Current Design of the Hydrogen Isotope Permeation Sensor for Liquid Breeder

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1. Introduction

One of the main objectives in the ITER project is demonstration tritium self-sustainment in the fusion reactor because tritium, source of D-T fusion reaction, is essentially required to operate a commercial fusion power plant [1-5]. Therefore various tritium breeding technologies have been studied and these researches require proper tritium measurement device. Tritium concentration in the solid breeder can be measured using commercial gas analyzer; however there is no commercial sensor for measuring tritium concentration in the liquid metal such as liquid lithium or lithium lead breeder.

In EU, permeation sensors have been developed to measure tritium concentration in the liquid lithium lead based on the hydrogen characteristic of permeation into metal membrane [6-7]. However, the sensing time is quite long to measure hydrogen concentration in the liquid metal. Lee et al. proposed the porous inner-structure concept and the vacuum flange concept to improve sensing time of a permeation sensor [8-9].

In present paper, the development of permeation sensor designs and issues are briefly introduced and design points for the permeation sensor is described.

2. Development of the Permeation Sensors

A. Ciampichetti et al. [2004, ref. 6] designed the permeation sensor Nb membrane to measure hydrogen isotopes concentration in liquid Pb17Li for WCLL or HCLL Test Blanket Module (figure 1). A. Ciampichetti et al. (2004) summarized the main constraints in designing of the permeation sensor as followed:

- higher Permeability of membrane
- higher diffusivity of membrane
- lower Sieverts' constant of membrane
- good chemically compatibility with liquid metal
- smaller sensor capsule volume as possible
- smaller dead volume as possible

Based on these guide lines for designing permeation sensor, they made a cylinder (capsule) shape permeation sensor with 1 mm thickness of Nb membrane (fig 1) and tested the permeation sensor to verify the sensor performance as shown in fig 2. However, it took more than a thousand second to meet hydrogen partial pressure of the test camber.

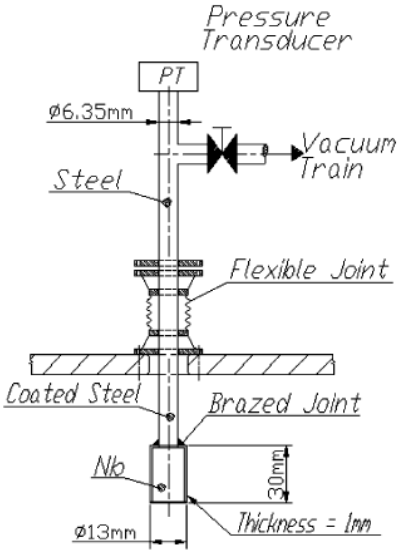

Fig. 1. The Hydrogen permeation sensor design [Ciampichetti et al., 2004, ref. 6]

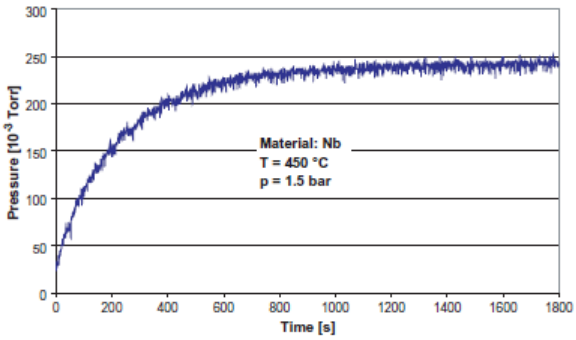

Fig. 2. Performance test result of the permeation sensor [Ciampichetti et al., 2004, ref. 6]

Three years later, A. Ciampichetti et al. [2007, ref. 7] concluded that the Nb and Fe permeation sensor have too long response time (several hours) to measure hydrogen isotopes concentration in liquid breeder. However, they suggested the optimized permeation sensors to overcome this extremely long sensing time as following sensor design guide lines:

- minimizing 'total sensor volume/permeation area
- minimizing membrane thickness
- preventing oxidation of membrane surface

A. Ciampichetti et al. (2007) suggested the optimized sensor designs and calculated theoretical sensor performances as shown in fig 3-4. The annulus type and annulus with filling type permeation sensors are shown very good sensing time results by theoretical calculation. However, the annulus empty sensor and ultra-thin membrane sensor could have welding issue and resistance of hydro-pressure issue because it is very difficult welding very thin membrane (less than 0.1 mm) and these thin capsules hard to bear hydro-pressure of liquid metal [7].

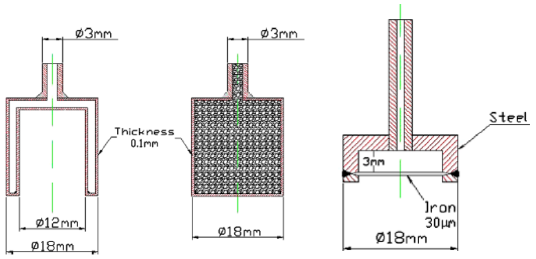

Fig. 3. The optimized permeation sensor designs and its theoretical sensor performance results [Ciampichetti et al., 2007, ref. 7]

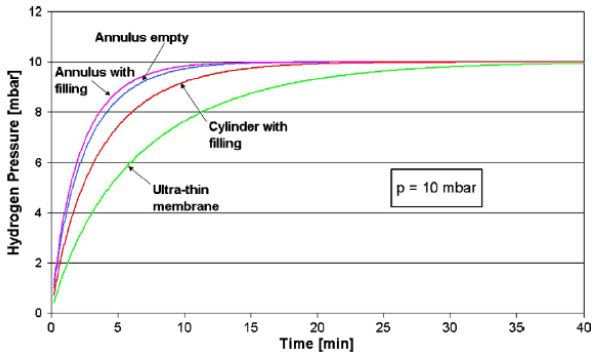

Fig. 4. The optimized permeation sensor designs and its theoretical sensor performance results [Ciampichetti et al., 2007, ref. 7]

3. Current Permeation Sensor Designs

To improve performance of a permeation sensor a ratio of a sensor 'inner volume'/'permeation area' should be minimized. Therefore, cylinder shape is not a good sensor design but annulus shape is suited for this design guide line. However, the annulus shape sensor with thin membrane has welding issue and structure weakness as discussed above.

Lee et al. (2013 ref. 8-9) proposed a flange type permeation sensor with very thin permeation membranes and an inner porous structure in order to overcome the welding, hydro-pressure weakness problems and to increase the sensor permeation surface per inner volume ratio extremely (fig 5). These 'inner porous structure' concept and 'flange body' concept are patented in Rep. Korea. [10-11]

Fig. 5. The flange type permeation sensor with porous structure [Lee et al., 2013, ref. 9]

4. Conclusions

For the liquid breeding research in fusion technology, the permeation sensor to measure tritium concentration in liquid metal breeder has been developed. In early 2000s, A. Ciampichetti et al. (2004) proposed cylinder capsule shape permeation sensor however; it had too long sensing time to measure hydrogen isotopes in liquid breeders. A. Ciampichetti et al. (2007) suggested the optimized sensor designs (such as annulus shape) and showed relatively good sensing time by theoretical simulation but it has welding and resistance of hydro-pressure issues. To overcome these problems of the permeation sensor, Lee et al. (2013) proposed the flange type permeation sensor with porous structure. The flange body permeation improves the surface/volume ratio, welding-free manufacture and very thin permeation membrane application at a time. The flange body permeation sensor will be verification and evaluation test under high temperature conditions in the near future.

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