Valves for Vacuum Service

Background:

A leak is a flow of gas (or liquid) through an unintended crack, hole or porosity or a sealing element in a pressure vessel or a flange joint. Leaks could either be from inside a pressure vessel to atmosphere or from atmosphere to inside an evacuated pressure vessel [1]. The units of measurement could be volumetric flow rate (std.cc/second), mass flow rate (mg/second) or concentration in parts per million (ppm). There are many leak detection methods available for valves namely Decay, Bubble, Sniffing, Accumulation and Vacuum. In this article, we'll see the differences in the vacuum tests used in valves, applicability, test parameters and valve design considerations for vacuum service.

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Valve Design for Vacuum Service

As per ASME Section VIII, Division 1 – Mandatory appendix 3, "Full Vacuum is a condition where the internal absolute pressure is 0 psi (0 kPa) and the external absolute pressure is on the vessel is 15 psi (100 kPa)". A vessel which is designed and constructed to Code requirements for internal pressure and which is required to be designed for an external pressure of 15 psi or less need not be designed to Code rules for the external pressure condition [2]. Special focus should be given to the sealing elements used in stem, body joint and obturator. It should be noted that condition of of full vacuum is not practicable due to the limitations of evacuation equipment and as it is virtually impossible to remove all the air molecules from any vessel, a perfect vacuum cannot be achieved. A popular end-user specification calls for valves to be suitable from 100 kPa (1000 mbar) down to 10 Pa (0.1 mbar) in vacuum service. Further, from figure 1, it can be observed that 100 kPa to 10 Pa can be categorized as low or medium vacuum [3]. Though valves designed for fugitive emissions could perform well in vacuum service there are certain subtle aspects to be taken care of when designing valves.

1. Use of cup and cone packing rings with an inverted Chevron V installation so that the vacuum inside the valve aids in sealing
2. Use of a metallic bellows for stem seal for high/ultra-high vacuum applications
3. Use of proven gasketing materials for sealability. Self-energized elastomeric seals and metal C or O rings could be considered for high/ultra-high vacuum applications.
4. Use of lantern ring as a water sealing connection in conjunction with compression packings. If water is pumped at the correct pressure, it prevents process impurities from entering the stuffing box, and thereby keeps a clean environment inside the stuffing box. In other words, it acts as a pressure chamber in which an external fluid is pressurized to a pressure equal to or slightly higher than the system pressure to prevent any leakage of the system fluid to the outside.

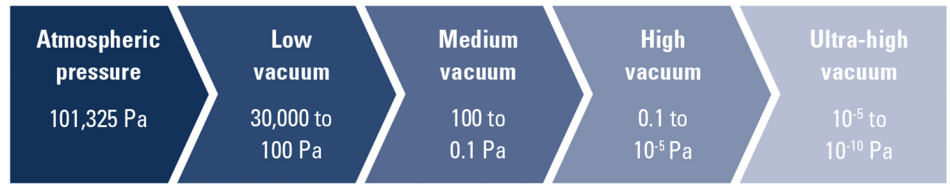

Figure 1: *Pressure ranges in vacuum*

Types of Vacuum Tests Conducted in Valves

Hard Vacuum Method

This method is referenced in ISO 15848 Part-1, Annex A, where the test involves pressuring the valve with helium while a chamber around the stem seal is connected to the mass spectrometer for removing air from the chamber. The detector measures the flow of helium escaping through the stem seal. The leak cannot be located in this case and this method is also called the global method. Refer Figure 2 for vacuum method leak test on a 4" Class 1500 Gate Valve.

Figure 2: *ISO 15848-1 Vacuum method - Global measurement*

Method	Test procedure ref	Type	Location/ Measurement	Leakage
Tracer probe	ASME Sec V, Article 10, App VI	Vacuum	Locating leak	Outside-In
Vacuum hood	ASME Sec V, Article 10, App IX	Vacuum	Measuring leak	Outside-In
Hard vacuum	ISO 15848-1, Annex A	Vacuum	Measuring leak	Inside-out
Detector probe	ASME Sec V, Article 10, App IV, ISO 15848-1 Annex B	Pressure	Locating leak	Inside-out

Table 1: Comparison of Leakage methods

Spraying Method

This method is referenced in ASME Sec V, Article 10, Appendix V as Tracer Probe Technique. The high sensitivity of the leak detector makes possible the detection and location of helium gas flow from the higher pressure side of very small openings through the evacuated envelope or barrier separating the two regions at different pressures. This is a semi-quantitative technique and should not be considered quantitative.

