CIRCE-ICE experimental activities in support of LMFR Design

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Abstract. In the present work, thermal stratification phenomena in the CIRCE large pool experimental facility are deeply investigated during a simulated Protected Loss Of Heat Sink (PLOHS) with Loss Of Flow (LOF) accidental scenario. Obtained results show a vertical thermal gradient mainly localized in a region between the outlet section of the Heat Exchanger (HX) and the Decay Heat Removal System (DHR). Moreover, the performed experiments evidence that the thermal stratification in the pool is purely vertical with negligible temperature variation on the horizontal planes. The temperature field inside the pool affects also the oxygen distribution in the coolant posing relevant issues related to the coolant chemistry control and corrosion of structural materials. Concurrently with the thermal hydraulic experimental activity, the calibration of various potentiometric oxygen sensor is performed in oxygen-saturated liquid LBE and Lead. Different oxygen sensor with various reference systems (Pt-air (gas), Bi/Bi_2O_3 (liquid) and Cu/Cu_2O (solid)) were manufactured and their performances investigated in a range of temperature between 160 and 550°C. Finally, different zirconia electrolytes: Yttria Partially Stabilized Zirconia (YPSZ, with $\approx$ 5 mol. % of Yttria) and Yttria Totally Stabilized Zirconia (YTSZ, with $\approx$ 8 mol. % of Yttria) are tested and experimental measurements are here reported and compared with the theoretical expected values.

Key Words: HLM pool facility, thermal-hydraulics, oxygen concentration, potentiometric oxygen sensors

1. Introduction

Thermal hydraulics of heavy liquid metal (HLM) is of wide interest between the nuclear engineering community since HLM are considered to be promising candidates as coolants for the new Gen IV Lead Fast Reactors (LFR). To provide a valuable experimental database for the assessment of new components and technologies, ENEA Brasimone R. C. is deeply involved in the design and operation of large scale experimental facilities working with HLM (lead, Lead Bismuth Eutectic (LBE) and lead-lithium). In particular, several experimental activities were performed and/or are still ongoing at ENEA Brasimone R. C. concerning integral circulation tests and pool thermal-hydraulic investigation [1], heat transfer investigation in fuel rod bundles [2], material corrosion characterization, development of prototypical components and coolant chemistry control [3].

In this frame the CIRCE pool facility (CIRCulation Eutectic) was refurbished to host a suitable test section able to simulate the thermal-hydraulic behaviour of the primary system in a HLM cooled pool reactor. The aim of the performed experimental campaign was to characterize the phenomena of mixed convection and stratification in a liquid metal pool in a safety relevant situation, considered one of the most important topics in the study of Generation IV reactors for increasing reactor safety and its structural integrity. Because of an accidental scenario, the reactor is scrammed, and assuming the total loss of the pumping system, the coolant flow rate reduces and large temperature variation takes place causing thermal stratification phenomena inside the pool. A steep vertical temperature gradient may induce significant thermal loads on the structure in addition to existing mechanical loads.

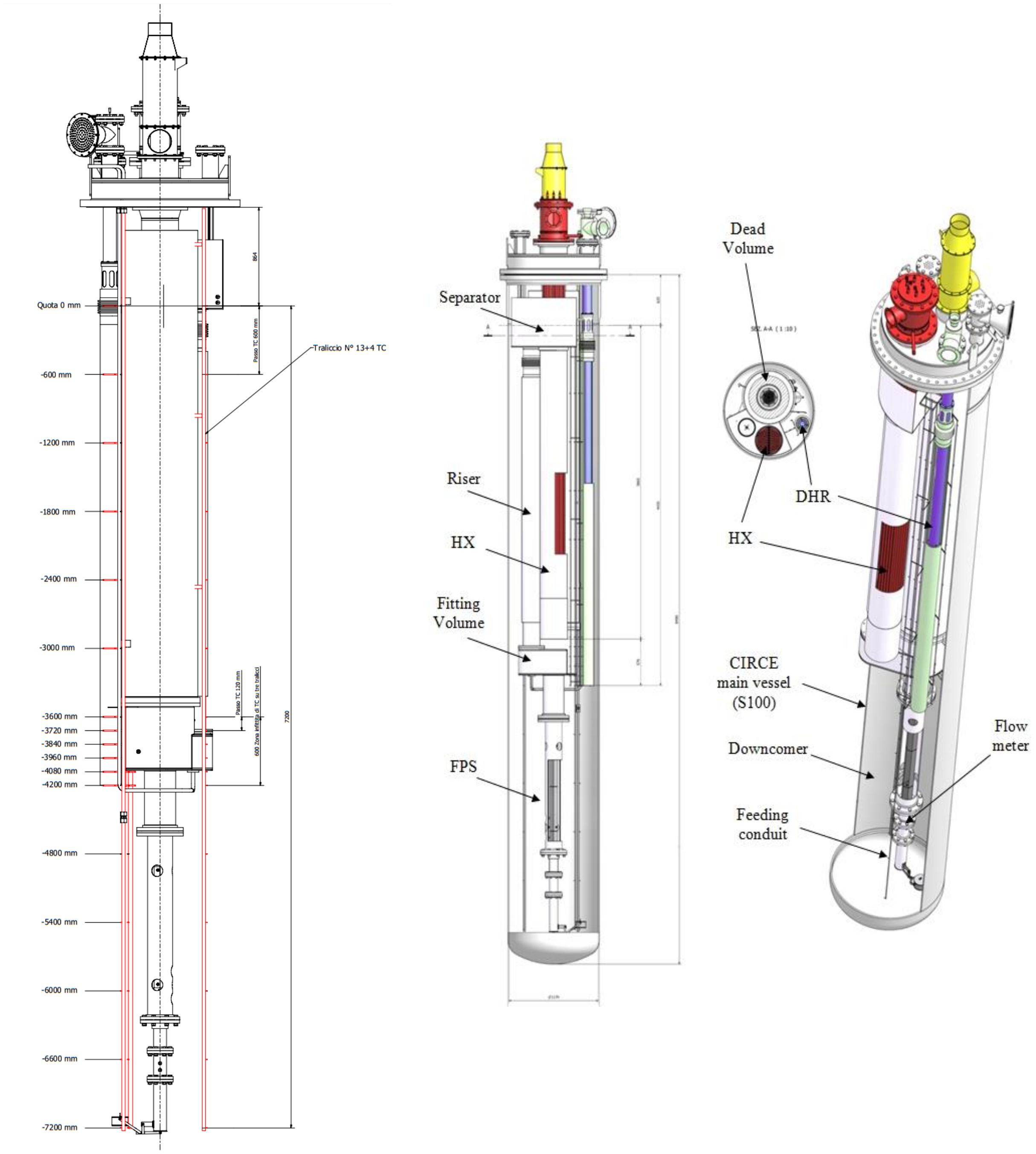
Thermal stratification phenomena affect also the oxygen solubility in the coolant posing relevant issues related to the coolant chemistry control. The oxygen concentration at the solubility level has to be avoided in any point of the system to prevent the formation of PbO, whose deposition in the cold zones may affect the heat transfer and the HLM circulation. [4-6]. However, a sufficient oxygen concentration in the HLM is usually required for the formation of a self-healing oxide layer (magnetite Fe_3O_4 + Fe-Cr spinel oxide) on steels surface, which acts as a barrier against corrosion and reduces the release of corrosion products in the coolant [4-6].

