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Liquid tin limiter for FTU tokamak

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HIGHLIGHTS

- First steady state operating liquid tin limiter TLL is under study on FTU tokamak.
- The cooling system with water spray coolant for TLL has been developed and tested.
- High corrosion resistance of W and Mo in molten Sn confirmed up to 1000 °C.
- Wetting process with Sn has been developed for Mo and W.

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ABSTRACT

The liquid Sn in a matrix of Capillary Porous System (CPS) has a high potential as plasma facing material in steady state operating fusion reactor owing to its physicochemical properties. However, up to now it has no experimental confirmation in tokamak conditions. First steady state operating limiter based on the CPS with liquid Sn installed on FTU tokamak and its experimental study is in progress. Several aspects of the design, structural materials and operation parameters of limiter based on tungsten CPS with liquid Sn are considered. Results of investigation of corrosion resistance of Mo and W in Sn and their wetting process are presented.

The heat removal for limiter steady state operation is provided by evaporation of flowing gaswater spray. The effectiveness of such heat removal system is confirmed in modelling tests with power flux up to 5 MW/m2.

1. Introduction

Development of Plasma Facing Components (PFC) is the main problem to be solved for steady state operating fusion reactors because many researches indicates that no solid material, including tungsten, can operate under expected conditions for a reasonable period.

As it indicated in final reports of the EFDA power exhaust (PEX) tasks, the liquid metals in a matrix of Capillary Porous System (CPS) could be a viable solution for the plasma facing materials. The key advantage of liquid metals is the possibility of surface renewal. The CPS provides it by the natural way owing to capillary forces and ensures the liquids confinement on PFC surface [1].

Up to now, only liquid Li based PFC has been intensively studied in tokamaks [2–5], stellarator [6] and demonstrated promising results in plasma parameters improvement and plasma facing surface long-life operation. The upper limit of the operation window for Li based PFC is determined by surface temperature of 550 °C when Li flux to the plasma is on the acceptable level.

The liquid Sn also has a high potential for application as the PFC base material owing to its low chemical activity. The high boiling point of Sn gives the hope in higher operation limit in comparison with Li and a good capability for withstanding of heat load as high as tens of MW/m^2. However, plasma pollution by Sn as high Z material is possible in consequence of ion sputtering. Therefore, all these aspects should be investigated experimentally in tokamak conditions. This is the main reasons for creating and experimental study of PFC on the base of liquid Sn.

The comparison of the behaviour of PFC with liquid Li and Sn under tokamak conditions and their influence on plasma parameters are supposed for further experiments in FTU tokamak. Several aspects of the PFC design, applied structural materials, operation parameters should be considered taking into account the physical-chemical properties of Sn.

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2. Design of liquid Sn limiter for FTU

First steady state operating limiter based on the CPS with liquid Sn is under development and construction for FTU tokamak. This activity is the extension of ideas has been realized in previous version of actively cooled liquid lithium limiter (CLL).

The tin liquid limiter (TLL) design meets the following demands: liquid state of Sn on operation condition; steady-state operation under power flux up to 10 MW/m^2 with opportunity for power flux monitoring; possibility of plasma facing surface temperature control and stabilization at plasma effect on desirable level in the range of 300–900 °C; easy movement with respect to LCMS of plasma column; possibility of visual inspection and Sn refilling.

The principal component of TLL design is the in-vessel plasma facing element (Fig. 1) covered with CPS made from W felt (pressed W wire with diameter of 50 μm and pore size of 30 μm) and filled with Sn. Taking into account high corrosive activity of Sn to structural materials the Sn filled CPS is installed on Mo protective screen. The element is equipped with electrical heater to keep the original liquid state of Sn ($T \geq T_{melt} = 232$ °C) and cooling channel for effective removal of incoming heat during plasma discharge.

The effective cooling of in-vessel element is performed by evaporation of fine-dispersed cooling media (water spray in gas) that comes from an atomizer incorporated into the element structure. Such cooling scheme is compatible with high temperature operation, ensure the low pressure of cooling media and quick response of the cooling system on temperature change of plasma facing surface.

