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

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ABSTRACT

The study concern an accurate evaluation of the reaction rate between Tungsten and H_2O and air as a function of conditions: temperature, total pressure, partial pressure of H_2O, substrate characteristics (e.g. specific surface area of the W). The (FV) vertical furnace with 3 different temperature zones and the (FF) molten furnace were used. A specific new reactor for sub-atmospheric pressure tests has been design and prodcued. Conditions tested ranged from 0,01bar up to 1 bar in air and in Argon atmosphere humidified up to 70% with the measurement of Hydrogen production generated during the oxidation phenomena.

BACKGROUND

The oxidation behavior of tungsten (W) in the presence of steam or air at high temperatures is a critical concern for nuclear fusion applications in accidents scenario, particularly in maintaining the integrity of plasma-facing components. In fusion reactors like DEMO, the risks of explosions, in incidents like LOVA or LOCA, pose a significant challenge, especially within the vacuum vessel, where hot tungsten surfaces including dust may interact with air and/or steam. 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.

CHALLENGES / METHODS / IMPLEMENTATION

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): $W(s)+3\,H_2O \rightarrow WO_3(s)+3H_2(g)$
The H_2 production flow rater is a function of T, and vapour pressure, $p_{(H_2O)}$ through an Arrhenius equation [2] [3] [4] as follows:

$$F_{(H2,\text{production rate})} = A \cdot e^{\frac{E}{RT}} \cdot p^{m}_{(H_2O)}\ ; \quad [\mathrm{l/(m^2 \cdot s)}]$$

There is a notable lack of data in the literature, particularly concerning tungsten dust, short exposure times (less than one hour), and experiments conducted under turbulent flow conditions. The research focuses on examining the effect of time, temperature, on the oxidation rate of pure tungsten within the 800˚-1200˚C temperature range in and atmospheric sub-atmospheric pressure . The study aims to:

- Understand mechanisms that lead to the oxidation of tungsten, especially in the early stages, the phases produced and the influence of the specific surface (Dust and Massive samples).
- Investigate morphology and chemical composition of the oxide formed in the oxidation of Tungsten at different temperature through different technique analysis (SEM, LECO, optical microscope, XRD).
- Evaluate different information from the analysis of the sample after tests to verify the possibility to derive the Hydrogen production rate as indirect measurements after test.
- Measure of oxygen concentration in the tungsten samples with an inert gas fusion (IGF) LECO apparatus was done to evaluate the hydrogen production rate according to the literature oxidation reaction.
- On-line Hydrogen measurement with micro gas chromatograph (micro-GC) apparatus. Tungsten oxidation tests

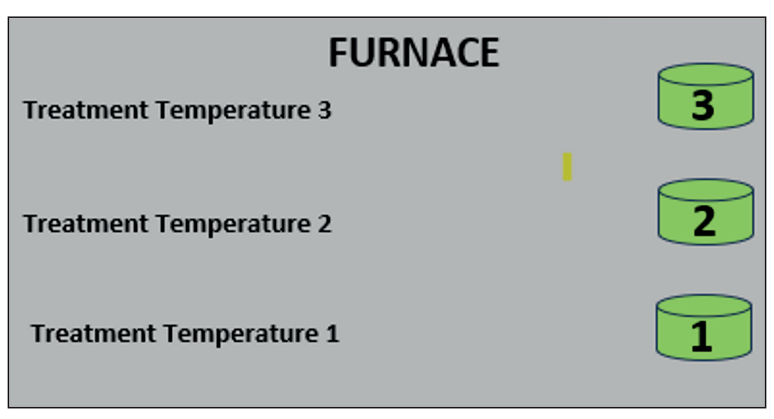
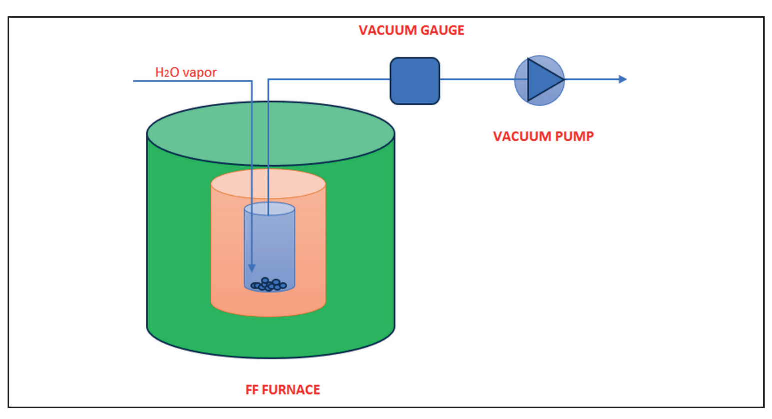
Atmospheric installation set up condition	Setup for sub-atmospheric dynamic conditions
	

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

ACKNOWLEDGEMENTS

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OUTCOME

Tungsten oxidation tests

The oxidation process and the subsequent production of hydrogen has been examined using both online and offline methods. 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 $WO_{2,9}$ oxide type [2] and is associated with a higher hydrogen flow rate produced.

