

Evaluation of Suspended Particles Impact on Condensation in Expanding Flow with Aerodynamics Waves

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Abstract : Condensation has a negative impact on turbomachinery efficiency in many energy processes. In technical applications, it is often impossible to dry the working fluid at the nozzle inlet. One of the most popular working fluid is atmospheric air that always contains water in form of steam, liquid, or ice crystals. Moreover, it always contains some amount of suspended particles which influence the phase change process. It is known that the phenomena of evaporation or condensation are connected with release or absorption of latent heat, what influence the fluid physical properties and might affect the machinery efficiency therefore, the phase transition has to be taken under account. This research presents an attempt to evaluate the impact of solid and liquid particles suspended in the air on the expansion of moist air in a low expansion rate, i.e., with expansion rate, $P \approx 1000 \text{ s}^{-1}$. The numerical study supported by analytical and experimental research is presented in this work. The experimental study was carried out using an in-house experimental test rig, where nozzle was examined for different inlet air relative humidity values included in the range of 25 to 51%. The nozzle was tested for a supersonic flow as well as for flow with shock waves induced by elevated back pressure. The Schlieren photography technique and measurement of static pressure on the nozzle wall were used for qualitative identification of both condensation and shock waves. A numerical model validated against experimental data available in the literature was used for analysis of occurring flow phenomena. The analysis of the suspended particles number, diameter, and character (solid or liquid) revealed their connection with heterogeneous condensation importance. If the expansion of fluid without suspended particles is considered, the condensation triggers so called condensation wave that appears downstream the nozzle throat. If the solid particles are considered, with increasing number of them, the condensation triggers upwind the nozzle throat, decreasing the condensation wave strength. Due to the release of latent heat during condensation, the fluid temperature and pressure increase, leading to the shift of normal shock upstream the flow. Owing relatively large diameters of the droplets created during heterogeneous condensation, they evaporate partially on the shock and continues to evaporate downstream the nozzle. If the liquid water particles are considered, due to their larger radius, they do not affect the expanding flow significantly, however might be in major importance while considering the compression phenomena as they will tend to evaporate on the shock wave. This research proves the need of further study of phase change phenomena in supersonic flow especially considering the interaction of droplets with the aerodynamic waves in the flow.

Keywords : aerodynamics, computational fluid dynamics, condensation, moist air, multi-phase flows

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