THREE-DIMENSIONAL COMPUTATIONAL FLUID DYNAMICS SIMULATION OF THE HOLLOW-CONE SPRAY PROCESS

Massimiliano Di Martino – Advisor: Prof. Pier Luca Maffettone

Curriculum: Ingegneria Chimica

The transition from bulk liquid to droplet dispersed phase, in a gaseous atmosphere, represents an outstanding question in several application fields. Most of them are related to the automotive and aerospace industries, where the injection performance determines the quality of the liquid fuel disintegration and combustion.

With the advent of the SARS-CoV-2, it was clear that sprays and aerosols are of the utmost importance in our daily lives. Special attention is given to new spray technologies for surface disinfection into open areas and workplaces. This application field emphasizes the current interest in investigating the key aspects that determine the performance of small-scale cleaning sprayers.

Other areas of interest, such as medical device for drug delivery, industrial painting and electrostatic coating processes, are also open to research on the multiphase atomization modelling. The latter plays a key role also in a wide variety of consumer goods, where spraying is needed to distribute liquids, often even complex liquids, onto surfaces.

Spray may be carried out in several ways, and different factors do affect spray performances. The atomizer configuration, gaseous medium and liquid properties influence the jet morphology and spray ligament/droplet distribution into the environment.

The first attempt to describe how a liquid jet disintegrates dates back to Rayleigh, who proposed a theory for ligaments breakup into drops from a cylindrical channel. Since then, different scenarios have been considered to analyse the details of jet disintegration under specific flow conditions.

The liquid breakup mechanism that characterizes the atomization process is influenced by several fluid flow parameters of both the dispersed phase, i.e. the liquid atomized, and the continuous phase, i.e. the gaseous medium in which the liquid is dispersed. The break-up phenomenon is divided in primary and secondary break-up/atomization. During the primary atomization, the liquid sheet disintegrates in small ligaments, blobs and droplets. Then, many of the droplets produced in the first step of fragmentation interact with each other and coalesce, collide or break down into smaller droplets. This latter step is known as secondary atomization.

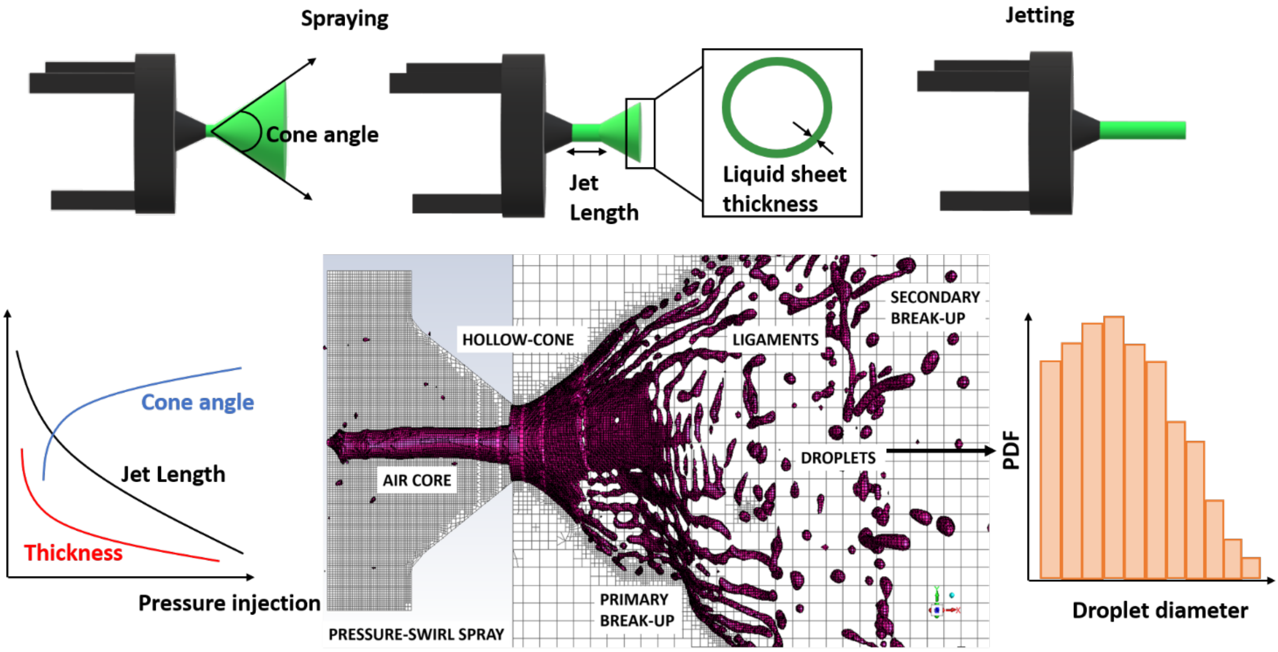
More complex atomizer configurations have been considered depending on the specific application requirements. When applications demand wide spray patterns, they are achieved by forming liquid sheets instead of straight jet. In this case, specific devices could be implemented to further expand the ejected liquid sheet against the contracting surface tension forces. The simplex pressure-swirl atomizers achieve this condition by making the fluid flowing through tangential holes, imparting a resultant swirling motion. In these devices, the pressure energy is converted into kinetic energy leading the swirling liquid to produce a core of air, resulting in a hollow cone spray. These swirling nozzles are the object of my PhD program.

