

# **Numerical Studies on Mass Transfer Enhancement by Vortex Generators**

*A Thesis submitted*

*in partial fulfilment for the degree of*

**Doctor of Philosophy**

*by*

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**February 2020**

## Abstract

Limited exchange time available for transfer processes in high speed flows calls for energy-efficient enhancement methods. Passive heat/mass transfer enhancement techniques such as flow or surface manipulations are widely preferred owing to its simplicity. Mass transfer enhancement methods by vortex generators with minimal pressure loss find applications in the field of chemical processing systems, aerospace, hybrid rocket propulsion systems, industrial gas turbines etc. Engineered surfaces, rough surfaces, extended surfaces, swirl flow generators, coiled tubes, etc. are used in conventional passive enhancement methods. Mass transfer enhancement is often achieved by generating secondary flows, and reducing boundary layer thickness that develops favorable gradients. Passive mass transfer enhancement from the surface of a liquefying substance using Lateral Sweep Vortex Generators (LSVG) alone and its combination with dimpled surface placed in high-speed flow are analyzed. Numerical simulation of three-dimensional turbulent compressible flow field involving species transport has been carried out using Advection Upstream Splitting Method (AUSM) scheme based Finite Volume solver. A temperature dependent mass efflux boundary condition has been developed and implemented in the computational procedure for updating the boundary mass flux as a function of the temperature of adjoining fluid mass. The computational procedure has been well validated using the experimental wall pressure profile and heat transfer coefficients reported for similar vortex generators placed in high-speed flow. Computations could capture the complex flow features resulted by the vortex-boundary layer interactions. Convective mass transfer of species is found to get improved in the wake region of the LSVG by the horseshoe vortices and further get transported downstream by the counter-rotating vortex pair. Extensive numerical simulations have been carried out with several lateral sweep angles of LSVG to explore the role of vortices in promotion of the convective mass transfer. It has been observed that the mass efflux enhances with an increase in sweep angle of the vortex generator due to the vorticity augmentation in the wake region. Analysis of the vortex trajectories could figure out the influence of vortex interactions leading to the peak mass efflux. An analysis using the method of images and potential flow theory establishes a coherence between vortex trajectory and location of peak mass transfer enhancement in the flow field. Further, an exponential-power law based correlation between relative Sherwood number and relative

streamwise vorticity has also been developed for various configurations analyzed. Intensity and strength of the asymmetrical vortices attributes to further mass transfer augmentation in the wake region. Placement of a Variable Sweep Vortex Generator (VSVG) in high-speed flow results in asymmetrical vortex interaction on the mass transferring surface. VSVG has a wedge shape with different sweep angles on its lateral sides and a slant top surface. This novel geometrical features induce large-scale asymmetrical transverse vortices in its wake region as the compressible freestream spills and expand over it. Thus, VSVG realizes larger gradients on associated boundaries that promote transfer effects. Oscillatory nature of the transverse counter-rotating vortex pair interaction enables the evolved mass to convect further into the free stream. Mass transport profile in the entire flow field is found to strongly depend on the vortical fluid motion. Combination of passive mass transfer enhancers is emerging due to the inherent limitations of flow manipulation that a single surface feature can perform. These methods can sustain sharp gradients on the solid-fluid interface for wider expanse, thereby the effectiveness of mass/heat transfer process can be augmented considerably. Convective mass transfer augmentation systems call for the requirement of not only the enhancement near the surface but also the evolved mass should be carried away to the farther locations in adjoining free stream. Therefore, the sustenance of the strength of the evolved vortex system in the wake of the vortex generator is a key objective while selecting combinational convective mass transfer augmenting system. Unsteady RANS method could accurately describe the unsteady vortex boundary layer interactions effects attributed by LSVG-dimple combination. Extensive numerical simulations have been performed to analyze the nature of the evolution of secondary flow structures and their role in the promotion of mass advection for various geometry and flow conditions. Q Criterion estimates have been used for identifying region of intense vortex fluid motion and its role in the promotion of mass transfer. Present vortex generator dimple combination can enhance mass transfer for the wider expanse of the domain. Unsteady numerical computations have been extended to derive correlations for the estimation of spatiotemporal convective mass transfer effects.