The need of working with an optimum oxygen concentration in the coolant requires specific devices for the control of the concentration during the pool operation [6]. In this context, the monitoring of the oxygen concentration is a fundamental step to get to define a proper oxygen control system (OCS) for large HLM pool. In the last decade potentiometric sensors based on ceramic solid electrolyte have been developed for HLMs but their application mostly involves small/medium scale experiments (small pools and loops) and oxygen sensors for large HLM pools are not yet fully available. To support the study about the coolant chemistry control for future LFRs, ENEA Brasimone R. C. is developing oxygen sensors for CIRCE pool facility, whose operation will help in identifying possible oxygen stratifications along the pool and defining a proper OCS for the facility. In the present paper, a basic study performed in laboratory about potentiometric oxygen sensors with different internal reference electrodes (Pt-air, Bi/Bi_2O_3 and Cu/Cu_2O) and solid electrolytes (Yttria Partially Stabilized Zirconia, YPSZ, and Yttria Totally Stabilized Zirconia, YTSZ) is described. Their performances were investigated in the temperature range 160-550°C and the results obtained were useful in defining the adequate features (reference electrode, solid electrolyte) of the oxygen sensor for the operation in CIRCE. Finally, the design of an oxygen sensor prototype for CIRCE is described and preliminary results about test in HLM are reported.

2. CIRCE experimental facility

CIRCE (Fig. 1 (*b*)) is a multipurpose facility suitable to investigate thermal-hydraulic phenomena occurring in a large pool type system both in nominal and accidental operations (PLOHS, LOF, etc.).The CIRCE main vessel was designed for studying key operational principles of the 80 MW experimental driven accelerator systems (1:5 the XADS diameter) [7]. Concerning the Integral Circulation Experiment (ICE) test section, it was designed to reproduce as close as possible the thermal-hydraulic behavior of the XT-ADS and EFIT primary systems (the main ICE experimental parameters are roughly in the range expected for the XT-ADS and EFIT concepts [8]). It is a pool type experimental facility consisting of a main vessel (8.5 m height and 1.2 m diameter) containing about 70 tons of molten LBE, auxiliary equipment for the eutectic circulation (gas enhanced circulation) a storage and a transfer tank [1-9] (Bandini et al., 2011 and Tarantino M. et al., 2015). The ICE test section is located inside the main vessel and it includes a Venturi flow meter (used to measure the LBE mass flow rate entering the FPS) and the Fuel Pin Simulator (FPS) connected through a fitting volume to the riser (where argon gas is injected promoting the LBE enhanced circulation). The riser is welded to the upper part to a separator consisting in a volume needed both to separate argon from the LBE and to ensure primary flow continuity towards the main Heat eXchanger (HX).

The ICE FPS represents the heat source of the facility. It consists in a 37 pin bundle arranged in a wrapped hexagonal lattice with a pitch to diameter ratio of 1.8 and a pin outer diameter of 8.2 mm. The relative position between the pins and the wrapper is assured by means of grid spacer while the active length of the pins is 1000 mm and the total installed power is 925 kW. Concerning the LBE pool instrumentation, vertical rods were installed in the pool in order to fix thermocouples (TCs) at 17 different elevations (Fig. 1 (*a*)) and 9 different radial positions (Fig. 2) for a total of 119 TCs having a diameter of 3 mm and an accuracy of ± 1 °C.



