GAS SYSTEMS

TROUBLESHOOTING

COASTAL INSTRUMENTS

PREPARED BY: ROY BROWNING

CONTENTS:

INTRODUCTION:

Since the 1960's when NASA set some of the first requirements for sensing gas flow and the control of life sustaining oxygen to the Apollo astronauts, the measurement and control of gas flow has been on a steady advancement. This advancement has been driven by industry and the steadily increasing demand for product quality.

In the very early days of gas flow control technology a small company known as Tylan, received a patent on a "hot wire flow sensor" that started an evolution driven by the semiconductor industry. The rest is history but it should be noted that the original Tylan design has been copied by other companies and is still available, virtually unchanged in over 40 years of manufacturing.

We will discuss all of the items that make up a modern, ultra high purity, gas flow control system. We will discuss the highlights of various designs, the reasons for various design features, and problems associated with various components and design features. We will also explore many common and uncommon problems and the reasons for those problems with gas control systems.

SAFETY

SUMMARY: Individuals working with gas source semiconductor tools must be aware of potential hazards associated with them, and must be trained and proficient in methods to work with the tools and associated apparatus in a safe manner. Each PERSON must conduct a risk assessment identifying potential hazards and the precautions necessary to protect themselves from hazards. This is essential to safeguard both the individuals as well as surrounding facility areas. A release of a gas can easily impact on the entire facility as it is carried through the ventilation system as well as you who are working on the tool.

SCOPE: This Guideline applies to all who maintain or operate equipment used to manufacture, measure, assemble and test semiconductor products using a hazardous (HGS) gas source.

REFERENCE REGULATIONS: Control of Hazardous Energy (Lockout/Tagout) (OSHA Part 85) Hazard Communication (OSHA Part 430)
Inorganic Arsenic (OSHA Part 308)
Hazardous Work in Laboratories (OSHA Part 431) Personal Protective Equipment (OSHA Part 433) International Building Code
International Fire Code
NFPA 45 – Standard on Fire Protection for Laboratories Using Chemicals NFPA 50A – Standard for Gaseous Hydrogen Systems at Consumer Sites Factory Mutual 7-7, 17-12 (Semiconductor Fabrication Facilities)
Extremely Hazardous Substances List and Threshold Planning (EPA 40 CFR Part 355)

DEFINITIONS:

Buddy system – an administrative control requiring the presence of two trained persons when work of a potentially hazardous nature is being performed. All gas systems work is considered potentially hazardous.

Continuous gas monitoring system (GMS) – uninterrupted monitoring, occurring in real-time, with associated alarms.

Decontamination **–** the removal of materials in or on equipment, people, or personal protective equipment.

EMO – emergency off button.

Exhaust treatment devices – systems designed to remove specific toxic particles and gases from an exhaust stream. These include but are not limited to scrubbers, charcoal traps and burn boxes.

Flammable gas – a gas is considered flammable when either a mixture of 13 percent or less (by volume) with air forms a flammable mixture, or the flammable range with air is wider than 12 percent regardless of the lower limit. The limits shall be determined at atmospheric temperature and pressure.

Gas cabinet – cabinet used to house and contain gas cylinders, and connected to gas distribution piping or to equipment using the gas.

Gas delivery system – the system made up of a gas source, gas panel, piping and all associated valves and safeguards.

Gas panel – an arrangement of gas handling components (e.g., valves, filters, mass flow controllers) that regulates the flow of gas into the process.

Gas panel enclosure – an enclosure designed to contain leaks from gas panel(s) within itself.

Hazardous Production Material (HPM) – a solid, liquid, or gas that has a degree of hazard rating in health, flammability, or reactivity of class 3 or 4 as ranked by NFPA 704 and which is used directly in research, laboratory, or production processes that have as their end product materials that are not hazardous.

High Efficiency Particulate Air (HEPA) –refers to an air filter that must be 99.97% efficient (i.e. a maximum of three particles of 0.3 micron aerodynamic diameter can pass for every ten thousand particles fed to the filter).

Local exhaust ventilation (LEV) – a ventilation system that captures air contaminants at their point of origin and moves the air to the external environment.

