Modeling and experimental validation of the heat accumulator in a Low Trust Cryogenic Propulsion (LTCP) system

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In the European funded project: - In Space Propulsion-1 (ISP-1) -, fundamental knowledge about Low Thrust Cryogenic Propulsion systems (LTCP) has been acquired. One of the components, the heat accumulator, stores thermal energy from the fuel cell that provides electrical energy to the whole system. This thermal energy is employed for the pressurisation of the propellant tanks. In this first stage, the study is focused on the LTA accumulator. The device consists of a set of tubes. Inside some of them the cryogenic flow of propellant (LOX) circulates. In the other tubes a secondary flowcirculates (typically He or N_2) that exchanges thermal energy with the fuel cell. Around the tubes there is a Phase Change Material (PCM-in this paper water-ice) that transfers the energy from the secondary fluid to the propellant. This unsteady process involves accumulation of thermal energy in the PCM during the fuel cell cooling mode of the LTA and the release of thermal energy from the PCM to the LOX flow in the tank self pressurization mode of the LTCP system.

In this paper, a numerical study of the thermal and fluid-dynamic behaviour of the two-phase flow inside ducts working under cryogenic conditions, coupled with the analysis of the PCM accumulator is presented. The numerical analysis is based on:

i) a one-dimensional and transient integration of the governing equations (conservation of mass, momentum and energy) for the fluid flow of propellant and secondary fluid inside the tubes, and

ii) a multi-dimensional and transient integration of the conservative equations in the region occupied by the PCM. The solid elements are modelled considering a multi-dimensional and transient treatment of the energy conservation equation.

The discretization of the governing equations has been developed by means of the Finite Volume technique. The two-phase flow phenomena inside of the tube are simulated considering the two-fluid model and solved by means of the semi-implicit pressure based method (SIMPLE) [1]. The two-fluid model [2] is interacting, capable of defining the behaviour of the velocity, the pressure, the temperature and the distribution of each one of the phases, gas and liquid, separately.

The phase change phenomenon of the PCM is simulated by means of the numerical resolution of the conservative equations (mass, momentum and energy) and solved using a tri-dimensional, parallel, non-structured and object oriented code of CFD&HT (Termo Fluids). The methodology employed for the phase change solid-liquid is the enthalpy method [3], which is adapted to the fractional step resolution method.

In a previous work [4], the need of a more complete experimental validation was detected. Therefore, different validation tests, reproducing different working conditions were performed in the framework of the ISP1-project. The comparison will be made with the results obtained in an experimental set-up by another partner (DLR) of the ISP1-project [5][6]. Different type of analyses combining single-phase/vaporisation of the flow of LN_2 with single phase (solid ice)/water-ice melting in the PCM were performed. Details of the multidimensional simulation of the PCM will be also given.

References:

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