FEASIBILITY STUDY OF TUNGSTEN-WATER/AIR REACTION IN DEMO CONDITIONS

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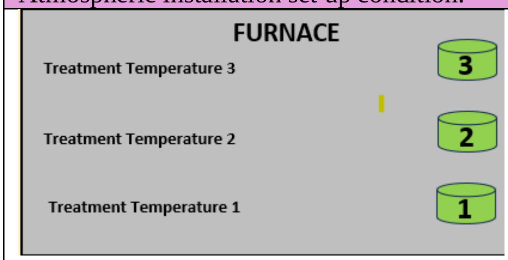
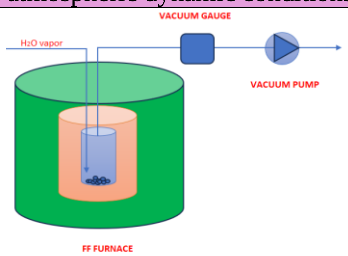
The oxidation behavior of tungsten (W) in the presence of water vapor (H_2O) at high temperatures is a critical concern for nuclear fusion applications, particularly in maintaining the integrity of plasma-facing components. In fusion reactors like DEMO, explosion risks pose a significant challenge, especially within the vacuum vessel, where hot tungsten surfaces—including dust—may interact with air, steam, or water. Recognizing the importance of addressing nuclear safety from the earliest stages of reactor design, this issue has become a key focus within the EUROfusion program, specifically under the Work Package for Safety and Environment (WP-SAE), in a consolidated collaboration in the last several years on these topics.
Air may come from a LOVA (Loss of vacuum accident) accident scenario while water from LOCA (Loss of coolant accident) scenarios. Particularly LOCA scenario led to the generation of hydrogen that added to the inventory of tritium present in the vacuum chamber and an eventually succeeding LOVA represent a risk of explosions [1]. This condition requires accurate monitoring and control to mitigate explosion risks. Moreover, exposure to such conditions can lead to the formation of volatile tungsten oxides, notably tungsten trioxide (WO_3), which poses risks due to potential environmental release.
The objective of this work is to assess the key parameters that influence hydrogen production from H_2O tungsten interaction in LOCA scenarios under DEMO conditions. This includes evaluating the effects of tungsten material temperature (bulk and dust) and affected surfaces as well as conducting experiments to complement the existing experimental data.
It is well known that tungsten oxidation rate expressed in terms of H_2 production flow rate as during the oxidation of tungsten in presence of H_2O vapor hydrogen is produced according to the reaction (when it reaches the complete state of oxidation): $W(s) + 3H_2O \rightarrow WO_3(s) + H_2(g)$
The H_2 production flow rater is a function of T, and H_2O pressure, p_{H_2O}, through an Arrhenius equation [2] [3] [4] as follows:

$$F_{H_2,production\ rate} = A \cdot e^{\frac{E}{RT}} \cdot p_{H_2O}^{m};\ [\frac{L}{m^2 \cdot s}]$$

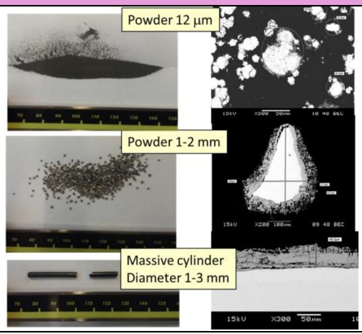
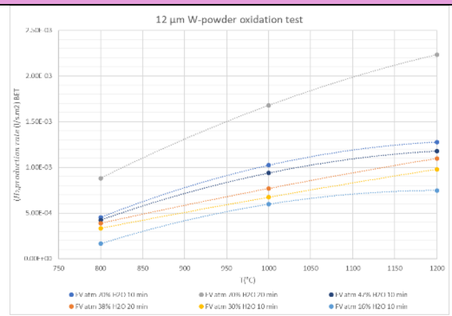
This study aims to further investigate and extend the knowledge of the oxidation of tungsten-based materials in the presence of H_2O. The research focuses on examining the effect of time, temperature, and sub-atmospheric pressure on the oxidation rate of pure tungsten within the 800˚-1200˚C temperature range.
To conduct oxidation tests at high temperatures and variable pressure conditions, a specialized reactors were designed and constructed for use within two furnace types and dedicated for atmospheric and sub-atmospheric condition. See the representation of the installation schemes in the Table 1.