Personal protective equipment (PPE) – devices worn by workers to protect against hazards in the environment. Examples include gloves, safety glasses, face shields, respirators, and self contained breathing equipment.

Pyrophoric material – a chemical that will spontaneously ignite in air at or below a temperature of 54.4°C (130°F).

Restrictive flow orifice – a flow-limiting device inserted in the cylinder valve by the gas vendor to control excess flow in an unrestricted gas release.

Standard operating procedure (SOP) – the technical requirements necessary to complete FAB procedures and actions safely. Once developed, SOPs are documented and implemented in the workplace and used for training purposes.

Threshold Limit Value→ (TLV®) - TLVs® refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects.

TLV-TWA – Threshold limit value as an 8-hour time-weighted average.

RESPONSIBILITY: All Personnel exposed to any HGS

Ensure compliance with this Guideline by supporting the proper design, purchase, and installation of equipment, ongoing maintenance, and training of staff.

Ensure that a comprehensive plan for the design, installation and maintenance of the tool, gas delivery and GMS is drawn up prior to bringing the tool on site.

Assume the responsibility for installation, operation, maintenance and training for the tool (including vacuum pumps, chillers and other support equipment), gas delivery and GMS, and for any specialized exhaust treatment systems.

Identify proper storage locations for gas bottles unless using a just in time delivery system.

Develop a risk assessment to clearly define the source and nature of all potential hazards and people who may be affected by them. This assessment must be performed and significant findings recorded by a person or persons who are adequately trained and competent to perform such duties by virtue of their professional qualifications and experience with semiconductor tools and processes.

Develop SOPs for routine tasks, maintenance and decontamination procedures on each gas source tool, gas delivery and GMS, and for any specialized exhaust treatment systems. This includes incorporating emergency response procedures to address the potential for fire and release or generation of toxic gases.

Ensure that all staff is trained on the SOPs and able to safely operate each gas source tool owned or operated by the FAB. Ensure written records of training are maintained for review by investigators following an adverse event.

Ensure that all engineering controls are in place and operational prior to commencing operations involving use of the tool.

Maintain "as built" drawings of the tool and associated gas delivery, HGS and exhaust treatment equipment installation for future reference and updating as modifications occur.

- Maintenance and operation Staff

  Be knowledgeable and familiar with each gas source tool used in the FAB.

  Perform only those functions for which they have been trained.

  Be able to implement emergency response procedures associated with the use of the gas source tool.

  Properly use all safety equipment and follow safety procedures.

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HAZARDOUS GAS DELIVERY SYSTEMS:

- Containment and delivery of HPM gas

  All HPM gases must be delivered through continuous, orbital welded, coaxial tubing that is of a material compatible with the gas. Only employees who are specifically trained and qualified to perform orbital welding on coaxial tubing may do so. Hydrogen, methane and fluorine, though HGS gases, can be delivered in single wall stainless steel tubing provided all mechanical connections are inside exhausted enclosures equipped with GMS. No mechanical connections exposed to the process gas stream are to be outside of exhausted enclosures equipped with GMS.

All HGS gases in use and in storage must be kept in locally exhausted gas cabinets or in suitable gas storage bunkers. Each of the storage locations must also have provisions for actively monitoring the ambient environment and exhaust to detect for the gases stored. This provision must provide for both local and remote annunciation in the event there is a gas leak. This annunciation may also be required to be tied into a building type alarm (facility dependent).

Restrictive flow orifices, where appropriate, must be used to preclude massive releases in the event of a catastrophic failure.

- Continuous gas monitoring system (GMS)

Tools utilizing HGS gases must be equipped with continuous GMS applicable to the material in use with remote readout capability. The GMS.

- Fire Detection & Suppression

The fire detection system that includes detectors, alarms and their associated controls should be installed and certified in accordance with all applicable fire standards.

All aspects of the fire detection and suppression system must meet the requirements of the IFC.

- Ventilation

Local exhaust ventilation must be available in the FAB to capture and remove contaminants at the source. This includes but is not limited to gas cabinets for cylinders, gas panel enclosures and snorkel exhaust for chamber openings and pump exhaust, and exhaust treatment devices for Pyrophoric and corrosive gases. Ventilation systems must meet all University standards and the IBC, IFC and the International Mechanical Code and must be reviewed by facilities management.

