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Measurement of liquid films thickness in a condensing and re-evaporating environment using attenuation of near infrared light

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ABSTRACT

A novel technique developed to measure liquid film thickness up to 2 mm was tested under thermodynamic conditions encountered in containment during severe accident scenario. The tests were performed in the thermal-hydraulic facility LINX located at PSI (Villigen, Switzerland), a 10 m^3 pressure vessel with precise control of the boundary conditions. In the experiments, liquid films were created on a temperature controlled wall placed in the center of the vessel. Selected tests involving condensation and evaporation on film with steady state conditions are presented. In each test, sequences of thickness mappings were recorded with an image size of 246 × 180 pixels, a projected pixel size of 0.63 mm and a frame rate of 250 fps. Uncertainty on the film thickness was estimated to 35 μm absolute over the entire measurement range based upon current calibration. Large and small structure can be observed spatially but also temporally through extracted local signal. Average and fluctuating part of the film thickness are presented and discussed for four tests where the controlled wall temperature and bulk composition were varied. Strong time-correlation in the signal was observed for rivulets whose formation is enhanced by an increase of the wall temperature.

1. Introduction

The formation of liquid films on the containment structures of a nuclear power plant is expected to occur during postulated accidents involving steam release. The evolution of the condensate on wall surfaces and its potential re-evaporation is of relevance since it influences the temperature, the pressure and the distribution of gases and aerosols inside the containment building. Extensive research with condensation on the containment structure was carried on in the last decades (de la Rosa et al., 2009). Several models such as the heat and mass transfer analogy have been developed to characterize the capacity of passive heat removal by condensation with the presence of non-condensable gases (Peterson, 2000). Thermal-hydraulic facilities were set up to validate the models and advance knowledge on the phenomena involved (Anderson et al., 1998; Malet et al., 2005). Among the experiments involving heat and mass transfers, innovative instrumentation was developed to measure global and local punctual values such as film thickness and temperature (Pan and Schultz, 2015; Ambrosini et al., 2002). The lumped parameter code ASTEC (Chatelard et al., 2014) and the CFD type code GOTHIC (GOTHIC, 2006) are examples of computational tools to simulate the containment response in the evolution of an accident. In containment codes films are treated in a rudimentary way using the Nusselt formulation (Nusselt, 1916) with correction factors and empirical relations for the case of turbulent flows and dropwise condensation. Previous investigations were conducted in the frame of the OECD/NEA SETH project where series of tests were performed in the experimental facility PANDA (Paladino et al., 2010; Bentaib et al., 2009; Andreani et al., 2010). The authors concluded that a better description of the film dynamics would be necessary to improve the predictive capabilities of the code. In particular the progression of the film towards the lower part of the containment and its re-evaporation could not be properly captured. Experimental data is needed to characterize the 2-dimentional patterns and flow regimes of films and the nature of the related heat and mass transfers.

In the frame of the LINX project, conducted at the Paul Scherrer Institut (Switzerland) we brought modern infrared technologies on a thermal-hydraulic facility in order to study water films in condensing and evaporating environments. We measure simultaneously the film thickness and the film surface temperature with a

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near infrared (NIR) and a mid-wave infrared (MWIR) camera respectively.

The present paper focused on the first technique dedicated to the film thickness measurement. After describing in details the facility and the new measurement technique, selected results obtained under heat and mass transfer conditions are presented and discussed.

2. Experimental facility and instrumentation

This section describes the LINX facility where the condensation and re-evaporation experiments were conducted and the implemented instrumentation.

2.1. LINX facility

The original LINX facility consists of single stainless steel vessel 2 m in diameter and 3.4 m high (10 m^3 in volume) designed for pressure up to 10 bar at 250 °C. It is insulated with two 200 mm thick layer of rock wool (0.06 W/m-K at 100 °C). Auxiliary lines penetrating through the top and the bottom of the facility enable the injection or venting of superheated steam as well as non-condensable gas such as nitrogen or helium. Dry gas can be injected up to 1400 ln/min while steam is produced by a 240 kW steam generator with a maximum stable output flow of 250 kg/h. A vertical temperature controlled wall, 0.4 m wide and 2.1 m high, consisting of 9 aluminum blocks (400 × 238 × 94 mm) was built in the center of the pressure vessel (Fig. 1, right). The blocks are covered by a single 0.7 mm thick aluminum sheet. The surface of the metal sheet has undergone a chemical etching treatment to ensure a diffuse reflection of the light. Contact between the block and the aluminum sheet is ensured by use of thermally conductive paste (Dow Corning DC1-4174). The blocks are connected to two independent water loops: one cold loop connected to the demineralized water network and one warm loop fed by a 2 m^3 reservoir tank (Fig. 1, left). The mass flow rate is independently controlled for each block. The water from the reservoir tank can be heated up to 95 °C with a parallel loop directed through a heat exchanger

