Abstract

Steam turbines play a vital role in energy and industrial sectors due to their high efficiency and reliability. Among various turbine stages, the low-pressure (LP) stage is of particular interest because of the formation of wet steam caused by condensation during expansion. This phenomenon leads to energy losses, reduced efficiency, and mechanical issues such as blade erosion due to droplet impact. The present thesis focuses on investigating and improving the performance of the LP stage of a steam turbine by analyzing the behavior of wet steam through advanced numerical simulations and experimental comparisons.

To achieve this, several CFD models were evaluated, and their results were validated using experimental data from a Laval nozzle and a linear blade cascade. Among the tested models, those using Gyarmathy and Fuchs-Sutugin droplet growth approaches coupled with appropriate equations of state showed the most accurate predictions. These findings emphasize the need for careful selection of numerical models to reliably simulate wet steam flows.

Furthermore, detailed 3D simulations were conducted on the last stage of a 200 MW steam turbine to analyze the impact of condensation on flow behavior and efficiency. The results revealed that the stator blades contribute significantly to overall losses, with entropy generation concentrated near the stator hub and rotor shroud. Condensation was found to alter shock wave patterns, reduce Mach numbers in high-wetness regions, and lower outlet flow angles, ultimately decreasing stage efficiency and power output.

In the final stage of this study, various stator blade modifications were tested, including spanwise rotation, pitch changes, profile alterations, and axial/circumferential sweeps. The Bakhtar profile combined with a circumferential lean in the direction of rotor rotation showed the best performance, improving stage efficiency by 3.2%. These results underscore the critical influence of blade geometry on the aerodynamic and thermodynamic performance of wet steam turbines.

Overall, this work contributes to the development of accurate numerical tools for predicting condensation effects in steam turbines and provides practical guidelines for blade design improvements aimed at minimizing energy losses and enhancing turbine efficiency.