A dedicated HEPA vacuum must be available for use in the FAB. Nilfisk is one manufacturer that offers a vacuum with a combination of HEPA and charcoal filters.

The exhaust system for removal of any HGS must be a dedicated system. Emergency Safeguards and Procedures
The tool, gas delivery system, and other high hazard processes that could potentially produce an uncontrolled emergency release of HGS must be capable of automatic and remotely activated emergency shutdown, as per IBC and IFC. The EMO actuator should be readily accessible along the emergency egress path from the room or facility, and its activation should place the equipment in a safe mode. Activation of the EMO should not affect fire, gas monitoring or safety systems.

All safety systems including ventilation, GMS, fire protection, EMOs, and suppression must have emergency back up power capable of supporting the system for 24 hours or be integrated into an Uninterrupted Power Supply system.

The EMO system, GMS and fire detection should be tied into the facilities emergency notification system. A written Emergency Response Plan specific to the FAB must be developed.

STANDARD OPERATING PROCEDURES:

All managers with gas source tools must develop and implement standard operating procedures (SOPs) for normal operation and maintenance procedures. This includes incorporation of emergency procedures to address personal exposure as well as the potential for fire and release or generation of toxic gases. The SOPs need to be reviewed and/or updated at least annually.

SOPs must include the following information on routine tasks, as well as appropriate maintenance and decontamination methods to enable safe operation and maintenance of the tool and gas delivery, containment and detection systems, and any specialized exhaust treatment systems:

- A list of all personnel authorized to perform gas bottle changes, and a description of the access requirements to the gas storage/delivery area.
- A description of any safety measures provided in and associated with the tool (i.e., safety interlocks, restrictive flow orifices on gas bottles, emergency off (EMO) circuits, local exhaust ventilation, HEPA vacuum for particulate capture).An explanation of any hazard alerts including but not limited to visual alerts, auditory alarms, status indicators, and hazard alert systems integral with the equipment's operating system.
- A summary of hazards inherent in the tool and associated equipment, including their location and any safety controls and recommendations to prevent injury from the hazards. This summary must include protocols to address equipment failure in the event of power interruption.
- Specific instructions for routine operation of the tool and gas delivery, containment and GMS systems
- Hazardous energy control procedures for any source of electrical, chemical, thermal or mechanical energy, radiation and compressed air or liquid energy that exists in the tool.
- A listing of all chemical substances that will be used in and with the tool. Attaching the Material Safety Data Sheets for each chemical to the SOP is ideal. However, in the event that numerous chemicals will be used, a reference to where the MSDS(s) are maintained in the lab is acceptable.
- The hazards associated with each chemical, the personal protective equipment required to prevent exposure, and emergency procedures to follow in the event of exposure or release of a chemical. When listing necessary PPE, be as specific as possible (i.e., butyl rubber gloves as opposed to "gloves").

- Waste handling procedures as applicable.

- Procedures for ordering, receiving, inspecting, transporting, storing and changing the gas bottles. Procedures for when and how DPS will be notified. A description of when and how leak check procedures will be performed must also be included. A gas cylinder change checklist and use of the buddy system for cylinder change outs are highly recommended. FABs should arrange for JIT delivery of gases to minimize the quantities stored on site.. Emergency and decontamination procedures in the event of toxic or flammable/Pyrophoric gas release, fire, or personal exposure.

- A description of the training and qualification requirements for each person who will use or work on the tool and gas delivery and GMS.

- Maintenance and calibration procedures for GMS equipment.

- Maintenance procedures for any specialized exhaust treatment systems.

ROUTINE MAINTENANCE PROCEDURES AND REPAIRS:

- If applicable, ensure the lockout/tag out procedure has been followed.

- Prior to beginning work, ensure that all necessary PPE is available, and then used as necessary during the work.

- Pumping and purging of gas lines may not always remove all toxic material. Use local exhaust ventilation (LEV) to capture and remove any airborne particulate or gas released upon opening the chamber ports and vacuum pumps (when applicable). LEV must remain in operation during maintenance and decontamination procedures unless alternate exhaust provisions have been arranged. If it is not possible to use LEV, respiratory protection must be used.

