Numerical Investigations on Direct Contact Condensation of Vapor Jets in Subcooled Liquid

At the booster turbopump exit of a high pressure staged combustion cycle based cryogenic rocket engine, hot gaseous oxygen after driving the booster turbine mixes with subcooled liquid oxygen from the booster pump leading to the complex phenomena of direct contact condensation of hot oxygen gas. Direct contact condensation (DCC) occurs when a stream of gas/vapor comes in contact with subcooled liquid and is accompanied by high heat transfer coefficients due to the absence of separating walls as in the case of conventional heat exchange processes. Although substantial works are available in the direct contact condensation of steam jets in subcooled water due to its wide range of applications in the nuclear reactors, chemical and process industries, there is little information available in the open literature on direct contact condensation phenomena of cryogenic fluids like oxygen.

In the present thesis, a numerical technique based on two-fluid framework with thermal phase change model is adopted to understand and predict the different phenomena associated with DCC of steam jets in subcooled stagnant/flowing water in the subsonic oscillatory regime. The necessary modifications in the solution methodology to enhance the accuracy of the solution have been suggested. The results are validated with the experimental data available in the literature. The validated numerical model is then extended to predict the DCC of oxygen vapor jets in subcooled liquid oxygen cross-flow. A detailed parametric analysis is carried out to find out the effects of all the operating parameters and suitable correlations for the critical design parameters are proposed. The numerical model is finally applied to analyze the flow-field through a multi-port oxygen condenser, typically found at the booster turbopump exit of a staged combustion cycle based rocket engine. Design recommendations are provided for the economic and efficient design of the multi-port condenser.

The present thesis will serve as an useful guideline for researchers working on numerical studies of direct contact condensers at room and cryogenic temperatures as well as for the design of these condensers.

Keywords: cryogenic rocket engine, direct contact condensation, two-fluid model, heat transfer coefficients, condensers.