Application of a lookup table approach based on unstructured grids to the thermodynamic modelling of transcritical expansions

Marta Zocca*, **Antti Uusitalo***, **Teemu Turunen-Saaresti***

* Fluid Dynamics, School of Energy Systems
LUT University
Yliopistonkatu 34, 53850 Lappeenranta, Finland
e-mail: marta.zocca@lut.fi, antti.uusitalo@lut.fi, teemu.turunen-saaresti@lut.fi

ABSTRACT

In many technical applications, mainly in the sectors of power conversion and transportation of high-pressure fluids, the behaviour of fluid flows significantly departs [1] from the ideal-gas or the ideal-liquid models. Elaborate and computationally expensive models based on highly nonlinear and multiparameter Equations of State (EoS) are required in order to predict the thermophysical properties of such flows. In all mentioned applications, an accurate prediction of thermophysical properties is essential for adequate design and fluid dynamic analysis of components and systems.

Expansions starting from the supercritical thermodynamic region and ending in the superheated vapour region are exploited in technical applications such as Organic Rankine Cycles (ORC) to increase the efficiency of the cycle. These expansions, called transcritical, cross the thermodynamic region close to the critical point and around the critical isotherm, which is a region characterized by large gradients in thermodynamic properties. In addition to the high computational cost of the resolution of complex EoS, such large gradients in thermodynamic properties entail significant practical challenges in the numerical modelling of transcritical expansions, since they often cause the solvers of EoS to diverge.

In order to overcome these technical challenges, a lookup table approach for the numerical modelling of transcritical expansions is developed, which is presented in this talk. The derived thermodynamic properties are calculated from the input pairs (P, T), (P, s), (h, s), (T, s), and (P/P_{critical}) using external thermodynamic libraries [2, 3]. Moving from the promising results obtained by previous investigators in the simulation of single-phase non-ideal flows [4], lookup tables based on unstructured grids are adopted, instead of more conventional tabulations based on cartesian grids. The input pairs represent the two-dimensional coordinates of the nodes of a triangular unstructured mesh, which is generated for a given range of input properties using a fully-automated procedure. The derived thermodynamic properties at any query point over the input range are computed using linear interpolation. Specifically, a barycentric coordinate interpolation scheme is applied along the triangular grid element containing the query point, in order to reconstruct the derived thermodynamic property based on the values of the same property at the vertices of the triangle. At those baseline grid points where the direct computation of the derived thermodynamic properties fails due to the divergence of the thermodynamic solver, the values of the derived properties are reconstructed from the derived properties at neighbouring grid points using an inverse distance weighting algorithm.

Despite its simplicity, the method proved of satisfactory accuracy and computational efficiency when applied to the design and Computational Fluid Dynamics (CFD) analysis of components operating transcritical expansions. Exemplary applications are discussed, which include the design of supersonic ORC turbine blade passages and design verification through CFD simulations.

Keywords: Thermodynamics, turbomachinery, non-ideal compressible flows, supersonic flows.

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