Cryogenic Heat Exchangers for Space Exploration

by Shankar Ghosh, director, Shell-N-Tube Pvt. Ltd. (India), shankar.ghosh@shell-n-tube.com

Indian Space Research Organization (ISRO) is perhaps one of the most cost efficient satellite launching organizations in the world today. The two principal series of launch vehicles it uses are the Polar Satellite Launch Vehicle (PSLV) and the Geo Synchronous Launch Vehicle (GSLV). GSLV has three stages, the third of which is a cryogenic stage that utilizes liquid oxygen and liquid hydrogen as propellants. This process calls for indigenous development of a number of cryogenic heat exchangers for different ground testing applications.

Testing a cryogenic rocket engine and stage—as well as the subsystems— requires cold helium gas at two distinct temperature levels: 80K and 21K. The choice of helium as a cold testing fluid is obvious because of its lowest possible boiling point and chemical inertness. As a result, helium gas is the preferred fluid for actuation of the cryogenic valves of rocket systems, pressurization of the propellant tanks, etc.

Shell-N-Tube (CSA CSM) produced its first cryogenic heat exchanger for ISRO in 1998. It was the first multi-layer, super-insulated cryogenic vessel manufactured in India, and is still used by ISRO today for development testing for the steering engine of its Cryogenic Upper Stage (CUS), the indigenous cryogenic third stage of GSLV – MK I. This exchanger cools 12 g/s liquid oxygen/helium gas in separate cooling circuits, utilizing liquid nitrogen as expendable refrigerant. The liquid nitrogen vessel with the heat exchange coils inside is incorporated within the multilayer insulated vacuum jacket to minimize liquid nitrogen wastage during extended trials. ISRO has performed more than 20 tests using this exchanger and has conducted two launches of GSLV–MK I using the associated CUS.

In 2009, Shell-N-Tube produced its next set of heat exchangers for ISRO. These exchangers have a more complex design and are used at low temperatures up to 20K for development testing of helium gas bottles and other subsystems of GSLV–MK III. Shell-N-Tube designed this set to progressively cool down helium gas from ambient to 80K using liquid nitrogen as expendable refrigerant. Next we cooled helium gas, already at (or near) 80K, to approximately 21K using liquid hydrogen as expendable refrigerant. Cold helium gas was required at two distinct pressure levels, 30 bar and 300 bar. The 30 bar helium circuit has a nominal flow of 36 g/s and the 300 bar helium has a nominal flow of 12 g/s. Both the liquid nitrogen cooled heat exchanger and the liquid hydrogen heat exchanger have two distinct circuits within a common bath to cater to the two different pressure levels of helium required to test cryogenic rocket engine components. Testing of different subsystems using these heat exchangers is ongoing.

Coils inside the UHE 200 heat exchanger.

Shell-N-Tube faced quite a few design and manufacturing challenges with this set of exchangers. To start with, no heat transfer details were available with respect to helium with liquid nitrogen or helium with liquid hydrogen, so we used conventional heat transfer coefficients for film boiling. This did not take into effect the configuration of cooling coils and the possibility of partial coverage of coils with coolant vapor formed at the lower portion of the coils and rising up. In order to account for such uncertainties, adequate margin on heat transfer areas was provided in the earliest heat exchangers. Currently, this margin in heat transfer is progressively optimized based on feedback from test results.

Another problem we faced was accommodating the restrictive dimensions of the required heat transfer surface within the cooling bath. All the heat exchangers here are pool type, in that the fluid being cooled passes inside tubes that are immersed in the expendable boiling refrigerant at atmospheric pressure or below. To address this issue, the coil's size and pitch were optimized so it could be accommodated within the inner vessel that contains the expendable refrigerant. Distribution of helium gas into multiple heat exchanger coils was achieved by incorporating circular headers at inlet and outlet at different elevations to accommodate the two different helium gas streams (30 and 300 bar). To ensure vacuum and process integrity, the heat transfer coils were subjected to multiple pressure and mass spectrometer leak detector tests at liquid nitrogen temperatures before integration into the shell/cold bath.

Shell-N-Tube has used similar concepts and technology in other tailor-made cryogenic heat exchangers, such as for cooling argon in liquid nitrogen or oxygen in liquid nitrogen.

Performance tests at the design pressure level, with actual fluids and expendable refrigerants (helium gas, liquid nitrogen and liquid hydrogen), were carried out at ISRO. Performance of both heat exchangers exceeded design expectations. The helium gas outlet temperature from the liquid nitrogen heat exchanger was just over 78K whereas the tender allowed up to 80K. And helium gas temperature at the outlet of the liquid hydrogen heat exchanger was 21K against the tender requirement of 22K. Both of the exchangers were accepted by Indian Space for its ongoing subsystem trials for the CE20 cryogenic engine to be used in GSLV–MK III, a rocket designed to place four ton class satellites in geosynchronous orbit. **www.shell-n-tube.com** ■