(*a*) (*b*)

Fig. 1: CIRCE TCs vertical positioning (a) and CIRCE-ICE configuration (b)

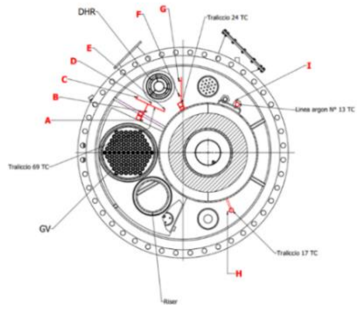


Fig. 2: CIRCE experimental facility configuration

3. Thermal Stratification analyses

3.1. Test Matrix

The experimental campaign dedicated to the study of the thermal stratification phenomena in the CIRCE facility included several tests for a total experimental time of more than 600 h. Tests here considered are named *A, B* and *C* are representative of an PLOHS+LOF accidental scenario with consequent modification of the thermal stratification of the coolant in the pool caused by the transition from forced to natural circulation regime. For each test, steady state conditions were reached under forced circulation regime and then the accidental scenario was simulated switching off the gas injection that was used to promote the LBE circulation, reducing the electrical power of the Fuel Bundle Simulator to simulate the decay heat (about 5-7% of the full power) switching off the water line feeding the HX in order to simulate the loss of the water secondary systems and activating the Decay Heat Removal System (DHR) fed by air at ambient temperature. Test *D* is the simulation of a PLOHS in which the forced circulation is ensured by the argon gas injection for all the duration of the test. In Table 1 the boundary conditions of the tests are reported.

Table 1: Test Matrix

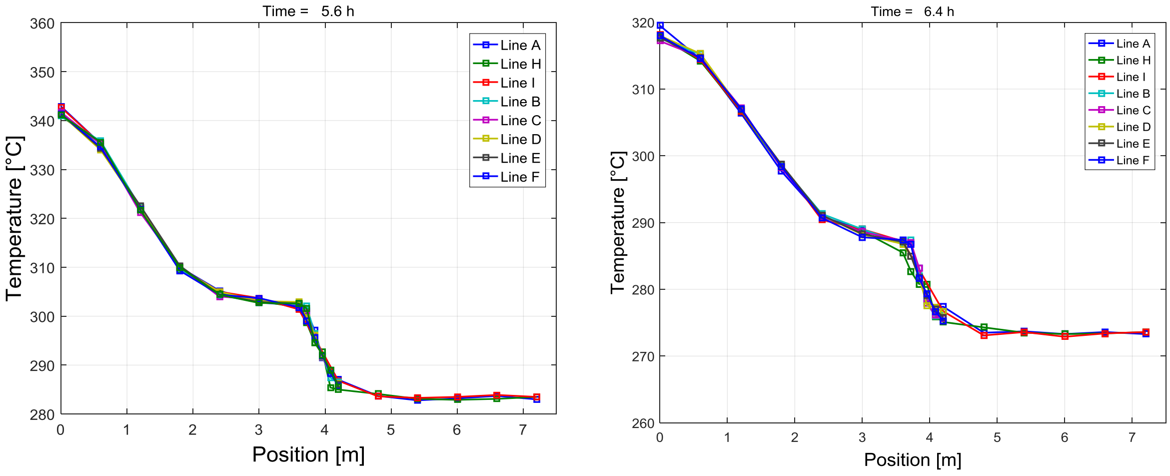
	EVENT	**TIME**
Test *A* Full *Power run*	Power ramp (0-730 kW)	0.253 h → 0.30 h
	Full power (730 kW)	0.302 h → 7.029 h
	Feedwater injection (main HX)	0.30 h → 7.063 h
	Argon Injection	0.12 h → 7.062 h
Test *A* *Transition Phase*	Power ramp (730-50 kW)	7.02h → 7.061 h
	Air Injection (DHR)	7.08 h → **47.08** h (0.223 kg/s)
Test *B* *Full Power run*	Power ramp (0-600 kW)	0.902 h → 0.98 h
	Full power (600 kW)	0.98 h → 6.98 h
	Feedwater injection (main HX)	1h → 6.986 h
	Argon Injection	0.77 h → 7.009 h
Test *B* *Transition Phase*	Power ramp (600-40 kW)	6.98h → 7.01 h (up to 198 h)
	Air Injection (DHR)	7.02 h → 24.625 h (0.192 kg/s)
	Air Injection (DHR)	24.625 h → **96.933** h (0.25 kg/s)
Test *C* *Full Power run*	Power ramp (0-800 kW)	0.3h → 0.35h
	Full power (800 kW)	0.35 h → 10.3 h
	Feedwater injection (main HX)	0.35 h → 10.35 h
	Argon Injection	0.17 h → 10.35 h
Test *C* *Transition Phase*	Power ramp (800-30 kW)	10.3 h → 10.35 h
	Air Injection (DHR)	10.35 h → **20.09** h (0.24 kg/s)
Test *D* *Full Power run*	Power ramp (0-750 kW)	0.427 h → 0.467 h
	Full power (750 kW)	0.467 h → 11.155 h
	Feedwater injection (main HX)	0.49 h → 11.155 h
	Argon Injection	0 h → 198 h
Test *D* *Transition Phase*	Power ramp (750-30 kW)	11.155h → 11.19 h (up to 198 h)
	Air Injection (DHR)	11.24 h → **192.8** h (0.22 kg/s)

3.2 Experimental results

The experimental results show that the steady state under full power condition, was reached in less than 10 h. In this first part of the run the power supplied to the electrical bundle (depending of the relative test) raged from 600 to 800 kW and the gas injection ensured a forced circulation of the coolant in the range between 55-65 kg/s.