- While disconnecting equipment or removing components, gas monitoring at the source for toxic gases must be performed.

- If the chamber is to be vacuumed, a dedicated vacuum with HEPA filter must be used. All users must be knowledgeable in the maintenance requirements of the vacuum and procedures for changing and disposing the filter.

- Any surface potentially contaminated with toxic solids must be thoroughly wiped down with water. Specify how this waste will be collected for eventual disposal by OSEH Hazardous Materials.

TRAINING:

Training will include:

- Information on the physical and chemical hazards associated with use and maintenance of the tool.

- A review of all established SOPs pertaining to use and maintenance of the tool and gas delivery, containment and GMS systems and any specialized exhaust treatment systems.

- Access requirements for those personnel authorized to change the gas bottles.

- A review of emergency procedures.

RELATED DOCUMENTS:

SEMI S10-1296 *Safety Guideline for Risk Assessment*
SEMI S12-0298 *Guidelines for Equipment Decontamination* SEMI S2-200 *Environmental, Health & Safety Guideline for Semiconductor Manufacturing Equipment*
Hazard Communication Program
Personal Protective Equipment, General
Lock-out/Tag-out – Control of Hazardous Energy Sources

TECHNICALSUPPORT:

All referenced guidelines and regulations are available through OSEH (7-1142).

SYSTEM COMPONENTS

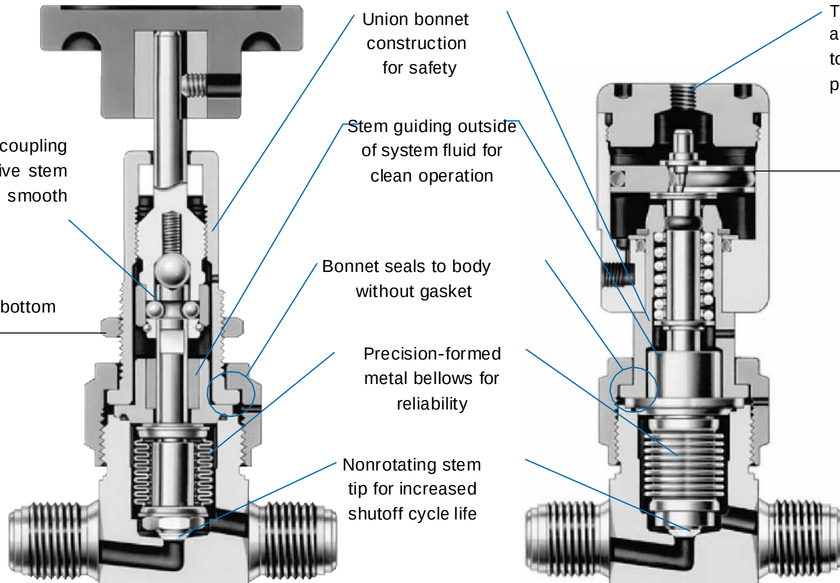
VALVES

Bellows-Sealed Valves

BN Series

- Packless valves with all-metal seal to atmosphere
- Working pressures up to 500 psig (34.4 bar)
- Temperatures up to 200°F (93°C)

Features



Valve

- 316L stainless steel construction—316L VAR for bodies with butt weld end connections
- Flow coefficients (C_v): 0.30 and 0.70
- Swagelok tube fitting, weld, and VCR® and VCO® fitting end connections
- Easily purged to maintain clean operation

Pneumatic Actuator

- Normally closed (C) model requires air to open and spring to close.
- Normally open (O) model requires air to close and spring to open.
- Pneumatic actuator rotates 360° for ease of installation.
- Green cap identifies normally open model.

High-Flow, Springless Diaphragm Valves

DF Series

- 316L VAR stainless steel body
- Working pressures up to 300 psig (20.6 bar)
- 1/4, 3/8, and 1/2 in.; 10 and 12 mm end connections

Features

Valve

- Flow coefficient of 0.62 meets high-flow requirements.
- No springs or threads in wetted areas improves cleanliness.
- Fully swept flow path enhances purging and gas replacement.
- Minimal PCTFE volume minimizes gas adsorption and desorption.
- Fully contained seat insert increases cycle life.
- High-flow Swagelok® “H” Type VCR® fittings, Swagelok VCR fittings, and tube butt weld end connections are available.

