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Effect of superheating the inlet steam on the steam-liquid two-phase flow in the Bakhtar steam turbine blade

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Extended Abstract

Introduction

Numerous challenges in power generation cycles arise from the phenomenon of condensation in compressible steam flow, leading to thermodynamic losses and mechanical damage to turbine blades. These issues result from the formation of liquid droplets due to rapid pressure and temperature drop in steam flow, creating a two-phase flow. In this research, by applying the technique of increasing the superheat degree of inlet steam to the turbine blade, the effect of this parameter on pressure ratio, temperature, Mach number, liquid mass fraction, droplet radius, and nucleation rate has been simulated and investigated. The primary objective of the current study is to analyze the impact of increasing the superheat degree to reduce the destructive effects of the liquid phase and enhance the performance of steam turbines.

Problem Definition

In the power generation industry, a portion of the energy losses in the thermodynamic cycle occurs because steam turbines are not designed to operate with wet steam flow. The presence of the liquid phase leads to efficiency losses and mechanical damage, such as erosion, which incurs significant costs given the high price of steam turbines. In the low-pressure stages of the turbine, steam expands and, due to supercooling, non-equilibrium condensation occurs, resulting in a two-phase flow. This non-equilibrium condensation happens as an irreversible phase change, and the presence of liquid droplets causes efficiency loss, blade erosion, and mechanical damage. This study numerically investigates a two-dimensional simulation on the stator blades of the low-pressure section of a Bakhtar turbine, focusing on increasing the inlet blade temperature and superheating the steam to prevent these losses.

Results

The primary objective of the present study is to investigate the effect of increasing the inlet temperature to mitigate the adverse effects of the liquid phase. The presence of the liquid phase in steam turbine blades leads to thermodynamic losses and mechanical damage. Thermodynamic losses result from the phase change, while mechanical damage is caused by the impact of liquid droplets on the surface of the steam turbine blades. In the results section, the impact of increasing the inlet temperature on the following parameters within the steam turbine blade and supersonic nozzle is examined: static pressure distribution, temperature, Mach number, nucleation rate, droplet count, supersaturation ratio, liquid mass fraction, droplet radius, inlet mass flow rate, condensation losses, and droplet growth.

The considered temperature range for the blade inlet is from 380 K to 410 K. When the flow enters the steam turbine blade, pressure and temperature decrease in the convergent section due to flow expansion, while the Mach number increases in this region. At the throat, the flow reaches a choked condition, and the Mach number becomes unity. In the divergent section of the blade, the flow continues to expand and becomes supercooled. This supercooled flow is in a non-equilibrium state. Pressure and temperature continue to decrease, and the Mach number increases. With the occurrence of the nucleation phenomenon and the flow becoming two-phase, latent heat is released. According to the principles of Rayleigh flow, the release of latent heat in the divergent section of the blade causes abrupt changes in the flow. These abrupt changes refer to a shock wave. The shock wave resulting

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from the two-phase flow is known as a condensation shock. Upon the occurrence of the condensation shock, temperature and pressure increase, and the Mach number decreases. After the shock, the flow resumes its expansion and, at the trailing edge of the blade, experiences fluctuations due to the occurrence of aerodynamic oblique shocks.

Conclusion

One technique to mitigate the effects of liquid droplets in steam turbine blades is the superheating technique. This study employed the superheating technique to reduce the adverse effects of moisture. Initially, seven different temperature levels were considered for the turbine blade inlet, and then the impact of increasing the inlet temperature on the flow pattern was investigated and analyzed. The most important results are as follows:

- The low-temperature region in the steam turbine blade shifts downstream with increasing inlet temperature, aerodynamic shocks occur with a delay, and their intensity increases.
- Increasing the inlet temperature causes nucleation to begin slightly later along the blade centerline, and the peak nucleation rate increases with higher inlet temperatures.
- As the inlet temperature increases, the liquid mass fraction in the steam turbine blade decreases, with Case 7 exhibiting the lowest liquid mass fraction. The highest liquid mass fraction, approximately 0.05, was observed in Case 1. By increasing the steam inlet temperature to 410 K, the peak liquid mass fraction is reduced to less than 0.03.

This study demonstrates that increasing the inlet temperature can effectively contribute to reducing the formation of the liquid phase and mitigating condensation-related losses in steam turbine blades.

Key words: steam turbine blade, non-equilibrium condensation, droplet radius, condensation losses, turbine inlet temperature

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