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Vacuum Requirements for Cryogenic Vessels

The ability of a cryogenic vessel or transfer line to maintain the liquefied gas in a liquid state is crucial. This attribute is usually referred to as its “holding time.” This means that some sort of insulation be provided to prevent warm air from contacting the actual container. The generally accepted method of insulating the container is by taking advantage of a good vacuum’s almost nonexistent thermal conductivity. A double-walled container with a vacuum between the walls constitutes the concept of the dewar flask. This can be best visualized by thinking of the classically ubiquitous thermos bottle. If the volume between the walls is filled with gas molecules at atmospheric pressure, the heat transfer across the volume is basically by the heat being exchanged between hotter and colder molecules as they collide with one another. If the molecules are removed with a vacuum pump, the number of molecular collisions drop in proportion to the pressure which can be thought of as the molecular population per unit volume. As the gas is pumped out, the thermal conductivity between the walls will fall off quickly until a pressure corresponding to molecular flow conditions is achieved. Molecular flow is defined as a statistical condition where a gas molecule, in normal motion, will strike a wall before it strikes another molecule. Below this pressure, usually about 10 millitorr or so, changes in thermal conductivity with lower pressure still occur due to fewer molecules, but the changes occur at a lower rate. This explains, for example, why thermal conductivity vacuum gauges such as thermocouple or pirani gauges, have a useful limit only slightly below 1 millitorr.

The basic simplicity of using a vacuum space as a high performance insulator is often overshadowed by the complexity of achieving and maintaining a good vacuum level. It looks like a fairly simple exercise in vacuum technology, but there are several practical problems. The vacuum levels necessary will usually require both a roughing pump and a high-vacuum pump. Even though an oil-sealed mechanical pump can easily produce a vacuum of 10 millitorr, which is often considered adequate for some liquid nitrogen dewars, the pumping speed of mechanical pumps drop to near zero at these pressures. At higher pressures, the gas load is atmospheric gases that pump away relatively easily, but water vapor, desorbing from the walls, becomes the major component of the gas load at lower pressures. A high -vacuum pump is required to provide enough low pressure pumping speed to deal with the desorbed water vapor. In fact, a much lower pressure than 10 millitorr is required in most dewars at the termination of the pumpdown cycle. This is especially true with liquid helium dewars. The degree of vacuum, then, is proportional to the boiling point of the cryogen. A lower boiling point requires a lower heat load, and that means a better vacuum to provide adequate insulation for an acceptable holding time.

Although a dewar is sometimes pumped continually by a high-vacuum pump, it is more common to isolate the vacuum space from the pumping system. This is usually done by a permanent “tip-off” formed by heat sealing a glass tube or pinching off a copper tube. In cases where a dewar requires

disassembly, a vacuum valve is used for isolation. In both cases, practicality requires the breaking of a common vacuum rule which states that the high vacuum pumping line be as short and wide as possible to allow full gas flow. The diameter of a line that will be tipped-off is limited by the ease of collapse of the tube, or that a bigger valve consumes too much space and is more expensive. The small diameter of the pumping line presents a constriction to gas flow. This results in a longer pumpdown time to deal with the water vapor desorbing from the vacuum space’s surfaces. Additionally, it is seldom practical to place a high vacuum gauge sensor directly on the dewar. The sensor is usually mounted on the pump side of the tube or valve. The constriction causes a loss in pumping speed across its length, and this means that the pumping speed is higher at the gauge than within the dewar. This translates to an expected error in pressure reading since the actual pressure within the dewar might easily be several orders of magnitude higher than on the gauge/pump side. The solution in a valved system is closing the valve for a short period to allow the pressure to rise within the dewar, and when the valve is reopened, watching the sudden pressure rise. This can be repeated until an adequately small pressure spike is observed. In a pinched-off application, a ratio must be determined between the two.

Although the vacuum insulation is only one of many design parameters required to achieve adequate holding time, it can be a crucial parameter. Understanding and care used in pumping out the vacuum space can result in a much more acceptable performance in either a dewar or transfer line.