At full power steady state conditions, the temperature trend in the pool was similar for all the investigated tests as shown in Fig. 3 and Fig. 4. Thermal stratification phenomena were evident inside the pool, with a thermal gradient of about 30-40°C in the first 3.5 m (up to the outlet section of the HX). Then, there was a region between the outlet sections of the HX and the DHR were the slope of the thermal gradient increased with a temperature difference of about 15-20°C in 0.5 m. In the lower part of the pool (from the outlet section of the DHR to the bottom of the vessel), the temperature was uniform for all the simulated tests. After the transition to natural circulation regime the time needed to reach a new steady state was relatively high if compared to that required for steady state condition under forced circulation regime. This is essentially due to the high thermal inertia of the system (about 70 tons of melted LBE).

Moreover, the temperature trend after the simulated accidental scenario deeply changed. Concerning tests *A*, *B*, and *C* (see Fig. 5 and Fig. 6 (a)) the LBE temperature in the upper plenum quickly become uniform and the region where thermal stratification phenomena are significant moved downwards starting from the DHR outlet section (4.2 m, see Fig. 1 (*a*)) up to about 4.8 m; the temperature difference between these two sections was about 10-15°C. Finally, test *D* differs from the other test being the forced circulation maintained after the simulated accidental scenario. In particular, in test *D* for the high power run the LBE mass flow rate was about 56.5 kg/s ensured by a gas injection flow rate of 2.75 Nl/s. For the long low power run the argon mass flow was reduced to 2.6 Nl/s and the consequent LBE mass flow rate was about 53.2 kg/s. After the transition to low power (30 kW) temperature become uniform in the pool increasing up to 330 °C, at steady state conditions as shown in Fig. 6 (*b*).



(*a*) (*b*)

Fig. 3: Pool vertical trend test A (a) and test B (b), steady state FC

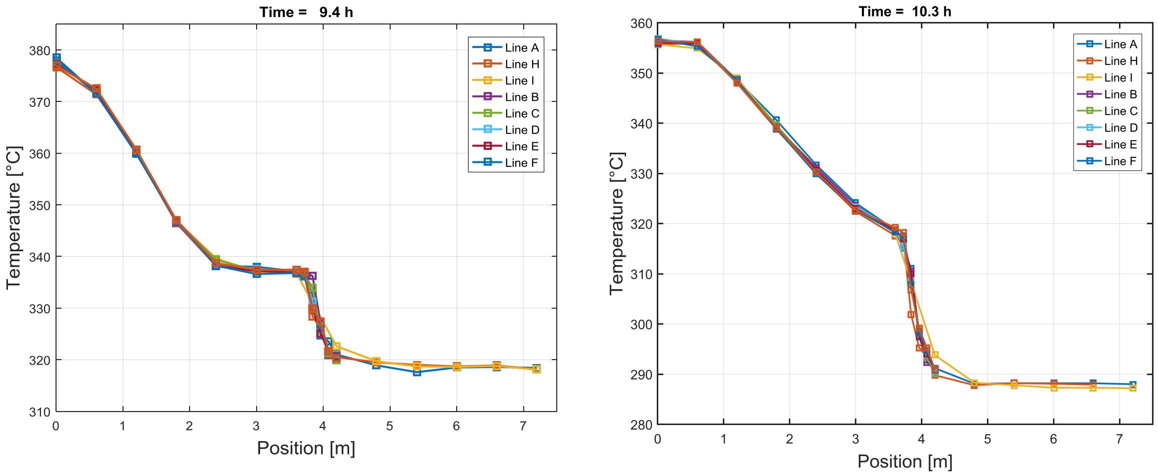


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Fig. 4: Pool vertical trend test C (a) and test D (b), steady state FC