- Actuators require low actuation pressure.
- Construction is lightweight aluminum.

Manual Actuators

- Three-quarter turn actuation
- Handle orientation provides visual indication of open and closed

Technical Data

<table>
<tr><th rowspan="3">Model</th><th colspan="2" rowspan="2">Working Pressure
psig</th><th colspan="2" rowspan="2">Temperature Rating
°F (°C)</th><th rowspan="3">Flow Coefficient (C_v)</th><th rowspan="3">Orifice
in. (mm)</th><th rowspan="3">Internal Volume
in.^{3}</th><th colspan="2">Pneumatic Actuator</th></tr>
<tr><th rowspan="2">Actuation Pressure
psig (bar)</th><th rowspan="2">Air Displaced
in.^{3} (cm^3)</th></tr>
<tr><th>Operating</th><th>Burst</th><th>Operating</th><th>Bakeout</th></tr>
<tr><td>Manual</td><td>Vacuum to 300 (20.6)</td><td rowspan="2">3200 (220)</td><td rowspan="2">–10 to 150
(–23 to 65)</td><td rowspan="2">302 (150)
(valve open)</td><td rowspan="2">0.62</td><td rowspan="2">0.23
(5.8)</td><td rowspan="2">0.27 (4.4) body with HVCR fittings</td><td>—</td><td>—</td></tr>
<tr><td>Pneumatic</td><td>Vacuum to 125 (8.6)</td><td>70 to 100
(4.9 to 6.8)</td><td>0.1
3</td></tr>
</table>

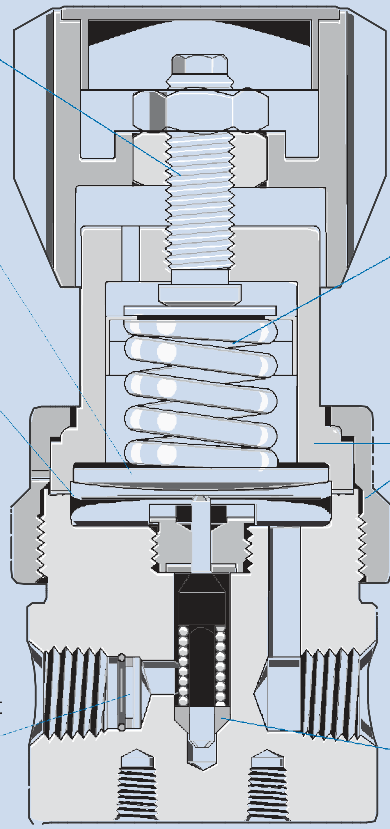
SYSTEM COMPONENTS

REGULATORS

Pressure Regulators

- Pressure-reducing models
- Back-pressure models
- Gas cylinder changeover model
- Vaporizing models

Swagelok® Pressure Regulator Features



Stem

Fine-pitch threads enable precise spring adjustment with low torque.

Stop Plate

This disc is braced by the cap shoulder to protect against a ruptured diaphragm.

Convoluted Diaphragm

The all-metal diaphragm acts as the sensing mechanism between the inlet pressure and the range spring. The convoluted, nonperforated design ensures greater sensitivity and longer life. A piston sensing mechanism (shown below) can accommodate higher pressures.

Inlet

Range Spring

Turning the handle compresses the spring, pushing the poppet away from the seat and increasing outlet pressure.

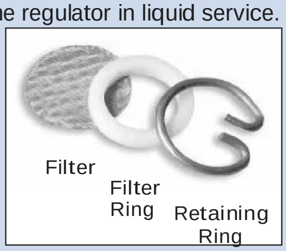
Two-Piece Cap

The two-piece design provides linear load on the diaphragm seal when the cap ring is tightened, eliminating torque damage to the diaphragm during assembly.