The out-vessel system permits proper operation of an in-vessel element at design conditions with automatic remote control of electrical heater and atomizer. A data acquisition system with detectors of temperature, pressure and Langmuir's probes provide monitoring of the limiter operation parameters. The colorimeter-accumulator is included in the system for monitoring of the incoming energy flux from plasma on the TLL surface. Scheme of the out-vessel system with calorimeter is presented in Fig. 2. According to the supposed scenario of the system operation the energy flux incoming during plasma discharge is removed from the in-vessel element and comes to the calorimeter as the flow of heated mixture of vapour and spray of cooling media. This mixture is bubbled through the specified volume of water in the calorimeter. Change of water temperature δT in the calorimeter during system operation permits estimate the value of incoming energy ***Qest*** from the energy balance equation developed for calorimeter and including all expected energy losses.

The main parameters of the limiter presented in Table 1.

Table 1
Main parameters of TLL.

Parameter	Value
Power flux, MW/m^2	up to 10
Operation time, s	up to 5
Initial surface temperature, °C	250-300
Surface temperature at plasma effect, °C	300-900
Removal heat to cooling system, J	4.25 10^5
Plasma facing area, cm^2	~85
Liquid Sn volume, cm^3	~100
Limiter size LxWxH, cm	27 × 2.6 × 40

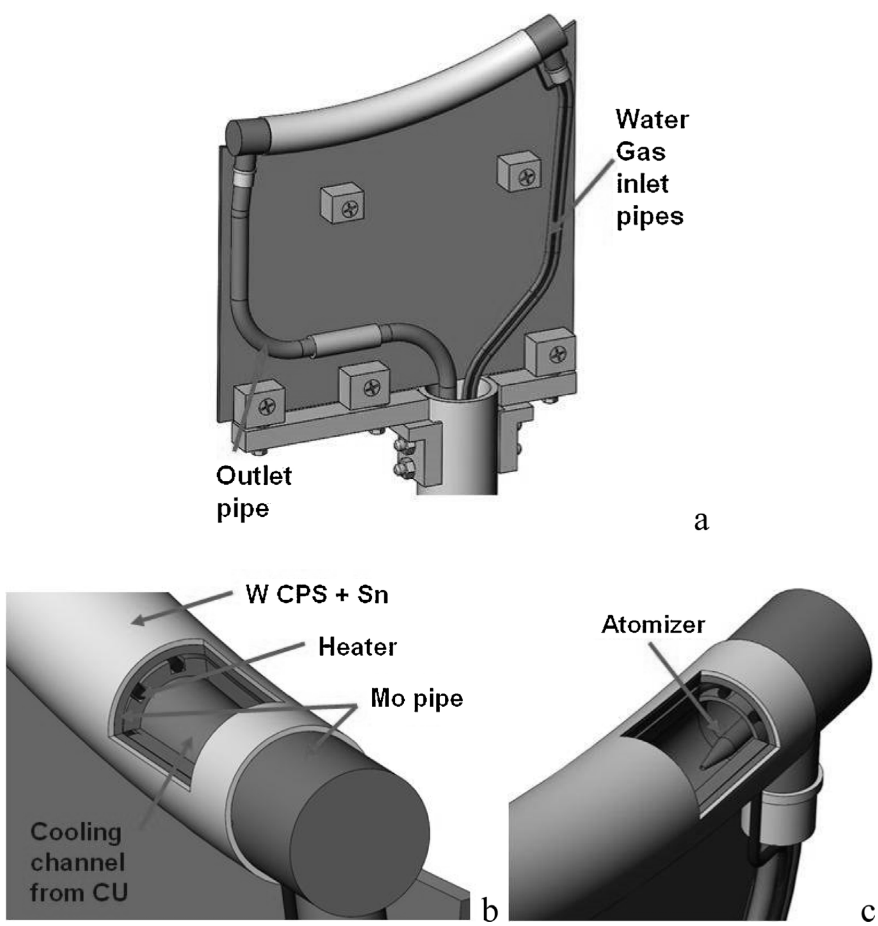

Fig. 1. View of in-vessel plasma facing element of TLL.