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Cooling performance of CO2 boiling flows: new measurements at LAPP and CERN

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Due to its many favourable thermo-physical properties, CO2 in boiling state has been adopted as preferred refrigerant for the future generations of silicon detectors at the LHC. The data available on CO2 boiling in channels of small hydraulic diameter (say, below 3 mm) is limited and often affected by too large uncertainties. This obliges the detector designers to long iterative phases of experimental tests, which could be sensibly reduced by the availability of reliable models. In order to cope with this unsatisfactory situation, two independent experimental activities have been conducted at LAPP and at CERN.

To prepare for the High-Luminosity phase of LHC (HL-LHC), the ATLAS Inner Detector will be replaced in 2024 by the new Inner Tracker (ITk) system, entirely cooled with two-phase CO2. In the barrel part of ITk, the heat flux values flowing from the pixel modules to the cooling fluid through the brazed local support can surpass the 100 kW/m2. As the model currently used to estimate the heat transfer coefficient (HTC) has never been validated for heat fluxes of this magnitude, it was decided at LAPP to test the predictions of the ITk detector thermal behaviour with simplified prototypes of the detector local supports. The thermal performances have been extensively measured in a dedicated test setup, under a wide range of operational conditions (coolant temperature, mass flow, vapour quality⋯). The HTC is then extracted from the large dataset using a nuisance parameter fit and compared to the theoretical predictions. It will be presented the thermal test setup, the FEA and HTC modelling of the ITk thermal prototypes, and the fit method used to extract from our dataset the model parameters (in situ material thermal conductivities, manufacturing variability, HTC⋯). The experimental HTC values extracted from the dataset are compared to the CO2 model predictions, and the discrepancies discussed. The results are shown to improve the precision of the predictions over a wider working region than the one considered by the current theoretical model. The impact of the cooling pipe material (titanium vs stainless steel) on the CO2 thermal performance is also discussed.

In the meanwhile, in the context of the AIDA-2020 project, a new test stand has been designed and built at CERN to characterize with an unprecedented level of accuracy boiling flows of CO2 in mini- and microchannels with hydraulic diameter ranging from 2 to 0.1 mm. In this presentation, initial important results from this long term campaign will be presented and discussed. In particular, we will discuss the trends of heat transfer coefficient and pressure drop in stainless steel tubular evaporators of different diameters for saturation temperatures from +15 to -25 ℃, mass fluxes from 1200 to 100 kg·m-2·s-1 and heat fluxes from 5 to 35 kW·m-2. Furthermore, to improve the understanding of the physical processes occurring in mini- and microchannels, flow visualisation have also been used to explain the measured trends. In particular, the CO2 flow patterns in a silicon- multi-micro-channels cold plate have been observed with a high-speed camera capable of up to 100 000 frames per second. The flow patterns have been observed for saturation temperatures from +20 to -25 ℃ and various flow rates whilst applying a fixed heat load on the face of the cold plate. With the help of these "visual maps"of CO2 flow boiling, it is possible to relate the trends of the heat transfer coefficient at specific saturation temperatures to the flow patterns occurring within the channels, which is again very valuable for the creation of new semi-empirical models on evaporative flow of CO2 in mini- and micro-channels. In addition, the observations made show in a very spectacular way how the fluidic and thermophysical behaviour of CO2 changes dramatically with the saturation temperature and how this may affect the resulting heat transfer coefficient and pressure drops across the evaporators.

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