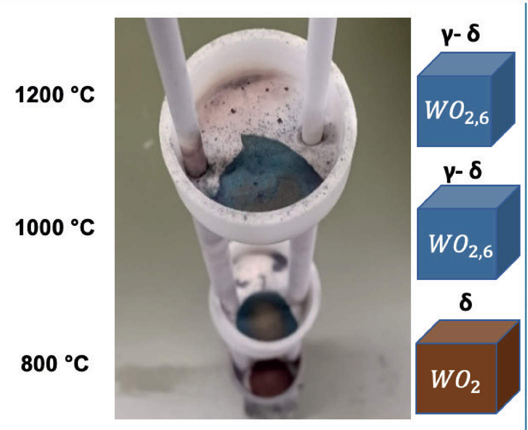
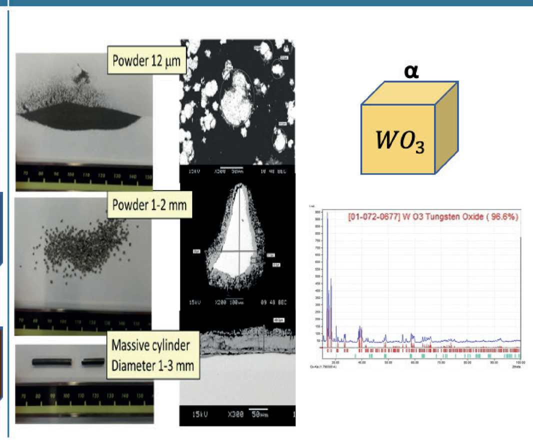
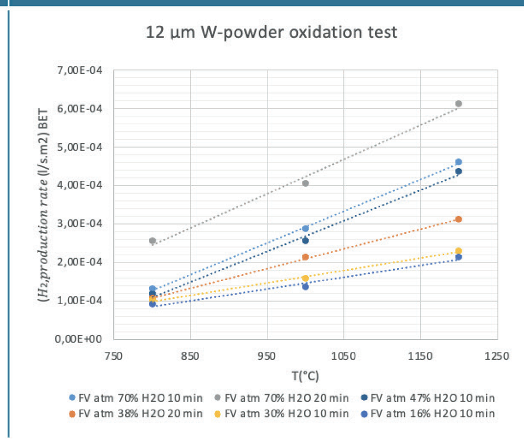
Oxidized W sample 12 µm, 30% water vapour, P 10 min test duration	*SEM and XRD; 30% water vapour, T= 1000˚ C ; P= 50 kPa, test duration 60 min;*	*H_2 flowrate at different T and test duration of W sample 12 µm*
		

Table 2: Tungsten oxidation test and analyses

CFD simulation of the sub-atmospheric reactor

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.

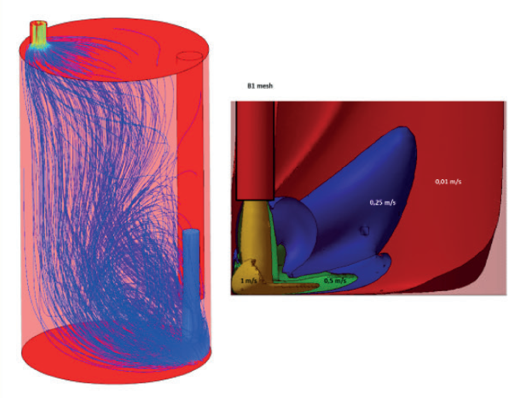
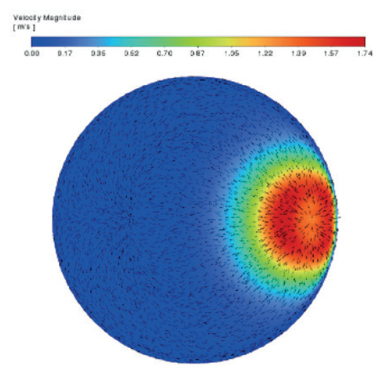
Reactor designed for sub-atmospheric test conditions	*CFD simulation of the dynamic vacuum state under experimental test conditions*	*Velocity field at 1 mm from the reactor bottom, corresponding to the level of the tungsten sample surface (1–2 mm)*
		

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

CONCLUSION

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.

REFERENCES

[1] Neill Taylor, «Lessons learnt from ITER safety & licensing for DEMO and future nuclear facility,» Fusion Engineering and Design, vol. 89, 2014. n. https://doi.org/10.1016/j.fusengdes.2013.12.030
[2] G. R. Smolik, « Tungsten alloy oxidation behavior in air and steam.,» Fusion Safety Program/Activation Products Task., (1992).
[3] V. D. Barth, «Oxidation of Tungsten.,» DMIC Report 155, (1961).
[4] C. Unal, «Modeling of heat and mass transfer in accelerator targets during postulated accidents,» Nuclear Engineering and Design, vol. 196, p. 185-200, (20 00)n. https://doi.org/10.1016/S0029-5493(99)00297-6.