The Development of LBE Integral Test Loop, HELIOS and tests by using HELIOS

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1. Introduction

As highly promising coolant for new generation nuclear reactors, liquid lead-bismuth eutectic (LBE) has been extensively investigated in worldwide. However, there are very important problems to solve before adopting LBE as coolant of fast reactor. One is material corrosion and the other is Po occurrence. Also, the lack of experimental data for LBE thermal-hydraulic test is another problem.

To solve these problems, thermal-hydraulic test and material test were conducted by using a twelve-meter tall LBE integral test facility, named as HELIOS (Heavy Eutectic liquid metal Loop for Integral test of Operability and Safety of PEACER) which has been constructed in 2005 at the Seoul National University in the Republic of Korea.

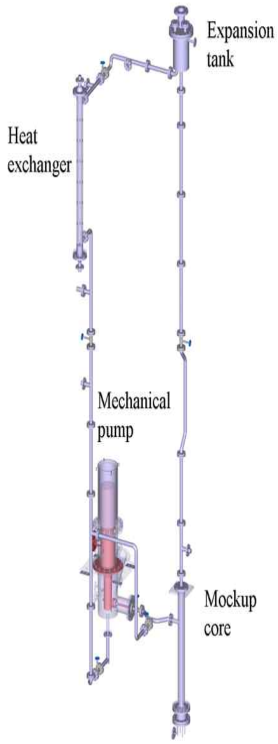

Fig. 1. 3D CAD drawing of HELIOS and picture located in the NUTRECK, Seoul National University

2. Design of HELIOS

PEACER-300 has been developed at NUTRECK of Seoul National University as a proliferation-resistant nuclear spent fuel waste transmutation reactor by using LBE coolant. The large LBE loop named as HELIOS has been developed in order to investigate the safety characteristics of LBE such as thermal-hydraulic, natural circulation capability, and operability test including prediction of material lifetime and manageability in PEACER.

HELIOS design process was based on a 3D CAD tool, CATIA®, in order to minimize the time, cost and errors. Figure 2 shows a 3D CAD tool, CATIA® of HELIOS without showing support structure. Especially for the design of materials test bypass, the CATIA and CFX combination was very powerful to find an optimized flow channel design satisfying well developed LBE flow in specimen cage. Figure 1 shows 3D CAD drawing of HELIOS and picture located in the NUTRECK, Seoul National University.

To assure the well-defined thermo-hydraulic condition of test section, thermal-hydraulic analysis was conducted by using an integrated design model consisted of CATIA and CFD. Table 1 shows the parameters of thermal-hydraulic capability from PEACER and HELIOS.

Table 1. Natural Circulation Parameters in PEACER-300 and HELIOS

Parameters	PEACER-300	HELIOS
Number of Loop	3	1
Decay Heat[Mw]	85.0	0.0174
Number of rods	77,280	4
Flow area[m^2]	6.92	0.00142
Cross sectional heated area[m^2]	4.20	0.000507
ΔT (between hotleg and cold leg)[^{o}C]	46.8	49.4
Representative flow velocity(at core)[m/s]	0.176	0.173
Natural circulation flow rate[kg/s]	12,550	2.40
Thermal center difference[m]	8.0	7.6
Total loss coefficient	30.4	24.5
Richardson number	15.2	12.2

Level sensors and oxygen sensors were designed and self-developed. A new calibration method was also developed and applied for newly developed oxygen sensors. The calibrated signal of the new oxygen sensor was -493mV for magnetite formation equilibrium line which is quite close to the theoretical value of -482mV. The measurement of mass flowrate was conducted by an orifice flowmeter calibrated by using a gyrostatic mass flowmeter within a ± 99% confidence limit. Thermocouple and pressure transducers were also calibrated.

3. The test using HELIOS

In this section, Thermal-hydraulic and material tests using HELIOS are described.

2.1 Thermal-hydraulic test

With high expectation about LBE coolant, a multi-national systematic study on LBE was proposed in 2007, which covers benchmarking of thermal hydraulic prediction models for Lead-Alloy Cooled Advanced Nuclear Energy System (LACANES). Through the LACANES benchmarking phase-I which covers forced convection behaviour, best practice guidelines for pressure losses prediction are established. Experimental test are conducted to obtain the pressure loss in the core, the gate valve, the orifice, the heat exchanger region, and the expansion tank region. LACANES benchmarking phase-II which covers prediction of natural circulation behaviour will be conducted during 2011.

2.2 Material test

The development of lead alloys coolant technology will allow for successful applications with maximized efficiency and enhanced safety. However it is well known that steels can be severely corroded by LBE if they are exposed to LBE directly at high temperature. So the main goal of this test is to develop new FeCrAl ferritic steels that are highly resistant to corrosion in LBE and have high resistance to age hardening and embrittlement at temperature up to 600^{o}C. To achieve this goal, corrosion behaviours of FeCrAl alloys with varying Cr, Al content have been experimentally studied and the amounts of hardening for these alloys were evaluated after exposure to LBE at 500^{o}C.

4. Conclusions

PEACER has been developed by Nuclear Transmutation Energy Center of Korea (NUTRECK) at Seoul National University (SNU) as dedicated transmutation reactor that is capable of eliminating all high level wastes, yielding on low and intermediate level wastes. An LBE coolant demonstration loop named as HELIOS has been developed by utilizing 3D CAD tool, CATIA®. HELIOS is a scaled-downed model of the prototype PEACER-300 with the same axial dimensions. LACANES benchmarking phase-I which covers forced convection behaviour have been conducted. LACANES benchmarking phase-II which covers prediction of natural circulation behaviour will be conducted during 2011. In material test, corrosion behaviours of FeCrAl alloys with varying Cr, Al content have been experimentally studied and the amounts of hardening for these alloys were evaluated after exposure to LBE at 500^{o}C and another material tests will be conducted during 2011.

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