Table 1 Experimental setup used for studying the oxidation of tungsten in the presence of water vapor.

Atmospheric installation set up condition.	Setup for sub-atmospheric dynamic conditions
	

The oxidation of tungsten has been studied, and the results have been analysed through various techniques. The oxidation process and the subsequent production of hydrogen has been examined using both online and offline methods. Online analysis, performed via gas chromatography, directly measured the H_2 flow rate, while offline techniques—including SEM, optical microscopy, and LECO analysis—has been used to characterize the oxidation state of the samples and indirectly estimate hydrogen production based on the amount of oxide formed.
As shown in Table 2, at higher temperatures and increased water vapor partial pressures, tungsten tends to reach a higher oxidation state. This is evidenced by the blue-violet colour of the oxide, which, according to Smolik's characterization, corresponds to a $W_{2.9}O$ oxide type [2] and is associated with a higher hydrogen flow rate produced.

Table 2: Tungsten oxidation test and analyses.

<table>
<tr><th>Oxidized tungsten sample</th><th>SEM Analysis</th><th>Hydrogen flowrate at different Temperature and time reaction</th></tr>
<tr><td></td><td></td><td></td></tr>
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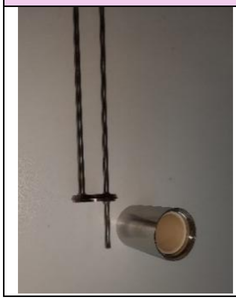
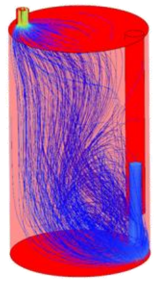
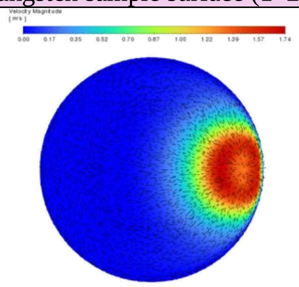
As well, CFD simulations were performed to validate the oxidation tests by analysing the fluid dynamics within the reactor under the same experimental conditions. These simulations provided insights into key parameters such as flow velocity, temperature distribution, and partial pressure, helping to characterize the reactor's fluid dynamic regime. This analysis was crucial for assessing the influence of flow conditions on the oxidation process. As shown in Table 3 the experiments conducted under sub-atmospheric conditions correspond to a turbulent flow regime and influence the tungsten oxidation rate.

Table 3: Reactor and its CFD model for dynamic sub-atmospheric test.

Reactor designed for sub-atmospheric test conditions	CFD simulation of the dynamic vacuum state under experimental test conditions.	Velocity field at 1 mm from the reactor bottom, corresponding to the level of the tungsten sample surface (1–2 mm)
		

Conclusions and future work

Preliminary tests on tungsten oxidation were conducted using both air and water vapor under atmospheric and sub-atmospheric pressure conditions. These tests provided initial qualitative and quantitative insights into the oxidation process and the associated hydrogen production rate. However, further studies are needed to expand on these findings.

The future research aims to investigate the oxidation behavior of tungsten when exposed to an oxidizing atmosphere for short durations, specifically no longer than one hour as initial observations indicate that during this phase, tungsten undergoes limited oxidation, resulting in lower hydrogen production. Additionally, the study seeks to evaluate the impact of different flow regimes on the oxidation rate and the corresponding hydrogen output. Finally, the research focuses on characterizing tungsten oxidation under sub-atmospheric conditions in a batch system to gain a deeper understanding of its behavior in such environments.

Bibliography

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