Measurement of Fe solubility in LBE

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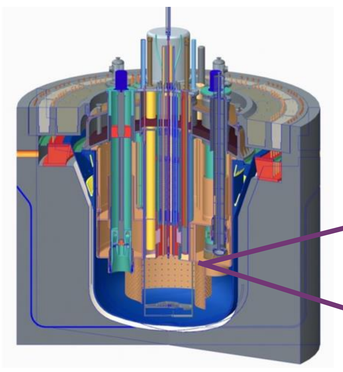
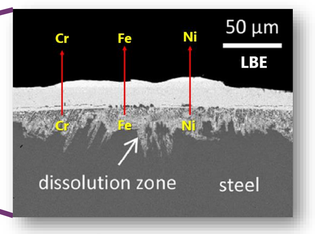
Introduction

- MYRRHA is the first prototype in the world of an Accelerator Driven System (ADS) cooled by liquid lead-bismuth eutectic alloy (LBE).



MYRRHA reactor

- LBE corrodes the structural steels of the reactor by leaching Fe and other alloying elements (Ni, Cr and Mn) into liquid metal:



LBE contamination

Steel corrosion

Dissolution corrosion

- Fe is a key impurity, affecting LBE chemistry significantly by interacting with oxygen in MYRRHA operating condition.

- Accurate measurements of Fe solubility in LBE are required to study its behavior, but available data are scarce within the MYRRHA temperature range.

- We are developing a new electrochemical method to measure accurately iron solubility in LBE at low temperatures.

Theory and Method

- Dissolved iron interacts with dissolved oxygen in LBE forming magnetite:

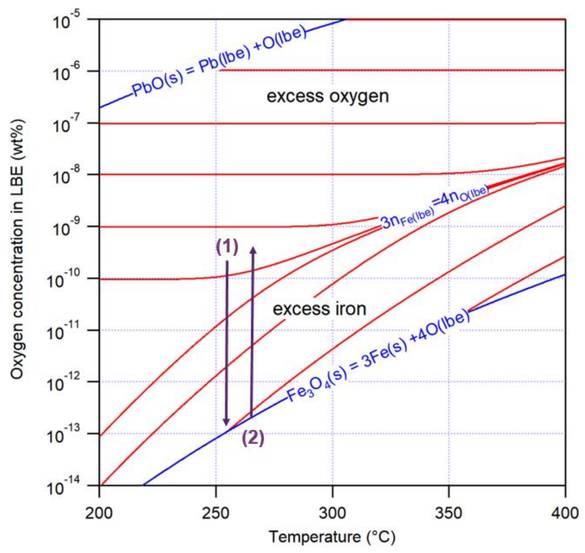
$$3\,Fe_{(LBE)} + 4\,[O]_{(LBE)} \leftrightarrow Fe_3O_4\,(s)$$

Increasing oxygen concentration in Fe-saturated LBE, the solubility product (K_{sp}) for magnetite can be obtained and subsequently be converted into solubility of iron:

$$K_{sp} = C_{Fe}^3 \cdot C_O^4 \longrightarrow S_{Fe} = \left(\frac{K_{sp}}{C_{O\,Fe_{(LBE)} \leftrightarrow Fe(s)}^4} \right)^{1/3}$$

Experimental Approach

- Experimental activities are carried out in two steps :



Oxygen concentrations for Fe-saturated LBE

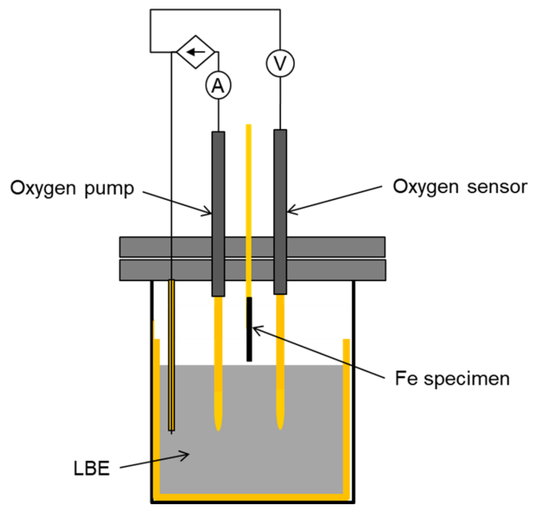
1) Oxygen removal: Fe-O interaction

Solid iron in LBE consumes oxygen

2) Oxygen addition: coulometric titration

Oxygen pump introduces oxygen in LBE

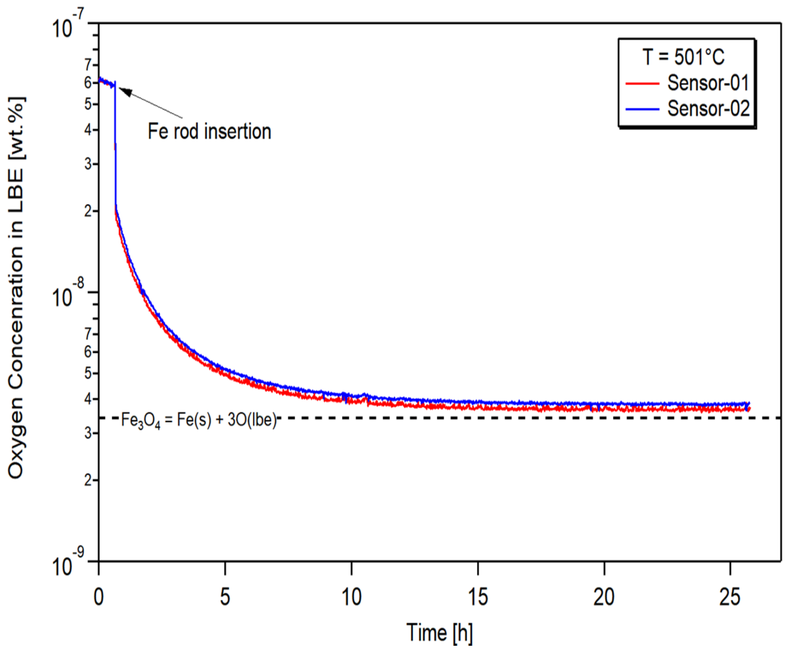
- Experimental activities are performed in the “Checkmate” facility :
  - Leak-tight capsule
  - Alumina crucible containing LBE
  - Flowing N_2 cover gas
  - Retractile Fe rod
  - Oxygen sensor
  - Oxygen pump



