Product Note, PN 407, Revision 1
Using Heat to Counter Joule-Thomson Cooling in Pressure Regulators

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Introduction

The regulation of gases from a high pressure to a low pressure generally results in a temperature drop. This is commonly known as Joule-Thomson cooling. This effect is observed primarily in cylinder cabinets or bulk specialty gas systems where the pressure drop is the greatest. Some typical gases used in the semiconductor industry that have a significant Joule-Thomson cooling effect are hydrogen chloride (HCl), carbon dioxide (CO_2), ammonia (NH_3), and nitrous oxide (N_2O).

A short review of gas thermodynamics

Pressure regulation of gases can be modeled as a constant enthalpy (throttling) process because no work is done, potential energy changes are negligible, and kinetic energy changes are small. The outlet temperature of a gas flowing through a pressure regulator can be determined if the inlet pressure, inlet temperature, and outlet pressure are known. This is done by locating the inlet conditions on a T-s (temperature-entropy) phase diagram (also known as a Mollier diagram) of the thermodynamic properties of the fluid. Then, by following a constant enthalpy line to the outlet pressure, the outlet temperature is determined. For example, if carbon dioxide at 72ºF (22.2ºC) and 813 psig (typical ambient conditions in a cylinder) is regulated to 75 psig, then the outlet gas temperature is -68ºF (-55.5ºC). This is a total temperature change of 140ºF (77.7ºC)!

If a temperature probe is placed immediately downstream of the regulator, the probe will not read the large temperature drop stated in the example above. This is because the gas immediately draws heat (energy) from the piping system components (regulator body, tubing, etc.). If the flow rate is very low or a short duration, then the air surrounding the piping system components can provide heat to maintain the piping system components surface temperature at close to ambient conditions. If the flow rate is very high or for a long duration, then more heat is lost than the surrounding air can provide, and the components cool below ambient temperature and will approach the theoretical gas outlet temperature.

What can happen to the pressure regulator?

A severe drop in temperature can cause stress cracks in the regulator seat material due to thermal contraction. Also, as the gas draws heat from the regulator body, the body temperature can drop below the dew point temperature of the water vapor in the ambient air, resulting in condensation on the outside of the regulator. In some cases, the regulator body temperature drops below the freezing point and the condensation turns to ice. High flow rates and longer flow duration will be more likely to result in condensation and icing.

Normally external condensation does not cause the regulator to malfunction, but water dripping on other equipment (such as electronic devices) can affect their operation. If ice forms, then the operation of the regulator can be affected, especially if the ice is inside the cap where the adjustment spring is located.

What can happen to the process gas?

When the gas temperature drops, then (1) there is the possibility that the gas will liquefy on the outlet side of the regulator and (2) there is the possibility that gas impurities will condense inside the process line. If liquid forms on the outlet side of the regulator, then the liquid will flash off into gas as it draws heat from the regulator body and tubing walls. This can cause pressure surges in the delivery line and if a downstream isolation valve is closed, the outlet side of the regulator can be pressurized above the maximum pressure rating potentially causing a leak to atmosphere. If gas impurities condense out, then acid can form causing corrosion, or contamination can collect on the seat causing a seat leak.

Countering Joule-Thomson cooling

The best method to prevent the adverse effects of Joule-Thomson cooling on the pressure regulator and process gas is to increase the gas enthalpy by heating prior to regulation. If the system is properly designed, then the gas temperature on the outlet after regulation will be close to the ambient temperature. This will prevent any condensation or icing of the regulator body and downstream tube lines. Plus, the process gas will not liquefy or condense impurities inside the delivery line.

Many system components can be adversely affected by a large temperature increase. Therefore, it is recommended that the gas temperature be increased to 120ºF (48.9ºC) maximum. This temperature is chosen to prevent exceeding the maximum temperature rating of the pressure regulator and other components, and because regulations such as CGA Pamphlet P-1 and gas suppliers recommend cylinders are never exposed to temperatures higher than 125ºF (51.7ºC). For some higher flow bulk gas systems, a two-stage pressure regulation system may be required with heating before both pressure regulators.

Heating of the regulator body is a poor way to transfer energy to the gas. The short residence time of the gas in the body and small surface area exposed to the gas make it difficult to transfer sufficient energy without heating the body above the maximum temperature rating of the regulator. A more effective method is to apply heat upstream of the regulator through a section of tubing using either a heat exchanger or electrical heat tape with insulation. Heat can also be applied to the source container, but the gas supplier should be consulted to ensure compliance with regulations governing the use of pressurized containers and to verify that any safety relief device on the container will not discharge.

Please consult the factory or your local distributor for further information or assistance.