Outlet

Gauze Inlet Filter

Regulators are susceptible to damage from system particles. Swagelok pressure-reducing regulators include a 25 µm filter that is held in the inlet port with a retaining ring to prevent it from accidentally falling out. It can be removed easily for cleaning or to use the regulator in liquid service.



Poppet Damper

The poppet damper keeps the poppet aligned and reduces vibration and resonance.

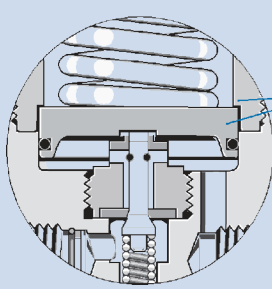
Venting Options

The self-vent option allows excess outlet pressure to vent through the body cap. This can occur when downstream flow is suddenly reduced or when the handle is adjusted to a lower pressure with little or no flow downstream.

① The captured-vent port is in the bottom of the KHR series body.

Piston Sensing Mechanism

Piston sensing mechanisms typically are used to regulate higher pressures than a diaphragm can withstand. They are also more resistant to damage caused by pressure spikes and have a short stroke to maximize cycle life.



Fully-Contained Piston

The piston is contained by a shoulder in the regulator body cap to prevent piston blowout if the regulator outlet is over pressurized.

Pressure Regulator Operation

- Regulators reduce the pressure of a gas or liquid from a cylinder to a lower value needed by a device
- A pressure regulator provides better resolution and control when its inlet and control range Pressures closely match the pressure requirements of the fluid handling system.
- *Resolution* is the number of handle turns needed to adjust a regulator from its lowest to highest outlet pressure setting.
- *Control* is the ability of the regulator to hold a given outlet pressure set point.

Pressure-Reducing Regulators

- Pressure-reducing regulators control outlet pressure by balancing an adjustable spring force against the forces caused by inlet and outlet pressures.
- The spring force is adjusted by turning the stem/handle, which sets the desired outlet pressure.
- As inlet pressure decreases, the force balance changes. To compensate, outlet pressure will increase. This supply-pressure effect (SPE) is a function of the design and type of regulator.
- If a regulator is subjected to fluctuating inlet pressure, and outlet pressure variations are not desirable, a two-stage regulator is used.

Specialty Pressure-Reducing Regulators

- *Gas Cylinder Changeover*
  - ü A two-stage gas cylinder changeover model automatically switches between two sources.
  - ü Automatic or manual changeover: The automatic changeover system is useful if the system consumes higher amounts of gases requiring a change of cylinders very often or if the system requires a continuous supply of gas e.g. operation during the weekend or operation without supervisor or operator.
- *Vaporizing*
  - ü Vaporization regulators are available with electric heat to vaporize liquid samples or to preheat gas samples.
- Single stage or dual stage
  - ü Dual stage pressure regulator should be used if the operating pressure has to be absolutely stable even if the inlet pressure drops
  - ü Dual stage pressure regulator should be used if the pressure has to be reduced from a high pressure level (e.g. 200 bar/2900 PSIG) to a low very pressure (e.g. < 1 bar/14.5 PSIG).
  - ü When using liquefied gases it is sufficient in nearly all applications (e.g. SF_6, NH_3, HCL, CO_2 and others) to use the single stage pressure regulator because the gas pressure remains constant until the cylinder is nearly empty

Two-Stage Diaphragm-Sensing, Pressure-Reducing Regulators (KCY Series)

The KCY series is designed for use in applications requiring constant outlet pressure even with wide variations in inlet pressure. This two-stage regulator is comparable to two single-stage regulators connected in series. The first stage is factory set to reduce the inlet pressure to 500 psig (34.4 bar). The second stage can be adjusted with the handle to achieve the required outlet pressure.

This two-stage arrangement minimizes the supply-pressure effect caused by fluctuating inlet pressure, such as with a depleting gas cylinder. As inlet pressure drops below the setting of the first stage, the regulator then functions as a single-stage regulator. The first-stage pressure setting can be reduced while monitoring the pressure at the Interstage port, but lower flow may result.

