ADVANCED PRESSURE TECHNOLOGY

# Product Note, PN 409
# Two-Stage Regulators

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## Introduction

Two-stage regulators are simply two single stage regulators placed in series and packaged into a single unit. Two-stage regulators have characteristics that make them advantageous for certain applications. These characteristics are primarily reduced supply pressure effect and splitting the total pressure reduction over two stages.

## Supply Pressure Effect

Supply pressure effect is the change in outlet pressure caused by a drop in source pressure. Mechanical pressure regulators operate under a balance of forces. In typical single stage diaphragm regulators used in semiconductor applications, if the inlet (source) pressure is reduced, then the force caused by the inlet pressure is reduced and the result is an increase in outlet pressure to balance the forces. Supply pressure effect is usually expressed as the **rise in outlet pressure per 100 psig drop in source pressure**. It should be noted that supply pressure effect can act in reverse – as the source pressure is increased, the outlet pressure will drop due the same balance of forces (flow is required through the regulator to observe this effect because otherwise there is no usage to drop the delivery pressure).

## Two-Stage Regulator Design

Two-stage regulators are designed to maintain a stable outlet pressure as the gas supply is depleted, diminishing supply pressure effect. In most two-stage regulator designs, the first regulator is preset to the typical pressure at which the gas cylinder would be replaced (200-300 psig) and the second regulator is hand adjusted by the operator to the desired process conditions. As the gas supply is depleted the pressure on the first stage regulator outlet will rise due to supply pressure effect. This will cause the pressure on the second regulator outlet to drop. Table 1 shows the calculated delivery pressure change of both stages in a two-stage regulator as the gas supply is depleted. The table demonstrates that the delivery pressure change in a two-stage regulator is very small and usually not detectable because creep, droop, etc. have a significantly greater effect on the regulator outlet pressure.

| Two-Stage Regulator Model | Delivery Pressure Rise on First Stage | Delivery Pressure Drop on Second Stage |
|---|---|---|
| AP1710 | 5.5 psig | 0.01 psig |
| AP2710 | 16.5 psig | 0.26 psig |

**Table 1. Delivery Pressure Change as Gas Supply Depletes from 2500 psig to 300 psig**

## Semiconductor industry use of two-stage regulators

The primary use of two-stage regulators in the semiconductor industry has been diborane service. The reaction of diborane with moisture and oxygen from the atmosphere can form contamination that collects on the seat. Joule Thompson cooling across the regulator poppet can result in condensation of gas impurities on the seat. By reducing the pressure in stages, the temperature drop is lower in each stage plus the gas is partially reheated between stages by the regulator body mass, resulting in less condensed impurities. Also, problems such as high creep due to seat contamination in the first stage are “masked” by the second stage. These theoretical advantages are confirmed by field experience that has found two-stage regulators have a longer mean time between failure (MTBF) compared to single stage regulators. In diborane service, the two-stage regulator is not being used to diminish supply pressure effect and maintain a constant outlet pressure, but to increase MTBF in a difficult application.

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A potential new use for a two-stage regulator is high flow gas delivery systems for non-liquefied gases such as silane ($SiH_4$) and nitrogen trifluoride ($NF_3$). The source pressure in these systems can drop by over 1000 psig as the gas supply is depleted. A high flow regulator is required to deliver the flow, but high flow regulators usually have higher supply pressure effect values. This can result in the outlet pressure rising by 20 to 50 psig depending on the regulator model. This large increase in delivery pressure can cause the source manifold to alarm and shutdown. The Series AP2700 regulator can eliminate supply pressure effect problems in these applications and deliver flow rates of 250 slpm nitrogen.

Another potential use for two-stage regulators is to reduce the temperature rise due to adiabatic compression. Heat from adiabatic compression has caused fires in oxidizer gases such as oxygen ($O_2$) and $NF_3$. Adiabatic compression occurs when a gas is rapidly pressurized in a dead ended tube line; for example when a cylinder valve is opened to pressurize the inlet to a closed pressure regulator. The theoretical maximum temperature (assuming no heat transfer) can be calculated using ideal gas law if the initial temperature, initial pressure, and final pressure are known. For an $NF_3$ cylinder at 1500 psig and the system initially at atmospheric pressure and temperature, adiabatic compression could heat the inlet of a single stage regulator to 622ºF. If an AP2700 two-stage regulator is used, then adiabatic compression could heat the inlet to the first stage to 340ºF and the inlet to the second stage to 257ºF. In this case, a two-stage regulator reduces the theoretical maximum temperature by 282ºF, from 622ºF to 340ºF.

## Over-pressure concerns in two-stage regulators

A failure mode and effects analysis looks at potential failures within a component and their consequences. One failure mode in all pressure regulators is that contamination can cause an across-the-seat leak. The severity of the leak depends on the amount of contamination and the regulator internal design. If the leak causes the outlet pressure to continually rise, the diaphragm could be exposed to excess pressure; potentially causing the diaphragm to rupture and resulting in a leak to atmosphere out the bonnet port. No shrapnel will be generated, but the leak will continue until the gas cylinder is depleted or the system is shutdown. Even if the diaphragm does not rupture initially, continued use of the regulator could cause failure due to fatigue cycling at high pressure. For two-stage regulators that have two places for an across-the-seat leak to develop, there are two diaphragms that could be exposed to excess pressure.

Gas manifolds incorporate a protection method to prevent a failure of the pressure regulator from exposing the equipment on the low pressure side of the regulator to excess pressures (reference SEMI F13). This protection method also prevents the regulator diaphragm from being exposed to excess pressure that could cause diaphragm rupture. Protection methods include a relief valve, burst disc, and pressure monitor with signal connected to shutdown an isolation valve.

For two-stage regulators, a protection method is needed for both regulator stages. AP Tech provides a port to monitor the pressure between the first stage and second stage in two-stage regulators. This port can be used to protect the first stage diaphragm from excess pressures using the methods mentioned above. In the event that the customer does not order or use this port, the customer should evaluate the effect of a diaphragm rupture and have suitable protection designed into the manifold.

## Conclusion

Semiconductor gas delivery systems have benefited from the use of two-stage regulators to increase MTBF in diborane service and may benefit from the use of two-stage regulators in high flow applications to diminish supply pressure effect and to reduce peak temperatures due to adiabatic compression. The system designer must consider the potential failure modes of two-stage regulators and incorporate protection methods that will prevent a failure mode from causing damage to equipment or injury to personnel.

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

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