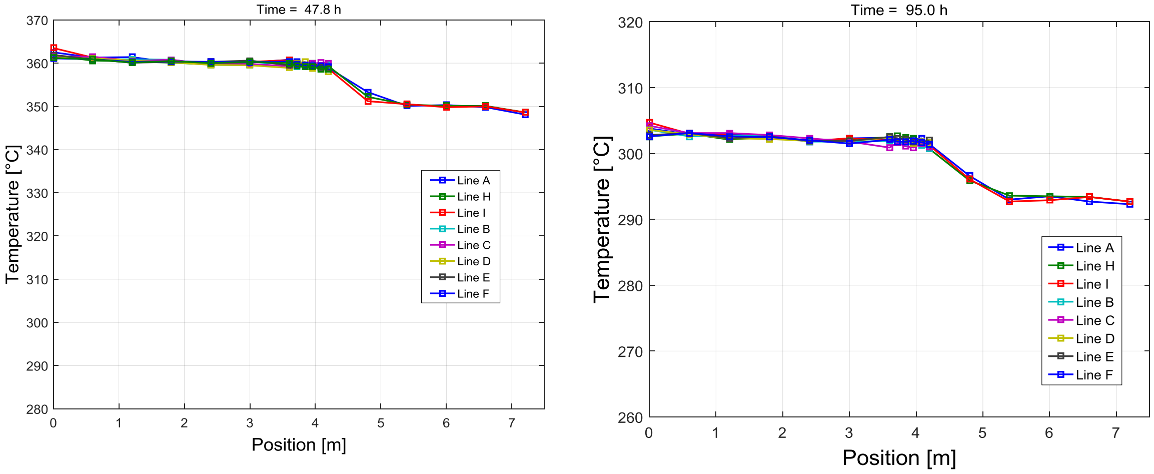

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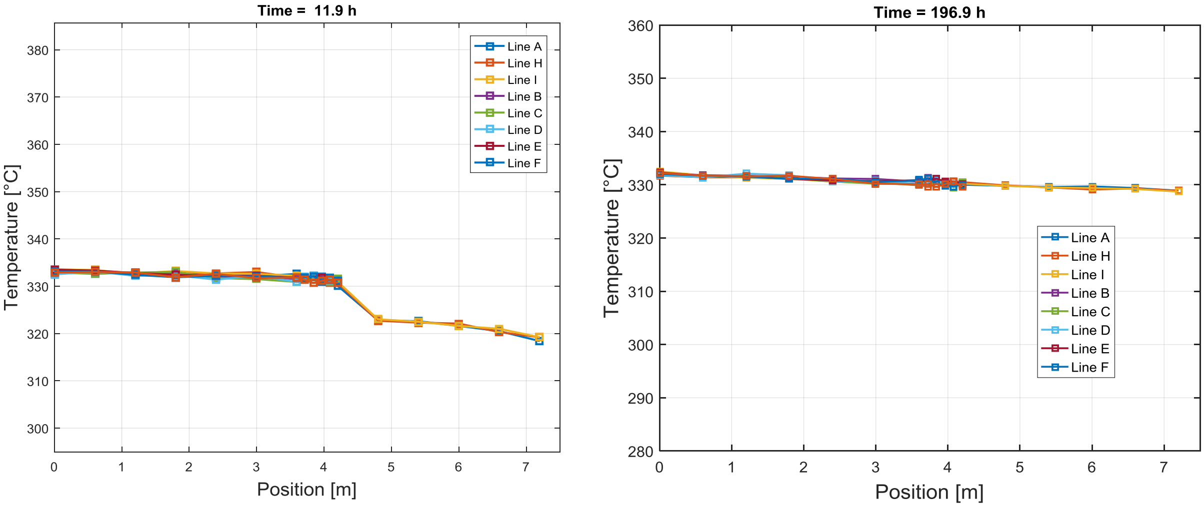
Fig. 5: Pool vertical trend test A (a) and test B (b) steady state NC



(*a*) (*b*)

Fig. 6: Pool vertical trend test C (a), and test D (b), steady state NC

The temperature trend showed for the steady state both at full power and under decay power conditions exhibit region of the pool at constant but different temperatures. This would result in different oxygen saturation concentrations which could introduce oxide formations and plugging issues in the coldest region and corrosion issues in the hottest part. To avoid this, oxygen sources and or gather should be adopted. Nevertheless, a proper functioning and operation of such devices is strictly connected to suitable oxygen sensor. For this reason, ENEA Brasimone R. C. is deeply involved in the design and manufacturing of specific oxygen sensor as reported in the following.

4. Oxygen Sensors Analyses

4.1 Comparison between different Oxygen Sensors

Potentiometric oxygen sensors in HLMs are composed of a ceramic solid electrolyte (generally Yttria Partially Stabilized Zirconia, YPSZ, 5 % mol. Y_2O_3) and a reference electrode inside the ceramic with well-known oxygen activity [10]. The ceramic is usually in the form of one-end closed tube or thimble. The reference electrodes are commonly the Pt-air and the liquid metal/metal-oxide Mo-Bi/Bi_2O_3 systems [10]. Pt-air sensors are easily manufactured but have a high minimum reading temperature around 400-450°C [11]. The minimum reading temperature of Bi/Bi_2O_3 sensors is around the 300-350°C but they are characterized by high tendency of failure of the ceramic piece due to the volume change of bismuth during melting and solidification steps [11]. Concerning metal/metal-oxide sensors, sensors with Cu/Cu_2O reference have been recently studied since more reliable due to the "solid reference" and able to measure in HLMs even at 200°C [13].

Oxygen sensors with different lengths and reference systems were manufactured and calibrated in HLMs to assess the accuracy and the minimum reading temperature. One sensor was constructed with Pt-air reference and using YPSZ electrolyte (one-end closed tube, L= 400 mm, d_e= 8 mm, d_i= 5 mm). The ceramic tube was glued to ½" AISI 316 tube with a high-temperature ceramic adhesive (total length 850 mm). The reference electrode lead was a AISI 316 wire with platinized tip and an alumina tube placed inside the sensor was used to inject the reference air on the bottom of the sensor. Two oxygen sensors were constructed with Bi/Bi_2O_3 and Cu/Cu_2O metal/metal-oxide references and YPSZ electrolyte (one-end closed tube, L= 400 mm, d_e= 8 mm, d_i= 5 mm). The internal reference was created by mixing together metal and metal-oxide powders ($Cu+Cu_2O$, $Bi+Bi_2O_3$). AISI 316 and Mo wires were used as reference electrode leads for Cu/Cu_2O and Bi/Bi_2O_3 system respectively. A high-temperature ceramic sealant was used to seal the upper part of the ceramic tube.

