‘Mini Venturi’ Benefits Demonstrated in Cryogenics Experiment

By Jim Bollinger
Source: Primary Flow Signal, Inc.

Experiment profile starts at zero flow, rapidly rises to choked flow and ultimately experiences exponential decay

At the National High Magnetic Field Laboratory in Tallahassee, Florida, cryogenics lab research includes study into the transient heat transfer consequent to a sudden rupture of the insulating vacuum jacket around a cryogenic system.

It’s the world’s highest powered magnet laboratory. Cryogenics is that branch of physics dealing with very low temperatures. The work is part of a larger effort in the cryogenic industry to characterize the mass and heat transport that transpire as ambient gas floods into a broken vacuum and condenses or freezes onto cryogenically cooled surfaces. The magnitude and rate of heat transferred could lead to significant damage to cryogenic systems or even large industrial accidents.

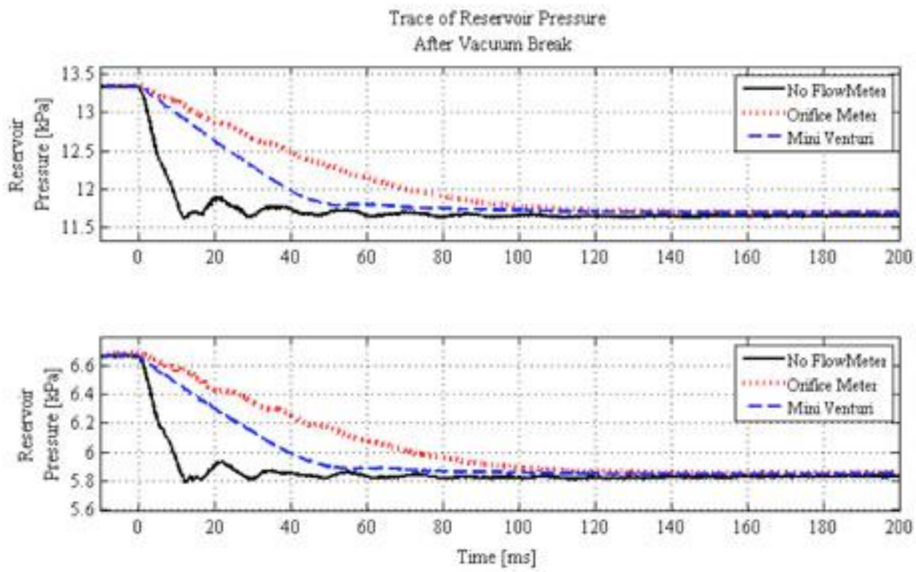
In academic research, accurate data and repeatable results are paramount for meaningful and valid conclusions. For this experiment, conditions were simulated to allow measuring the two most important factors: the gas mass-flow rates and the consequent transient heat transfer. Some cryogenic devices operate at extremely low temperatures (<4.2 K or -452 F) and are contained within a vessel surrounded by an annular vacuum jacket. This vacuum jacket provides critical thermal insulation from environmental temperatures (293 K or 68 F).

The Experiment

To simulate a vacuum failure, a test system was built using a series of two control volumes separated by a fast-acting solenoid valve. A reservoir tank was used to hold nitrogen gas at room temperature at a precisely controllable pressure. The second control volume modeled the insulating vacuum jacket and was initially evacuated to a very high level of vacuum (<0.1 Pa or 10-7 atm) with one of its walls in direct contact with the liquid helium at 1.8 K.

Opening the solenoid valve simulates a catastrophic rupture to a cryogenic system’s vacuum jacket — a vacuum break. Gas then rapidly flows from the reservoir into the evacuated volume. Upon contact with the cryogenically-cooled wall, the gas will immediately freeze onto the cooled surface, or “cryo-deposit.” The cryo-deposition process then continues to draw gas from the reservoir while simultaneously transferring heat to the liquid helium coolant.

In preliminary iterations of the experiment, a small reservoir was used where a mass flow rate was easily deduced from a pressure versus time trace of the reservoir. However, because the pressure in the reservoir fell, it failed to simulate a vacuum break to the environment, where the pressure remains constant. The small reservoir was thus replaced with a much larger one, more closely reflecting real-world conditions. In so doing, however, the smaller pressure change in the reservoir was no longer sufficient to precisely measure the mass flow rate. An orifice meter was then placed downstream of the reservoir to directly measure the mass flow rate of the gas moving from reservoir to broken vacuum.



In Figure 1, the solid black trace illustrates how quickly the pressure in the small reservoir fell as gas flowed from the reservoir into the broken evacuated volume. The orifice flow meter (the dotted red trace) is shown to have changed flow dynamics at levels that could not be tolerated for this experiment. Upon further analysis, it was found that the throat of the orifice plate was limiting the mass flow rate. The total pressure and temperature variations from the gas compression just before the orifice and expansion downstream of the orifice increased the error in the calculated mass flow rates.

What Was Needed

What was needed was a flow meter with high precision, low energy loss, and accuracy even at a small line size. Before finding the Mini Venturi, other devices were considered. However, the flow rate profile of the experiment starts at zero flow, rapidly rises up to choked flow, and ultimately experiences an exponential decay. Thermal mass flow meters are unreliable when starting from zero flow, and pitot-tubes obstruct flow when dealing with small line sizes. One of the best, if not the best, device that fit these requirements was a Mini Venturi meter designed and built by Primary Flow Signal, Cranston, Rhode Island.

After contacting Primary Flow Signal and discussing the nature of the research, the company donated the Mini Venturi. It replaced the orifice meter and immediately proved less obtrusive to the flow, as illustrated with the blue dashed trace in Figure 1. The reduction to adverse effects to the flow dynamics are due to the profile of the Mini Venturi, resulting in small head-loss and preserving the ability to accurately measure the differential pressure between inlet and throat. Effectively, the discharge coefficient of the Mini Venturi in this experiment was much closer to ideal than the orifice plate could achieve, particularly in a laboratory setup with limited upstream and downstream piping.

The final test system consisted of a solenoid valve separating the reservoir tank and the evacuated volume, with one wall of the evacuated volume in contact with the liquid helium coolant. As the experiment requires the presence of liquid helium, the setup included the cryogenic vessel holding the liquid helium and its respective insulating vacuum jacket. Finally, a series of thermometers were inserted into the system provided measurement of temperature changes in the evacuated volume wall and neighboring liquid helium, from which heat fluxes were calculated. To ensure that the results made physical sense, they needed to be balanced with the amount of heat energy brought in by the nitrogen gas. This was possible by measuring how much gas (mass) moved from the reservoir to the evacuated volume.

The Mini Venturi measured the mass flow rate, which was then correlated directly to how much heat had been dumped into the system. In effect, the mass flow rate is proportional to the total heat transfer rate. Both heat transport and mass transport measures were compared and found to closely match, characterizing the observed heat and mass transfer while ensuring the results remained self-consistent.

While data captured from this experiment will require further academic study, the practical application was intended to derive a better understanding of the cryo-deposition process and its effect on cryogenic system during vacuum failures in order to protect workers and equipment in commercial and industrial facilities.

About the Author: Jim Bollinger is the General Manager of Primary Flow Signal Industrial Products Group, a global manufacturing, engineering and technology resource focusing on highly accurate, repeatable and reliable differential flow meters.