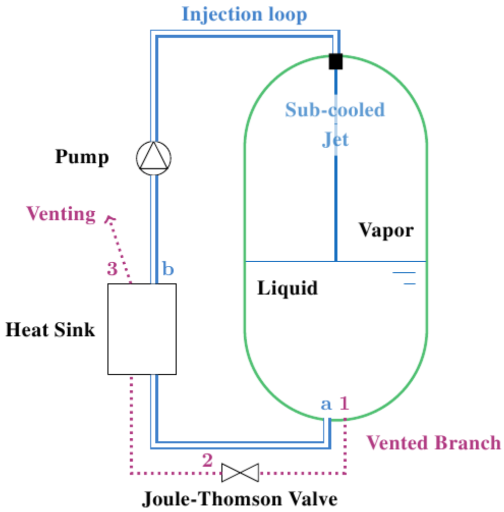
THERMODYNAMIC CONTROL OF CRYOGENIC PROPELLANT TANK

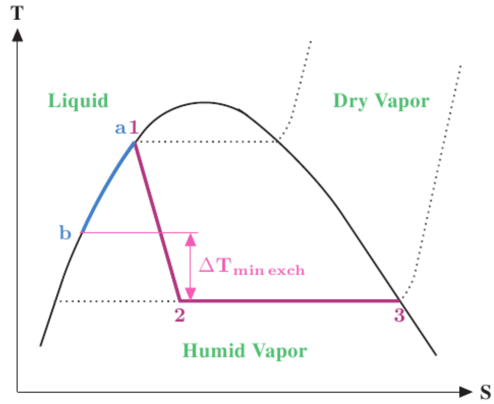
PhD thesis proposal
CNES grant

Schedule : grant application (end March 2017) starting period (Fall 2017)

Context

Future operations in space exploration will require the ability to store cryogenic liquids (hydrogen and oxygen) for long duration. Residual heat loads due to sun or heat conduction in the launcher structure induce cryogenic propellant vaporization and tank self-pressurization. Due to the extended duration of the mission, propellant management or control is required to avoid storage failure. In zero or micro-gravity, liquid concentrates on the wall of the tank, under the effect of surface tension forces, while ullage vapor is at the center. These specific conditions make complex the definition and evaluation of a pressure control system. A possible solution to the control consists in injecting, into the ullage of vapor, a subcooled fraction of the liquid propellant in the form of a jet or a spray. This control mode is designated under the generic name of Thermodynamic Vent System (TVS).





During previous phases of the project, conducted at LEGI with the support of CNES and Air Liquide, a thermodynamic control experiment was designed and operated. It uses a simulant fluid which, at atmospheric pressure, vaporizes at 50°C. The development of a novel method for active thermal insulation ensures to date excellent control of wall conditions. Measuring the vertical distribution of temperature of the fluid (vapor and liquid) is used to characterize the thermal stratification occuring during the self-pressurization and control phases.

A first 0D time-dependent model based on balance equations was validated using the experimental measurements and permits to optimize the full TVS device including the Joule-Thomson valve and the heat exchanger. Performance indices were constructed to quantify the potential gains of the control system. The 0D time-dependent model can predict with reasonable accuracy the characteristic times of transient cooling and potential equilibrium states. It does not, however, quantifies thermal stratification.

For these reasons, a more refined modeling effort was undertaken. The heat and mass transfer models typically available in CFD codes proved to be irrelevant to conduct a predictive study of the thermal state of the fluid in the conditions of the experiment. They are just as unsuitable for a predictive calculation of TVS acting on the actual fluid (cryogenic propellant) in microgravity conditions. A solver capable of predicting the transfer of heat and mass in a vapor-liquid interface in the case of boiling and condensation is under development at LEGI/LMFA for application to academic problems. The approach is based on a direct calculation of the mass transfer from the heat flow at the vapor-liquid interface using a sharp description of the interface, ensured in particular through a stiffening equation.

The proposed PhD is twofold:

- In the experimental part, the database for model validation is completed but further work is needed to clarify the role played by the jet configuration (degree of atomization) on the flow dynamics and thermodynamic control effectiveness. Experiments will also be performed to specify the sensitivity of the dynamics and control performance to the sub-cooled jet heat-management (fixed temperature, prescribed temperature difference).

- In terms of modeling, the numerical methodology allowing the direct calculation of mass transfer from the heat flow at the vapor-liquid interface will be implemented within the YALES2 solver in order to simulate realistic turbulent flow patterns using Large Eddy Simulation (LES). This will be done in close collaboration with the MoST team at LEGI (G. Balarac and G. Ghigliotti), which has extensive experience in developing and implementing models in this solver for the simulation of multiphase flows. The self-pressurization and TVS control of the tank using simulant fluid will be first computed since a large range of measurement data is now available for these experiments. The simulation of the device involving the actual fluid in microgravity will be conducted in a second time.

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CNES granting :

https://cnes.fr/en/les-ressources-humaines-du-cnes/thermodynamic-control-cryogenic-propellant-tank