The sensors were calibrated in steel capsules containing oxygen-saturated HLM (lead or LBE) to evaluate the minimum reading temperature of the sensor. The HLM temperature was changed in the range 160-550°C and the experimental electric potential compared with the theoretical expected value in oxygen-saturated condition. During the calibration, an alumina crucible inside the capsule was used as inert container of the HLM. A K-type thermocouple inside a one-end closed tube of alumina was used to monitor the HLM temperature. Argon gas (99.9999% purity, 0.1 ppmv of O_2) was continuously flowed above the HLM surface to maintain the oxygen saturation. AISI 316 or Mo wires were used as working electrode in the HLM.

During the calibration, the HLM temperature was changed at rate of 2°C/min. After the reaching of the target temperature, it was waited about 20 min before collecting the electric potential values. Several potential values were collected with a frequency of 20-30 min for each temperature step and an average value was calculated. The measures were performed with high-impedance multi-meter ($\geq$ 10 GΩ). The result of the calibration of Pt-air sensor with YPSZ tube is reported in Fig. 7. The experimental potentials (blue points) are compared with the theoretical potential (red line) calculated according to the equations given in [4]. The sensor provides an electric potential in agreement with the theoretical line between 430-540°C. When the temperature was at 410°C, the electric potential deviated from the theoretical (deviation -6 %). The minimum reading temperature of Pt-air sensor is then around 430°C.

Fig. 8 shows the result of the calibration of Bi/Bi_2O_3 and Cu/Cu_2O oxygen sensors. The theoretical electric potential of Bi/Bi_2O_3 sensor was calculated using the equations suggested in [4] whereas the theoretical potential of Cu/Cu_2O sensor was calculated as described in reference [13]. Concerning the results of Bi/Bi_2O_3 sensor, the analysis of the experimental points (gray points) shows that the sensor provides electric potentials in agreement with the theoretical ones down to 290°C. When the LBE temperature was below the melting point of bismuth (T_m= 271°C), the sensor stopped working as a result of the block of the diffusion of the oxygen ions in the bismuth solid phase. Cu/Cu_2O sensor has instead a minimum reading temperature around 200°C. Indeed, the experimental points (green dots) are in good agreement with the theoretical line in the range 200-550°C and the deviation from the theoretical line was observed below 200°C (-6 % at 160°C).

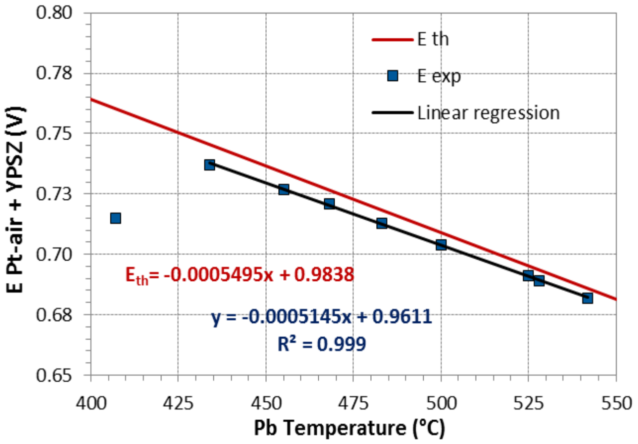


Fig. 7: Calibration of Pt-air oxygen sensor with YPSZ electrolyte in oxygen-saturated liquid lead in the temperature range 410-540°C.

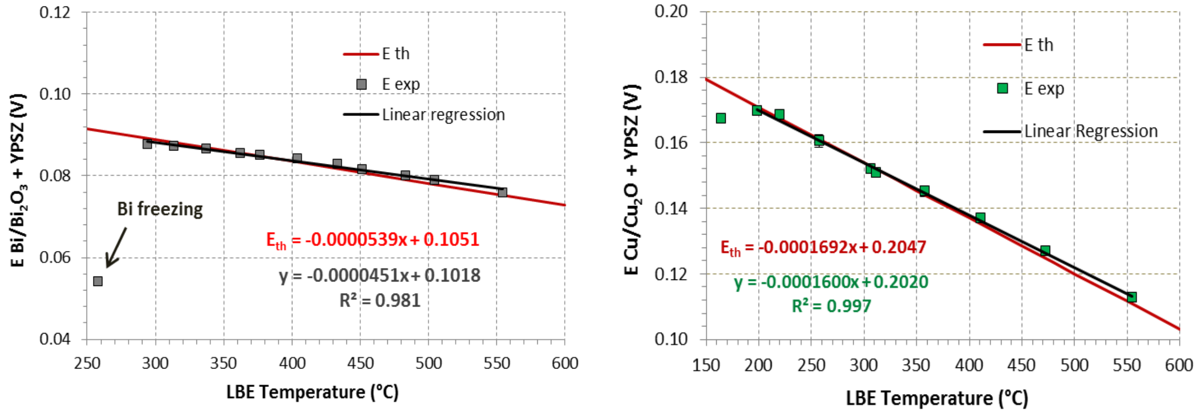


Fig. 8: Calibration of Bi/Bi2O3 oxygen sensor and Cu/Cu2O sensor with YPSZ electrolyte in oxygen-saturated LBE in the temperature range 260-550°C and 160-550°C respectively.

The type of solid electrolyte has influence on the minimum reading temperature of the oxygen sensor. As a matter of fact, the ionic conductivity of a “stabilized zirconia” is maximized when the amount of dopant is added to the zirconia at the exact level required to achieve the full stabilization of the cubic phase, which is the O^{2-} conductive crystalline form of the zirconia. A lower amount of dopant provides a partial stabilization of the zirconia (mixture of cubic and tetragonal phases) with lower ionic conductivity but better thermo-mechanical strength. In the case of zirconia doped with yttria, the partial stabilization is provided when 5 % mol. of Y_2O_3 is added (YPSZ). The total stabilization is obtained by adding 8 % mol. of Y_2O_3 and the solid electrolyte is the Yttria Totally Stabilized Zirconia (YTSZ).