Features

- Convoluted, nonperforated diaphragm
- Metal-to-metal diaphragm seal
- Excellent set-point stability
- Supply-pressure effect of approximately 0.01 %
- High-flow, dual-gauze type filter positively retained in inlet port

Technical Data

Maximum Inlet Pressure

- 3600 psig (248 bar)

Pressure Control Ranges

- 0 to 10 psig (0.68 bar) through 0 to 500 psig (34.4 bar)

Flow Coefficient (C_v)

- 0.06 and 0.20

See page 42 for flow graphs.

- 0.50 also available

Maximum Operating Temperature

- 176°F (80°C) with PCTFE seat
- 392°F (200°C) with PEEK seat

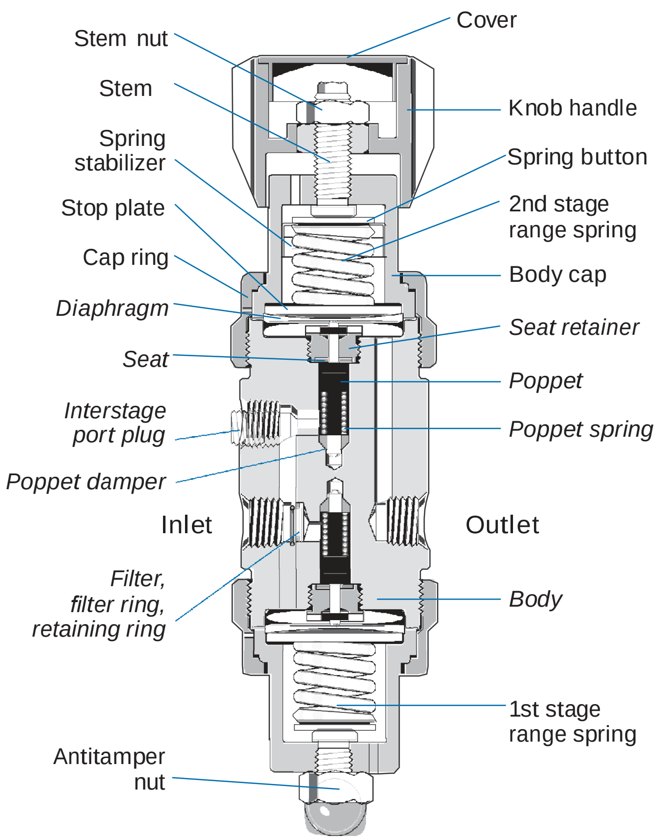
Weight

- 4.2 lb (1.9 kg)

Ports

- 1/4 in. female NPT inlet, outlet, and gauge ports

Materials of Construction



Component	316 SS	Brass CW721R
	Material	
Knob handle, cover	Nylon with 316 SS insert	
Spring buttons	316 SS (1st stage) Zinc-plated steel (2nd stage)	
Spring stabilizer①	301 SS	
Range springs	316 SS (0 to 10 through 0 to 100 psig control ranges)② Zinc-plated steel (0 to 250 and 0 to 500 psig control ranges)	
Stems, stem nut, cap rings, stop plates, body caps, panel nuts,③ antitamper nut	316 SS	
Nonwetted lubricant	Hydrocarbon-based	
Seat retainers, filter, retaining ring	*316 SS*	
Seats	*PCTFE or PEEK*	
Diaphragms,④ poppet springs	*Alloy X-750*	
Poppets	*S17400 SS④*	
Poppet dampers, filter ring	*PTFE*	
Interstage port plug	*316 SS with PTFE tape*	
Self-vent seal③	*Fluorocarbon FKM*	
Body	*316 SS*	*Brass CW721R*
Wetted lubricant	*PTFE-based*	

Wetted components listed in *italics*.
① Not required in all configurations.
② Regulators with control range 0 to 100 psig (0 to 6.8 bar) and 0.20 C_v have zinc-plated steel range spring.
③ Not shown.
④ Regulators with control ranges higher than 0 to 100 psig (0 to 6.8 bar) are assembled with two diaphragms.

