**The Role of Safety for the Implementation of Cryogenic Systems**

Gianmaria Pio

*Dipartimento di Ingegneria Civile, Chimica, Ambientale e dei Materiali dell’Università di Bologna*

*gianmaria.pio@unibo.it*

The need for sustainable and environmentally friendly raw materials, together with the geopolitical instability, pushed toward the development of alternative technologies in several industrial fields. A clear example of this tendency is the energy supply chain, where several molecules showing the potentiality to be alternative fuels have been produced and deeply investigated. The novelty in the chemical structure, leading to different physical properties, has required the adaption of the existing combustion and storage conditions, together with process layout. Besides, the utilization of low-temperature conditions has been largely suggested because of the possible lean solutions and the subsequent reduction in the production of the most harmful pollutants. Moreover, also storage and transportation systems are facing an era of great changes. Indeed, cryogenic transportation has promoted the exploration and exploitation of remote reservoirs, with obvious implications for the differentiation of possible sources. One of the main actors involved in this mutation is liquefied natural gas (LNG), as testified by the increasing number of research projects investigating this topic. The knowledge and know-how required for the realization of infrastructures and processes suitable for LNG production, transportation, and utilization have positive spill-over toward the development of technological solutions promoting the hydrogen economy. Indeed, liquid hydrogen (LH2) has been considered one of the most promising fuels, especially for the civil and industrial transportation fields, mainly because of its carbon-free nature and elevated energy density. However, the shift toward cryogenic conditions has posed new challenges, especially from the safety perspective, requiring the development and validation of dedicated sub-models for the evaluation of the source terms and physical-chemical phenomena.

Dedicated research projects have unravelled some of the most peculiar phenomena occurring at extremely low temperatures (e.g., mist condensation, non-equilibrium evaporation, and the ortho-to-para transformation). It is also worth mentioning that the initial conditions strongly influence the chemical aspects too, making some empirical correlations developed for temperatures above atmospheric ones unreliable. In this sense, the development and implementation of detailed kinetic mechanisms deriving from automated approaches are strongly suggested. Besides, the increasing availability of computational power has opened the integration of these mechanisms, in a reduced form, in computational fluid dynamic (CFD) models for the evaluation of physical-chemical interactions in a wide range of operative conditions and 3-dimensional domains. On the other hand, the main drawbacks are represented by the increase in complexity of the analyses, requiring specific expertise and engineering tools. The numerical root of the described approaches suggests the realization of a validation procedure. However, practical limitations in producing a robust experimental database exist, requiring additional considerations in the design of experiments (e.g., the ineffectiveness of traditional emergency response strategies and material embrittlement).

In this view, this lecture outlines and presents the most relevant phenomena and available techniques for the experimental and numerical characterization of the safety aspects determining the behaviour at low temperatures relevant for applications related to chemical engineering and process plants.

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