity radiation lines. Effects of these wall conditioning techniques are investigated with the impurity monitoring system for ohmic discharges of VEST. The partial baking and He GDC show limited effects on plasma characteristics but sufficient H_2 GDC above 4 h enables the longer plasma current duration up to ∼15 ms within 3 h from the end of treatment.

1. Introduction

Wall conditioning is known to be a common tool to improve plasma performance in most fusion devices [1]. In fusion research, wall conditioning is critical for impurity removal to decrease radiation cooling, particle recycling control from wall retention [2], and high beta operation [3]. Various techniques for wall conditioning have been considered to control low Z impurities including oxygen for preventing plasma performance degradation [4,5].

Versatile Experiment Spherical Torus (VEST) has been built to be a low cost, compact, educational fusion research device at Seoul National University (SNU) and the main device parameters are $R_0 = 0.4$ m, $R_0/a > 1.3$ and $B_T = 0.1$ T on axis [6]. First plasma start-up experiments in VEST have been successfully carried out with the conventional start-up scheme and I_p of ∼70 kA with pulse duration of ∼10 ms has been achieved and the elongation and edge safety factor are estimated to be 1.6 and 3.7, respectively [7]. With successful ohmic startup experiments in VEST, neutral beam injection (NBI) system for advanced tokamak research is under preparation. For better coupling of the NBI heating, it is essential to make high-current long-pulse discharges as a target plasma with high density, which requires effective wall conditioning.

Oxygen impurities are identified to be one of the main impurity species in VEST. The impurity monitoring systems with residual gas analyzer (RGA) and optical emission spectroscopy (OES) are installed to monitor impurity levels as well as species. The RGA is used to keep a partial pressure log of various gas species. Partial pressure of impurities such as water vapor and oxygen, are compared to observe the effect of wall conditioning techniques. Line

* Corresponding author. Tel.: +82 2 880 6276; fax: +82 2 889 2688.
E-mail addresses: brbbebbero@snu.ac.kr (H.Y. Lee), yhwang@snu.ac.kr (Y.S. Hwang).

http://dx.doi.org/10.1016/j.fusengdes.2016.01.020
0920-3796/© 2016 Elsevier B.V. All rights reserved.

emission monitoring systems are essential for the simultaneous measurement of impurities during the discharge. The OES systems with a fast camera and line monitoring systems are prepared to measure the global plasma movement and temporal change of the light intensity, respectively.

For the removal of water, considered as a main source of oxygen impurities, a baking system utilizing heat tape is installed in VEST covering the vacuum vessel partially due to the complex configuration with O-rings. A glow discharge cleaning (GDC) system operating with both dc and 50 kHz powers is installed to remove the oxygen via chemical desorption [4,8] with hydrogen GDC and to reduce impurity and gas retention via physical desorption [9] with helium GDC. Effects of these wall conditioning systems are studied by comparing discharge characteristics with impurities quantified with the impurity monitoring systems.

Sections 2 and 3 describe installed wall conditioning systems and the impurity monitoring systems, respectively. Effects of each wall conditioning method are discussed in Section 4 by comparing discharge characteristics with the information from the impurity monitoring system. Finally a conclusion will be given in the last section.

2. Wall conditioning systems

Wall conditioning systems in VEST focus on reducing oxygen impurities. Baking system is considered with partial coverage of the VEST vessel to remove water and a GDC system with dual power supply is prepared to make low pressure operations feasible. Two systems are described in detail.

2.1. The baking system

As known an effective method to remove water in the vacuum vessel, baking technique is conducted in various devices with different methods. Generally high temperature baking over 150 °C is known to have a wall cleaning effect [10] while stand-alone baking with low and moderate temperature was reported to have no effect on wall conditioning [4]. However, KSTAR reported that temperature of about 110 °C had beneficial effects on wall cleaning [11].

In VEST, due to the vacuum components such as O-ring, baking temperature covering whole chamber is limited below 70 °C regardless of heating methods. Since the low temperature baking less than 100 °C seems to be ineffective [4], local heating of the vacuum vessel is considered while keeping temperature near the O-ring low. With flexible silicon rubber heater, the temperature is increased up to 180 °C locally in the applied region without unwanted heating of vacuum components with O-ring.

The flexible heat tape is cut with appropriate shape in the consideration for the locations of O-rings and vacuum ports and installed on the VEST vessel as shown in Fig. 1. Thermocouple thermometer is placed between the heat tape and the O-rings for ensuring safe condition of O-rings. The heat tape is installed near the port 7 and 8 of the center chamber partially as indicated in Fig. 2. Covering area of the baking system is about 7160 cm^2, one-sixth part of the central chamber, and maximum heating power of about 5.7 kW is used. The baking system consists of 4 pieces of heater, 4 units of control systems and 4 units of temperature sensors, which may be increased after evaluating the effect.

2.2. The GDC system

Typical techniques of H_2 GDC using chemical desorption to remove the oxygen and He GDC for physical desorption of impurity and removal of gas retention have been implemented in VEST.

Fig. 1. Baking system in VEST.

Novel design with two power supplies of dc and rf (50 kHz) are utilized in the GDC system, making GDC experiments under turbo molecular pump (TMP) pumping possible by operating at the pressure of below 75 mTorr. Gas breakdown is initiated using rf power supply at lower pressure of 30 mTorr, and then the glow discharge is sustained with both rf and dc power supplies. In this design, it is possible to operate TMP for better pumping capability during GDC.

Fig. 3 shows the GDC system schematically. Two electrodes of 24 mm in diameter which are located in the port 8 of the upper chamber and the port 12 of the lower chamber depicted in Figs. 2 and 3, respectively are used to provide a dc voltage and a 50 kHz modulated voltage. Since the plasma frequency is much higher than the modulated frequency, this method is different from the typical RF-GDC methods [12]. The rf modulated power is used for easy and economical breakdown at lower pressure of 30 mTorr while high voltage and current of DC power supply is needed for breakdown. After the breakdown, both electrodes are used to provide 1.5 A of anode glow current onto the total surface area of 15 m^2 in VEST, resulting in a current density of 0.1 A/m^2,

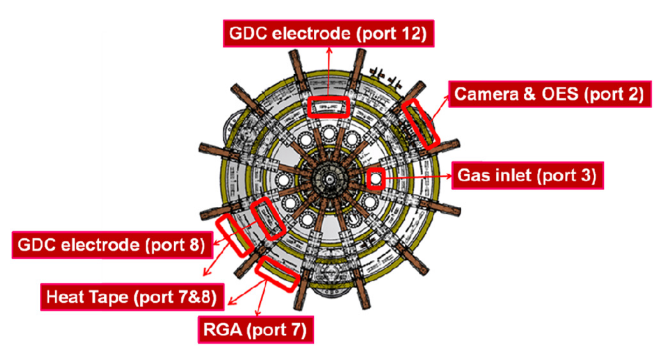

Fig. 2. Locations of the wall conditioning and impurity monitoring systems in VEST.