During the first year of the PhD research work, different key aspects and main characteristics of the pressure-swirl spray process at small distance from the nozzle exit orifice have been investigated by using a Computational Fluid Dynamics (CFD) software. Thanks to the Volume Of Fluid (VOF) method, we showed transient simulations in which the liquid-gas interactions take place within and outside the nozzle, simultaneously. Consequently, depending on the different liquid properties and geometric features, we examined qualitatively the hollow-cone spray performance in terms of cone angle and liquid sheet morphology. In this regard, a stability analysis of the liquid sheet morphology has been performed throughout the second year of the project. For a Newtonian fluid, by properly tuning Reynolds and Ohnesorge numbers, we showed that it is possible to differentiate two main spray configurations: spraying and jetting. The classical hollow-cone shape resulting from a pressure-swirl atomizer can degenerate into a straight jet under specific operating conditions. When the conical film collapses in on itself, the resulting spray deteriorates in terms of ligament and drop formation.

The hollow-cone spray investigation also included the characterization of the non-Newtonian atomization process. Since the significance of the viscosity effect is widely acknowledged in the field of pressure-swirl atomizers, we focused our attention also on the atomization quality by comparing the Newtonian and non-Newtonian fluid behaviors. In both cases, we find a critic viscosity that marks the switch from spraying to jetting regime.

Lastly, the third year of the PhD program concerned the detailed investigation of the Newtonian and non-Newtonian primary breakup at longer distances from the nozzle exit orifice of the pressure-swirl device. From the numerical setup point of view, a dynamic mesh adaption has been implemented to improve the mesh quality and capture accurately the primary breakup at larger length scales. In this way, we compared the Newtonian and non-Newtonian spray pattern also in terms of ligament and droplet distributions.

Concerning the droplet size, through the Volume Of Fluid – to – Discrete Phase Model (VOF-to-DPM), we showed the influence of the viscosity and surface tension on the particle size distribution over a larger external domain.



References:

Rayleigh, L., “On the instability of jets”. Proceedings of the London Mathematics Society. S1-S10 (1), 4-13 (1878).

Lefebvre, A.H., McDonell, V.G., “Atomization and Sprays”. CRC Press, Taylor & Francis Group (2017).

Laurila, E., Roenby, J., Maakala, V., Peltonen, P., Kahila, H., Vuorinen, V., “Analysis of viscous fluid flow in a pressure-swirl atomizer using large-eddy simulation”. International Journal of Multiphase Flow. Volume 113, 371-388 (2019).

Laurila, E., Koivisto, S., Kankkunen A., Saari, K., Maakala, V., Jarvinen M., Vuorinen, V., “Computational and experimental investigation of a swirl nozzle for viscous fluids”. International Journal of Multiphase Flow. Volume 128, 103278 (2020).

Ding, J.-W., Li, G.-X., Yu, Y.-S., Li, H.-M., “Numerical investigation on primary atomization mechanism of hollow cone swirling sprays”. International Journal of Rotating Machinery. Volume 2016, 1201497 (2016).

Shao, C., Luo, K., Yang, Y., Fan, J., “Detailed numerical simulation of swirling primary atomization using a mass conservative level set method”. International Journal of Multiphase Flow. Volume 89, 57-68 (2017).

Massimiliano Di Martino, PhD student XXXIV cycle, May 2021