Vacuum Hood Method

This method is referenced in ASME Sec V, Article 10, Appendix IX, Vacuum Hood Technique. The vacuum hood method involves removing air from the valve, connecting it to a mass spectrometer and spraying helium in to a bag that encapsulates the stem and body joint. The detector measures the helium leakage wherever a leak path exists. This is a quantitative measurement technique and the leak cannot be located with this method.

Applicability of Vacuum Tests to Real Word Applications

While the hard vacuum method is meant for measuring very low leakages and is meant for Class AH leakage class fugitive emissions, the spraying method and hood method are used for applications where the valves are used in vacuum service either in full or partial vacuum intermittently.

1. Full Vacuum can occur due to condensation of steam subsequent to a steam-out operation in case there are insufficient vents open or the vents are closed prematurely. Steam-out is a steam purging process to remove either hydrocarbons, prior to vessel opening for maintenance and inspection or to remove air in the vessel prior to start-up.

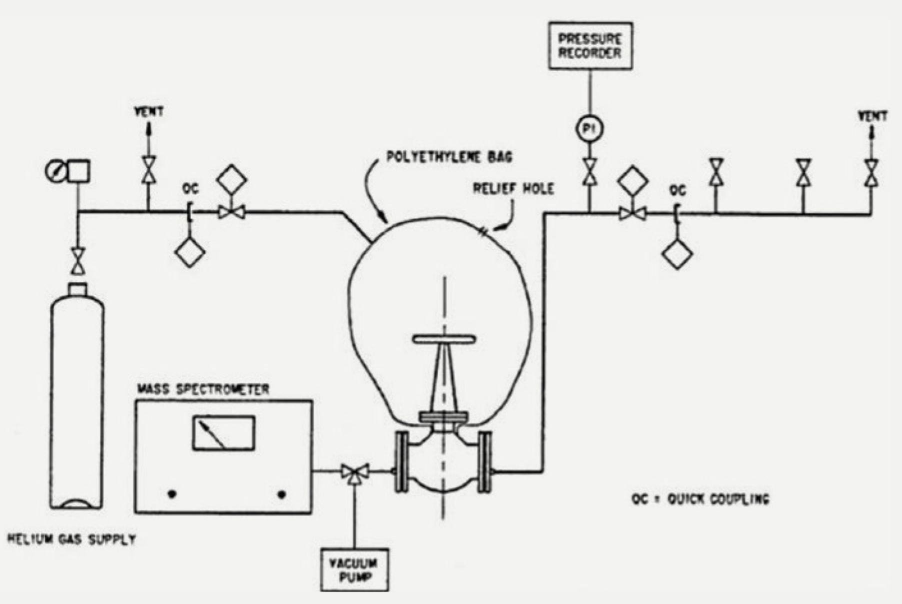

Figure 3: Hood method (SPE 77/307, Production testing of valves in vacuum service)

Parameters	Tracer Probe Technique	Vacuum Hood Technique	End-user spec for Vacuum hood method
Cleaning	NA	NA	Cleaned and degreased | No protective coating
Pre-test	NA	NA	Operational test at RT and effort measurement
Test Medium	Helium	Helium	Helium
Cycling	NA	NA	5 cycles
Vacuum level after evacuation	NA	NA	10 Pascal
Test Duration	NA	NA	3 minutes (NPS 2) to 21 minutes (NPS 24)
Leak test	The tracer probe tip shall be passed over the test surface with the probe tip within 1⁄ 4" of the test surface	The hood shall be filled with helium after the valve has been evacuated	The hood shall be filled with helium after the valve has been evacuated
Allowable Leakage	< 1 x 10-5 std.cc. second	< 1 x 10-6 std.cc. second	Class AHS or BH (as per purchaser agreement)

Table 2: Comparison of test parameters in tracer probe and hood techniques

2. Full vacuum can also occur when there is column separation in a pipeline. This commonly occurs when there is a loss of power or rapid closure of an upstream valve.

3. Vacuum is also an important parameter in Condensate lines in a power plant. The main purposes of the condenser are to condense the exhaust steam from the turbine for reuse in the cycle and to maximize turbine efficiency by maintaining proper vacuum. As the operating pressure of the condenser is lowered (vacuum is increased), the enthalpy drop of the expanding steam in the turbine will also increase. This will increase the amount of available work from the turbine. It is therefore very advantageous to operate the condenser at the lowest possible pressure (highest vacuum).

REFERENCE(S)

[1] Leak detection methods and defining the sizes of leaks, NDT.net - February 1999, Vol.4 No.2

[2] Pressure Vessel Handbook, 14th Edition, Eugene F. Megyesy

[3] www.pfeiffer-vacuum.com

[4] ASME BPVC-V-2017, ASME Boiler and Pressure Vessel Code, Section V: Nondestructive Examination

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