The effect of the zirconia solid electrolyte on the performance of oxygen sensors was investigated by calibrating Pt-air sensors with YTSZ tube (8 % mol. of Y_2O_3) in liquid lead in the temperature range 360-550°C. The oxygen sensors were produced by FER-Strumenti S.r.l. (Seregno, Italy), the solid electrolyte is a one-end closed tube with length 600 mm and the reference electrode lead was composed of Pt only.

The calibration (see Fig. 9) showed that the Pt-air sensor with YTSZ tube provided an electric potential in agreement with the theoretical one even at 350°C (blue points). The deviation of the experimental points from the theoretical one is -0.2 % and -0.4 % at 380°C and 360°C respectively. The gain of 80°C in the minimum reading temperature of the Pt-air sensor is ascribable to the higher ionic conductivity of the YTSZ compared to the YPSZ.

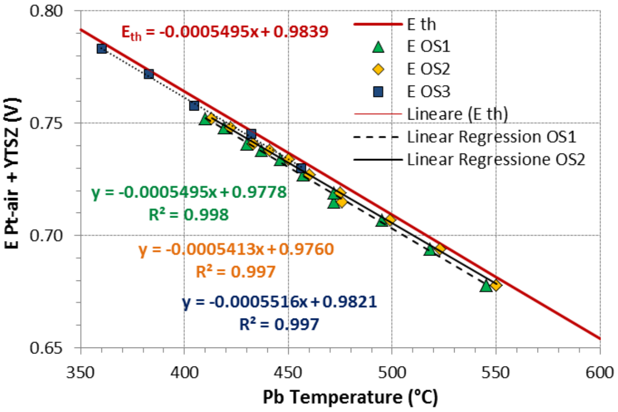


Fig. 9: Calibration of Pt-air sensors with YTSZ electrolyte

in oxygen-saturated liquid lead in the temperature range 360-550°C.

4.2 Development of an Oxygen Sensor for CIRCE pool

ENEA Brasimone, in collaboration with FER-Strumenti S.r.l. (Seregno, Italy) is developing oxygen sensors to be installed in CIRCE pool facility. The current design of the oxygen sensor (prototype) is 1-meter long and it has the Pt-air system as reference electrode. The length of the sensor can be adapted for different positions in the HLM pool. For CIRCE facility at least three length of the sensor are foreseen for the measure in different positions.

The schematic design and a picture of the last configuration of the sensor are shown in Fig. 10. The sensor body is a 2” tube made of AISI 316, which should provide good mechanical resistance when the oxygen sensor is dipped in CIRCE pool facility. The solid electrolyte is a YTSZ thimble placed in the lower part of the sensor body. The zirconia thimble is machined to create a lateral step and is pressed against the sensor body by a perforated flange (made of AISI 316) which pushes on the step. The tightness is given by a graphite gasket between the thimble and the sensor body. The reference air is blown into a tube within the sensor body. An electrically insulated Pt wire is located inside the same tube. In the upper part of the sensor a terminal box collects the Pt electrical lead, the pressure reducer and the rotameter for dosing the reference air towards the YTSZ thimble. The oxygen sensor prototype was calibrated in HLM to assess the quality of the tightness and the accuracy during the oxygen measurement. The calibration was performed by varying the temperature in the range 350-550°C in oxygen-saturated liquid lead (about 300 l) contained inside HELENA loop storage tank in Brasimone [3]. The oxygen-saturated condition was ensured providing a slight overpressure of argon (0.2 bar) in the storage tank.

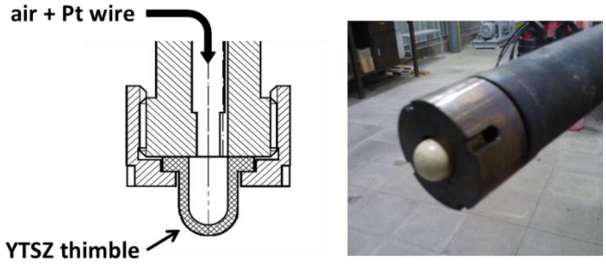


Fig. 10: Lower part of the oxygen sensor prototype showing the YTSZ thimble and the perforated cap.

Fig. 11 shows the electric potential as a function of temperature, with indication of the theoretical potential.

The electric potential was in very good agreement with the expected potential in the lead temperature range 350-450°C. The deviation of the electric potential from the theoretical one is about -1 % at 450°C and 400°C and -2 % at 375°C and 350°C. In addition, a high stability of the output was observed over time (up to 10 days or more for each temperature) and no HLM penetrations were observed in the zirconia thimble, indicating that the tightness of the sensor was good.

However, as the present configuration is able to measure oxygen in HLMs only down to 350°C, the upgrade of the oxygen sensor with other reference systems (such as Cu/Cu_2O) must be performed to have a detection capability even at 200-250°C. This will allow to perform an oxygen monitoring with good accuracy also in the cold pool zones of CIRCE pool. In addition, the use of YPSZ electrolyte should be preferred in place of the YTSZ. About the solid electrolyte, it is note that YTSZ is more prone to crack than YPSZ and more than one failure of the YTSZ thimble occurred during the experimental tests. For that reason, the use of YPSZ electrolyte should be preferred in place of the YTSZ to ensure higher service lifetime in CIRCE pool facility.

