ID contributo: **52** Tipo: **Short oral in replacement of poster**

Short_Oral_52: Development of a compact multivariable sensor probe for two-phase detection in high-temperature PbLi-Ar columns

lunedì 6 settembre 2021 17:55 (10 minuti)

Nuclear fusion Breeding-Blanket (BB) concepts employ attractive solid and liquid breeder materials in the form of lithium/lithium-containing compounds like Li, Pb-16Li, Li2O, LiAlO2, Li4SiO4, Li2SiO3, Li2TiO3 and Li2ZrO3. Out of these candidate materials, eutectic lead-lithium (Pb-16Li; hereafter referred to as PbLi) has gained immense focus owing to its various advantages including a high tritium breeding ratio (TBR) without an additional neutron-multiplier, circulation ability facilitating tritium-extraction outside fusion blanket, inherent immunity towards radiation damage and thermal stresses, high thermal-conductivity and reduced chemical-activity compared to pure Li. Success of a breeder concept is primarily governed by TBR and heat-extraction performance, which can be well achieved using PbLi in a self-cooled concept. However, interaction of Li with fusion neutrons to breed tritium leads to generation of helium gas as a by-product, which has a low-solubility in PbLi and could precipitate in the form of bubbles affecting system design and safety. Gas-phase generation and entrapment within a breeder/coolant liquid-metal circuit may lead to reduction in fuel-generation due to reduction in TBR, safety consideration caused by improper nuclear shielding and jeopardized structural integrity due to formation of local hot-spots. Recent simulation studies have reported significant gas generation for PbLi flow-rates upto 1000 kg/s, which further suggests various breeding blanket (BB) concepts like HCLL (Helium-Cooled Lithium Lead), WCLL (Water-Cooled Lithium Lead), DCLL (Dual Coolant Lithium Lead) and LLCB (Lead-Lithium Ceramic Breeder), therefore, would invariably be prone to such a phenomenon. An in-box Test Blanket Module (TBM) Loss of Coolant Accident (LOCA) will further lead to ingress of a high-pressure gas-phase (helium/steam) inside PbLi circuit, resulting in a liquid metal-gas two-phase flow with unconventionally high density-ratio between the two-phases, unlike the case of generally studies water-air flows. Preliminary experimental studies at Institute for Plasma Research (IPR) with water as a surrogate test-fluid corroborated presence of trapped gas-pockets at 90° bends and entrained gas-bubbles in re-circulation zones inside TBM-like complex geometry. A two-phase regime and trapped gas-pockets are also expected in lab-scale R&D facilities due to standard practices of charging liquid-metal in presence of an inert cover gas to avoid oxidation. To model such occurrences of relevance towards design and operational safety of ancillary breeder/coolant circuits towards applications in future fusion reactors, extensive experimental database needs to be generated, mandating development of proper diagnostic tools compatible with high-temperature and corrosive PbLi environment. Numerous experimental studies for room temperature and low-melting LMs have been conducted worldwide utilizing commercial and specialized techniques like particle image velocimetry, laser, γ-ray, X-ray, neutron radiography, ultrasound doppler velocimetry, etc. Although such techniques inherently benefit from their non-intrusive nature of detection, the required resources, licensing requirements, opaque nature of fluid coupled with extreme operating environments, installation constraints, requirements of localized detections and high-attenuation characteristics exhibited by liquid-metals towards radiation methods render most of the techniques challenging towards a practical implementation in a PbLi circuit. As a preliminary attempt to study two-phase flow regimes, electrical-impedance based techniques offer a better route considering ease of installation, feasibility of adaptation and better-response owing to large difference in electrical-conductivities of liquid-metal and gas. However, adaptation of such a technique towards PbLi scenario puts severe demands on electrical-insulation compatibility towards corrosive media and operational temperature upto 400℃. Considering above-mentioned limitations and unavailability

of experimental data, researchers have recently initiated studies utilizing numerical tools to predict two-phase flow regimes in PbLi/He environment. To the best knowledge of authors, no reported experimental data exists for two-phase flow detection in PbLi environments.
This work primarily aims to bridge the existing gap with development and preliminary validation of a compact sensor probe as a measurement tool to study two-phase regimes in PbLi environment. In this study, a multivariable probe employing electrical-conductivity based detection with simultaneous temperature measurement scheme is fabricated using an electrical-insulation coating of high-purity alumina (Al2O3). Fabricated probe is then validated towards detection on Argon bubbles rising in a high-temperature PbLi-Ar two-phase vertical column with bulk PbLi temperature upto 400℃. Two-phase generation in liquid-metal environment is achieved using an 8-legged spider-configuration gas sparger. Probe is functionally validated for time-averaged void-fraction varying from 0 to 0.95 covering flow regimes from dispersed bubbly flow upto in-box Loss of Coolant Accident (LOCA) characterized by a very large gas flow inside bulk PbLi. Developed probe provides high reliability with excellent temporal-resolution towards individual bubble detection using electrical-conductivity based principle while coherent two-phase bulk temperature trends provide qualitative insights about the presence of two-phase regime. Present paper provides details about sensor probe fabrication and calibration methods, PbLi-Ar two-phase test-facility, time-averaged void-fraction estimations using threshold method, bubble-frequency and bubble residence-time estimations alongwith critical observations from the preliminary experimental investigations.

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