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Concentration and Temperature Measurements by means of Raman Spectroscopy in Case of condensation with non-condensable gas

Abstract

The condensation of steam in presence of a non-condensable gas plays an important role in many technical applications, e.g. for design and operation of condensers. The process is particularly safety-relevant in case of loss-of-coolant accidents in nuclear reactors. If pure steam condenses at a cold surface, the heat and mass transfer resistances in the vapour phase can be neglected. If a non-condensable gas is present, it can accumulate at the phase interface and reduce the heat and mass transfer in the vapour phase. A large leakage in the primary system of a pressurised water reactor leads to a loss of coolant. Emergency core cooling (ECC) water, e.g. from accumulators, is injected to keep the core cooled. Steam condenses at the ECC water and thus the pressure in the system decreases and the temperature of the injected water increases. This warming reduces the danger of thermal stresses by cold water flowing down at the wall of the reactor pressure vessel. The ECC water in the accumulators is saturated with nitrogen, which is used for the pressurisation. This nitrogen is released during the pressure loss and reduces the condensation at the cold ECC water, in particular at low steam velocities. This hinders the pressure decrease in the primary system and the heating of the ECC water. A further point of interest related to leakages in the primary system is the pressure rise in the reactor containment. The steam must condense at the cold containment walls in order to avoid design exceed pressure in the containment. The presence of air leads to a reduction of the condensation and thus to a higher pressure in the containment. In terms of these two problem fields – condensation of steam in presence of a non-condensable gas at a horizontal cold water layer and a vertical cold wall – experiments were made to investigate the influence of a non condensable gas in case of direct contact condensation. An optical measurement technique, the linear Raman spectroscopy, is used to measure local concentration profiles. Approximation of the measured concentration profiles with suitable theories delivers the local heat and mass transfer.

The laser measurement technique linear Raman spectroscopy allows visualising and measuring the concentrations in the boundary layer of a stratified flow in case of condensation with non-condensable gas. Raman spectroscopy makes it possible to measure temperatures in the water layer. But the experiments show, that it is difficult to get accurate temperatures near the water surface. Experiments on a horizontal stratified flow point out several interesting phenomena in the vapour phase, like the accumulation of nitrogen in a small range of the steam Reynolds' number and the formation of a boundary layer with a linear nitrogen concentration profile. The transient experiments show, that the processes under natural convection are different between co-current flow and counter-current flow. This is caused by different accumulation of nitrogen in case of co-current and counter-current flow. The

experiments are a good basis for developing and validating numerical codes for the calculation of direct contact condensation in presence of a non-condensable gas.

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