**Profile LFR-44**

**LECOR**

**ITALY**

## GENERAL INFORMATION

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|---|---|
| NAME OF THE FACILITY | LECOR |
| ACRONYM | LEad CORrosion |
| COOLANT(S) OF THE FACILITY | Lead/Lead-Bismuth Eutectic |
| LOCATION (address): | Italian National Agency for New Technologies, Energy and Sustainable Economic Development, C.R. ENEA Brasimone, Italy. |
| OPERATOR | ENEA |
| CONTACT PERSON (name, address, institute, function, telephone, email): | Ing. Mariano Tarantino, ENEA UTIS-TCI C.R. Brasimone 40032 Camugnano (Bo) Tel. +39 0534 801 262, Head of Thermal Fluid Dynamic and Facility Operation Laboratory mariano.tarantino@enea.it |

| | |
|---|---|
| **STATUS OF THE FACILITY** | In operation |
| Start of operation (date): | 2015 |

**MAIN RESEARCH FIELD(S)**

- ☐ Zero power facility for V&V and licensing purposes
- ☐ Design Basis Accidents (DBA) and Design Extended Conditions (DEC)
- ☐ Thermal-hydraulics
- ☒ Coolant chemistry
- ☒ Materials
- ☐ Systems and components
- ☒ Instrumentation & ISI&R

## TECHNICAL DESCRIPTION

### Description of the facility

LECOR consists of a loop with the typical "8" shape, in which the hot leg and cold leg exchange power thanks to use of a regenerative heat exchanger (economizer EX). On the hot leg the test section (TS) and heating section (HS) are installed, while on the cold leg are installed the storage tank (S1), the expansion tank (S2) with the main circulation pump, air heat exchanger. At present, the test section consists is a flange placed vertically containing 4 open bars. Within the bars, the samples are piled up and separated from each other with

spacers. Each bars can place 8 samples. The liquid metal flows from the top to the bottom within the bars and laps the samples.
The main components are hereafter described (see P&ID).

**Storage Tank - S1:** it is made in SS 316L, has a volume of 700 lt, with a working temperature of 400°C. No oxygen sensors are installed, while gas bubbling system is available.
**Expansion Tank / Pump Tank – S2:** it is made in SS 316L, has a volume of 600 lt, with a working temperature of 450°C. No oxygen sensors are installed, while gas bubbling system is available. The pump is a vertical centrifugal pump with submersed impeller (SS coated TiC), with a flow rate of 4 $m^3/h$ and a pressure head of 5 bar.
**Economizer – EX:** it is made of ferritic steel 2 ¼ Cr 1 Mo, and it is tube bundle in shell type, with a thermal duty of 250 kW. The temperature in the hot side is 550°C – 400°C (in –out respectively), while it is 350 – 500 °C (in –out) in secondary side.
**Heater – H:** it is made of ferritic steel 2 ¼ Cr 1 Mo, and it is tube in tube type (6" and 4" respectively), with a thermal duty of 82,2 kW. In nominal condition the inlet temperature is 500°C, the outlet temperature is 550°C.
**Air Heat Exchanger :** it is made of ferritic steel 2 ¼ Cr 1 Mo, tube bundle, secondary side with forced circulation air. It has a thermal duty of 82,2 kW, and the lead inlet/outlet temperature are respectively 400°C and 350°C.

The whole facility has been designed at 5 bar (maximum operating pressure 4 bar) with a design temperature in hot leg of 600°C, and 550°C in cold leg.