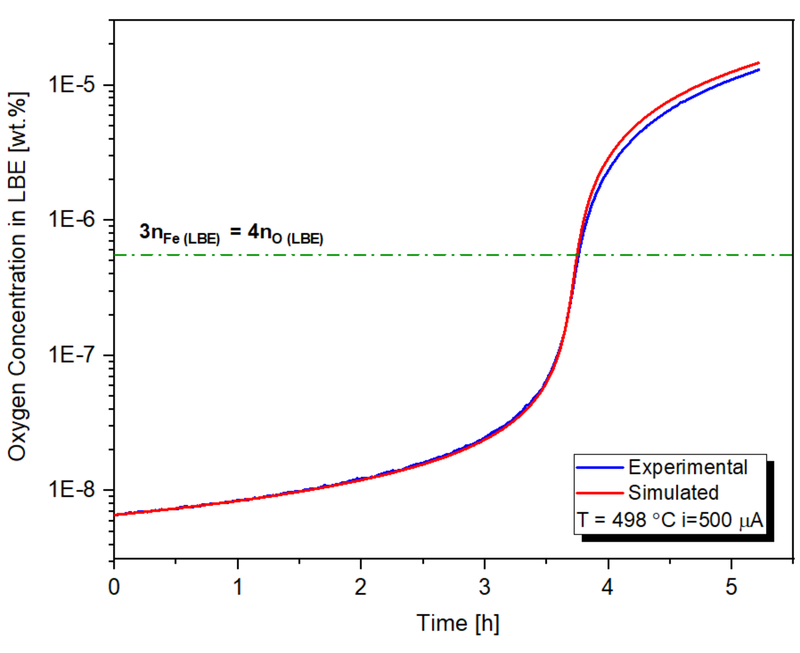
Experimental facility

Experimental Results

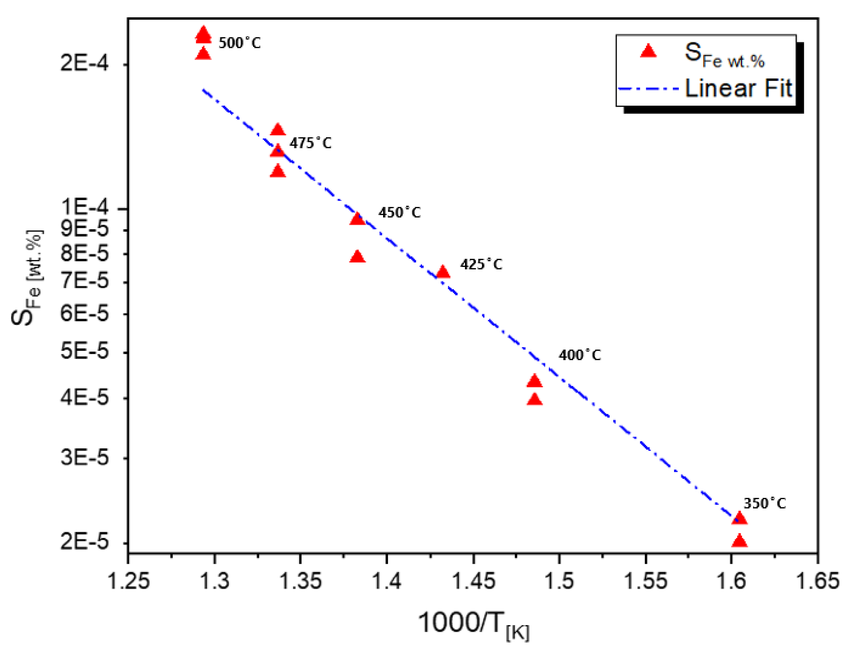
1) Oxygen removal: Fe-O interaction



2) Oxygen addition: coulometric titration



3) Data analysis: iron solubility



1) Oxygen removal: Fe-O interaction

Fe dissolves in LBE from the rod and reacts with oxygen, reducing the concentration towards the expected value for iron saturation.

2) Oxygen addition: coulometric titration

Experimental values for Fe_3O_4 solubility product constant are used to simulate the oxygen increase in order to evaluate the data reliability: a good matching is found.

3) Data analysis: iron solubility

The values of iron solubility converted from Fe_3O_4 solubility product constant are plotted over the temperature: the expected linearity is obtained.

Conclusions

We have developed and validated a new electrochemical technique to measure accurately the solubility of iron in LBE, which represents the first successful attempt to measure the solubility within the MYRRHA temperature range. Solubility has been successfully determined from 500 ºC to 350 ºC, whereas for lower temperatures experimental conditions are currently being optimized in order to improve the accuracy of the measurements.