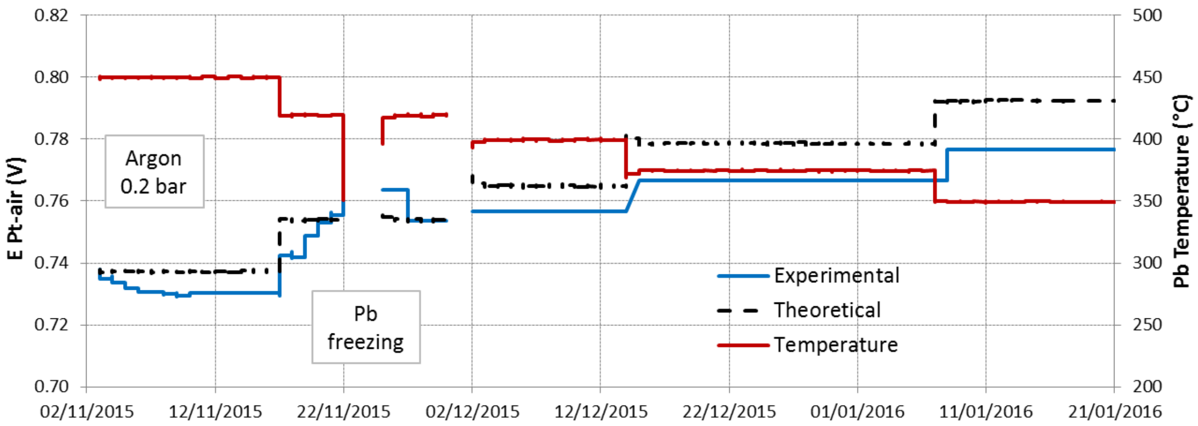


Fig. 11: Calibration of the oxygen sensor prototype in oxygen-saturated liquid lead in HELENA storage tank.

5. Conclusions

The first part of this paper describes the experimental activity carried out at the ENEA Brasimone R. C. dealing with the investigation of mixing and stratification phenomena under typical large pool reactor conditions.

Experiments simulating a PLOHS+LOF (*A, B, C*) and one test (*D*) with forced circulation maintained also after the simulation of the accidental scenario were performed for more than 600 h. Temperature field inside the CIRCE experimental facility was monitored through 119 TCs placed at 17 different elevations and 9 different radial positions.

Temperature in steady state conditions under full power normal operation conditions was reached for all the tests in less than 10 h independently from the power supplied to the electrical bundle (from 600 kW up to 800 kW). In this phase, thermal stratification phenomena were evident inside the pool, with a thermal gradient of about 30-40°C in the first 3.5 m (up to the outlet section of the HX). Then, there was a region between the outlet sections of the HX and the DHR were the slope of the thermal gradient increased with a temperature difference of about 15-20°C in 0.5 m while in the lower part of the pool (from the outlet section of the DHR to the bottom of the vessel), the temperature was uniform. After the transition to NC conditions, tests *A, B*, and *C* showed a similar pool temperature trend with two zones at constant temperature separated by a region where thermal stratification phenomena were gathered and placed after the outlet section of the DHR system. Finally test *D* differed from the other tests for the gas injection promoting the forced circulation also after the simulation of the accidental scenario. In this test the temperature field at low power condition was uniform in all the pool as it was expected. Noteworthy was the speed at which the temperature levels out in the pool after the reduction of the power supplied to the bundle (approximately 2800 s).

Because the of the temperature stratification, different oxygen saturation concentrations will come across different region. The oxygen control represents one of the main issues concerning the problems of lead oxide deposition and corrosion. Therefore, a suitable oxygen and monitor control system is mandatory for safety issues.

To this end, investigation about the performance of different oxygen sensors in HLMs and the first stage of development of an oxygen sensor to be installed in CIRCE pool facility were conducted at ENEA Brasimone R.C. The study about the calibration of oxygen sensors with Pt-air, Bi/Bi_2O_3 and Cu/Cu_2O reference electrodes and YPSZ electrolyte showed that the best performance at low temperature are exhibited by Cu/Cu_2O sensor, which has a minimum reading temperature around 200°C. Bi/Bi_2O_3 sensor follows with a minimum reading temperature of 290°C and Pt-air sensor of 430°C.

The use of YTSZ electrolyte in place of the YPSZ allows a gain of about 80°C in the minimum reading of Pt-air sensor thanks to the higher ionic conductivity. However, YTSZ is characterized by a lower mechanical strength compared to YPSZ electrolyte, making presume that the use of the latter could be a better solution in oxygen sensors for large HLM pool (where high mechanical resistance is mandatory to bare the high pressures exercised by the large HLM volume).

Finally, an oxygen sensor prototype with Pt-air reference electrode and YTSZ electrolyte was developed for the application in CIRCE and preliminary results in HLM were obtained. The calibration showed a good accuracy in the range 350-450°C and also a good tightness of the sensor.

Concluding, the investigation about different oxygen sensors and the preliminary results of the developed prototype for CIRCE pool helped in defying the next steps for the development of an oxygen sensor for large HLM pools. In order to have an accurate measurement also at low temperature, a Cu/Cu_2O reference electrode could be used in place of the Pt-air system and, YPSZ should be used as solid electrolyte to guarantee a long sensor service lifetime when installed in large HLM pools.

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