**Acceptance of radioactive material**
No

**Scheme/diagram**

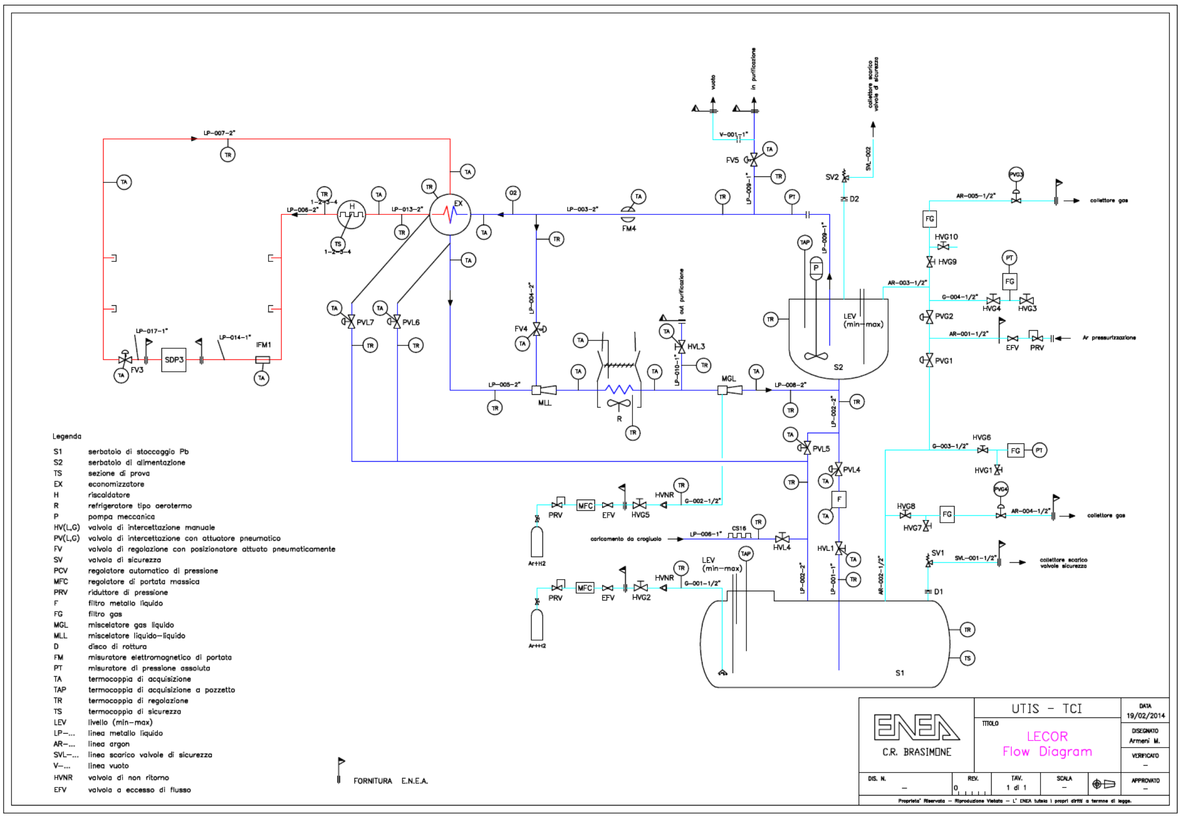
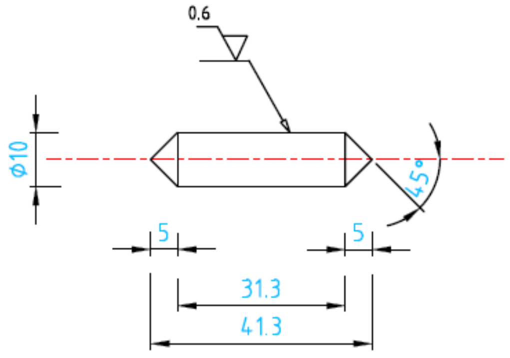



*FIG. 1. Scheme of the LECOR facility*

## 3D drawing/photo

*FIG. 2. View of the LECOR facility*

**Parameters table**

| | |
|---|---|
| Coolant inventory | 500 l pure lead |
| Power | 250 kW |
| Test sections | |
| TS #1 | *Characteristic dimensions*<br>Cylindrical specimen<br> |
| | *Static/dynamic experiment*<br>Dynamic experiment |
| | *Temperature range in the test section (Delta T)*<br>Uniform, 550°C |
| | *Operating pressure and design pressure*<br>4 bar operating pressure<br>5 bar design pressure |
| | *Flow range (mass, velocity, etc.)*<br>0,3 – 1,3 m/s |
| Coolant chemistry measurement and control (active or not, measured parameters) | Coolant chemistry measurement based on the use of oxygen sensors in hot leg and cold leg.<br>Oxygen control in gas phase. |
| Instrumentation | Thermocouples k-type, OD 3 mm<br>Inductive Flow meter<br>Probe levels |

## COMPLETED EXPERIMENTAL CAMPAIGNS: MAIN RESULTS AND ACHIEVEMENTS

In the framework of the EU project TECLA, the LECOR facility was employed to study the corrosion behaviour of some materials in flowing Pb–Bi with a low dissolved oxygen content. The studied materials were cylindrical samples of AISI 316L austenitic steel, T91 martensitic steel and pure refractory metals as W, Mo and Ta. In addition to the study of the corrosion behavior, tensile properties were also tested for the steels after exposure to the liquid metal. The temperature in the test section was set at 400°C. The liquid metal flow rate around the samples was about 1 m/s. Samples were extracted every 1500 h up to a maximum of 4500 h. To perform the tests in low oxygen conditions, Mg were added to the liquid metal in the LECOR loop (oxygen getter) and a pre-treatment with $H_2$ gas was performed in the storage tank. The oxygen concentration in the liquid metal was measured with an oxygen sensor placed in the hot part of the loop.During the experimental campaign, the oxygen content in the liquid metal was maintained between $10^{-10}$ and $10^{-8}$ w/w%.

Experimental data showed that initially both AISI 316L and T91 steels suffer a very limited attack by Pb-Bi (1500 h). This behavior was explained considering that the thin oxide layer naturally present on the steels acts as barrier, delaying the corrosion effect by liquid metal. Differently, at higher exposure time (4500 h) the steels started to corrode significantly.

For T91 martensitic steel, a uniform attack by LBE with no preferential dissolution of alloying elements was observed and liquid metal penetrations appears on the interface between steel and liquid metal. For the AISI 316L austenitic steel, corrosion phenomenon is not homogenous even after 4500 hours and it is possible to distinguish some areas still not attacked on the specimens surface. Moreover, EDS analysis performed on the corroded layer revealed that a strong depletion of Ni had occurred, indicating that 316L steel was corroded by preferential dissolution in the liquid metal. As a consequence, the Ni preferential dissolution leads to the formation a ferritic layer on the steel surface.

