Boiling Prediction in EGR Coolers

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VALEO Thermal Systems designs and manufactures systems to optimise thermal energy management for a cleaner, safer and more reliable mobility. Its product portfolio includes Exhaust-Gas Recirculation (EGR) coolers, which are the object of the present work.

The EGR system emerged with the increase of high-pressure direct injection (HDI) engines and its use was extended to turbocharged engines in the early 2000s, to reduce NOx and meet the European regulations. In recent years, the use of the EGR cooler has been also extended to gasoline engines aiming at the improvement of the knocking resistance and the reduction of fuel consumption.

The main function of an EGR cooler is to decrease the exhaust gas temperature by transferring heat to a coolant stream. Due to the new emission standards and the requirements for gasoline applications, the thermal loads of such heat exchangers are increasing, leading to critical operating points where coolant may boil resulting in the degradation of both the cooler and the coolant itself.

In this scenario, coolant boiling prediction has become an issue of major concern in the design process of EGR coolers. Therefore, a numerical tool ("egrcFoam") for the prediction and quantification of coolant boiling in EGR coolers has been developed in OpenFOAM® (-v1706). It consists of an evolved version of the standard "chtMultiRegionSimpleFoam" to account for the coolant subcooled nucleate-boiling, that may take place on the cooler internal walls.

The novelty of the solver relies on the boiling model developed to describe the coolant behaviour. The multiphasic nature of the flow, when boiling arises, is addressed using a mixture model approach. The condensation and evaporation rates are given by the widely used Lee model, whereas the wall heat transfer enhancement due to the presence of nucleate boiling is considered by means of an in-house developed wall law.

Accuracy and robustness of the methodology have been eventually checked for different EGR coolers operating under several operating conditions, even reaching severe boiling levels, for which experimental data was gathered at VALEO's boiling test bench. The results of the "egrcFoam" are in good agreement with experimental data, proving the suitability of the numerical tool as a support tool of the design process for the next generation of heat exchangers.