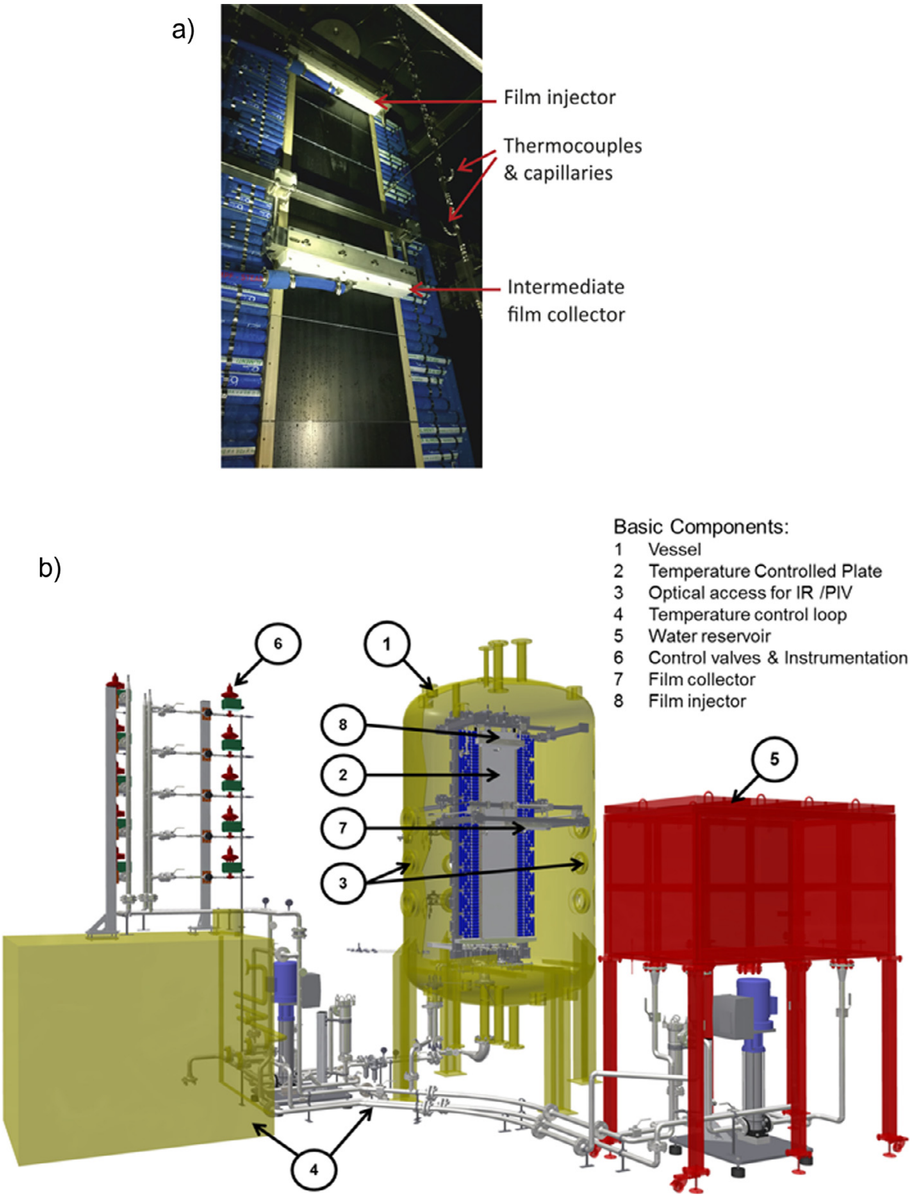

Fig. 1. left- 3D-view of the LINX facility: Main components are described on the facility overview; right – front view of the temperature controlled wall with film injector and film collector before covering with the treated aluminum surface.

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