Due to the dissolution of the alloying elements, both austenitic stainless steel AISI 316L and martensitic steel T91 exhibited weight loss after exposure in flowing LBE with low oxygen concentration. With increasing test time, the weight loss of specimens increased significantly. The corrosion rates of steels have been estimated from the weight variation assuming a linear evolution of the weight loss. After 4500 h of exposure, the calculated corrosion rate of AISI 316L is 6,8 $mg \cdot dm^{-2} \cdot d^{-1}$ while the corrosion rate of T91 is 10,2 $mg \cdot dm^{-2} \cdot d^{-1}$.

Comparing the obtained values, one see that the corrosion rate found for the martensitic steel T91 is higher than that for austenitic steel AISI 316L. That behavior could be due to a different stability/resistance of the oxide layers naturally present on two type of steels. Reasonable, under the test condition adopted in LECOR loop, the natural oxides film on the martensitic steel is more easily removed by the LBE than the one on the austenitic steel. This could also explain the increase in the corrosion rate observed with increasing the time of exposure.

The results about tensile tests performed after 1500 hours in LECOR loop showed that the tensile behavior of the AISI 316L steel seems to be unaffected by corrosion while the T91 steel exhibited a decrease of the area reduction factor in the engineering curve and a mixed ductile-brittle fracture morphology. This behavior of the corroded T91 steel was explained with the presence of the more aggressive Bi in the liquid metal together with long exposure of the T91 steel.

For what concerns the refractory metals, Mo, W and Ta did not show evident attacks by flowing LBE during the exposure in LECOR loop, indicating a high resistance of the materials in the liquid metal. With regard to the W and Mo, they exhibited a continuous weight loss due to dissolution phenomenon at low oxygen conditions. However, the weight loss of these metals is two orders of magnitude smaller than that of steels thanks to the low solubility of the elements in the LBE. Differently, Ta showed a weight gain, ascribable to the formation of a very thin oxide layer on the surface stable even at low dissolved oxygen content.

**PLANNED EXPERIMENTS (including time schedule)**

Planned activities will be carried out from April 2015. In this framework the LECOR facility will be employed to evaluate the corrosion behavior of 15-15Ti austenitic steel (DIN 1.4970) with and without a coating under conditions of flowing Pb at 550°C and with a high dissolved oxygen concentration (about $10^{-6}$ % wt.). The coating, to be studied to evaluate its effectiveness as anti-corrosion barrier, will consist of a $Al_2O_3$-based coating obtained by PLD (Pulsed Laser Deposition) techniques and manufactured by IIT (Italian Institute of Technology, Milan). The technique provides an $Al_2O_3$ fully dense and compact coating consisting of an homogeneous dispersion of randomly oriented ϒ-$Al_2O_3$ nanodomains in amorphous $Al_2O_3$ matrix, which allow to get a ceramic coating with metal-like mechanical properties and enhanced resistance to wear. Moreover, recent investigations of coated steel samples to static liquid Pb at 550°C after short term exposure (500 h) revealed a very good compatibility of the coating with the liquid metal. For the operation, the LECOR loop will be equipped with reliable and efficient oxygen control systems. The samples will be extracted in fixed time intervals to follow the evolution of corrosion damages by metallographic examination.

## TRAINING ACTIVITIES

Training activities can be agreed with ENEA C.R. Brasimone in the frame of these experimental campaigns under the supervision of ENEA qualified staff.

## REFERENCES (*specification of availability and language*)


1. FAZIO C., RICAPITO I., SCADDOZZO G., BENAMATI G., Corrosion behaviour of steels and refractory metals and tensile features of steels exposed to flowing PbBi in the LECOR loop, Journal of Nuclear Materials 318 (2003) 325–332.
2. AIELLO, AZZATI M., BENAMATI G., GESSI A., LONG B., SCADDOZZO G., Corrosion behaviour of stainless steels in flowing LBE at low and high oxygen concentration, Journal of Nuclear Materials 335 (2004) 169–173.
3. BENAMATI G., GESSI A., SCADDOZZO G., Corrosion behaviour of steels and refractory metals in flowing lead-bismuth eutectic at low oxygen activity, Proceedings of the IV International Conference/High Temperature Capillarity, Journal of Materials Science 40 (2005) 2465 – 2470.
4. GARCÍA FERRÉ F., BERTARELLI E., CHIODONI A., CARNELLI D., GASTALDI D., VENA P., BEGHI M. G., FONZO F. DI, The mechanical properties of a nanocrystalline $Al_2O_3$/a-$Al_2O_3$ composite coating measured by nanoindentation and Brillouin spectroscopy, Acta Materialia 61 (2013) 2662–2670.
5. FERRÉ F.G, ORMELLESE M., FONZO F. DI, BEGHI M.G., Advanced $Al_2O_3$ coatings for high temperature operation of steels in heavy liquid metals: a preliminary study, Corrosion Science 77 (2013) 375–378.