Ultrahigh-Purity Gas Filters

SCF Series

- Membralox® ceramic filtration technology
- Genuine Swagelok® VCR® face seal fittings
- Particle removal rating greater than 99.9999999 % at 0.003 µm at maximum flow rate
- Flow rates to 2700 std L/min

SCF Series UHP Filters

The Swagelok SCF series UHP gas filter is designed to meet the stringent requirements of SEMI E49.8-96. With the proprietary Membralox ceramic element and 316L VAR stainless steel housing, the SCF series UHP filter is a solution for many demanding gas filtering applications.

Features

- High particle removal efficiency
- Exceptionally low particle shedding
- Superior moisture dry-down characteristics
- Extremely low outgassing
- Outstanding chemical compatibility
- High differential pressure rating
- All-welded construction
- Inline and surface-mount configurations

Materials of Construction

Ceramic element: high-purity alumina

Gasket: high-density PTFE

Housing: 316L VAR stainless steel/ASTM A479

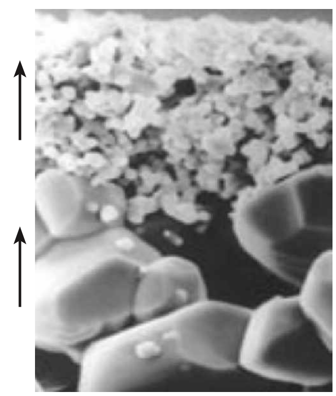
Membralox Ceramic Filtration Technology

The Membralox ceramic element is a multilayered filter medium. The material is a high-purity alumina with a precisely controlled pore structure.

The Membralox ceramic element is an

- extruded multiflow channel block or tubular structure. The flow channels within the structure are coated with precisely controlled membrane layers. A final sintering process fuses the layers together.
- The result is a filter element that is designed to minimize particle shedding and provide enhanced flow characteristics. The removal rating of the filter is greater than 99.9999999 % at 0.003 µm when tested in accordance with SEMI F38-0699.
- The Membralox ceramic element provides both high temperature and chemical resistance, along with superior particle removal and outgassing characteristics.

The ceramic element is a multichannel block or tubular configuration of high-purity alumina.



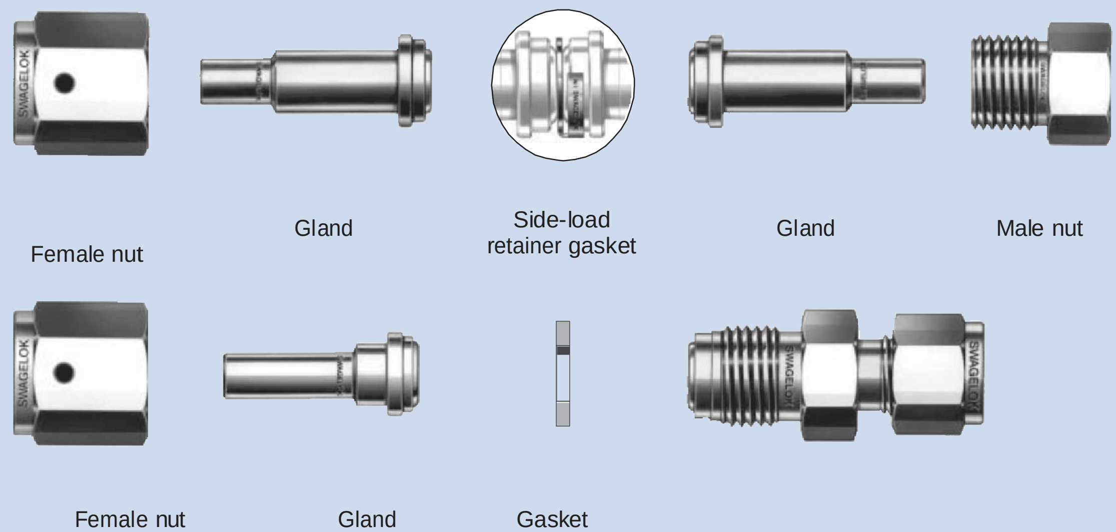
A scanning electron microscope image shows the two membrane layers of the filter element: ultrafine and fine (as shown from top to bottom).

VCR® Metal Gasket Face Seal Fittings

- 1/16 to 1 in. and 6 to 18 mm sizes
- High-purity stainless steels
- The original design, the authentic VCR brand

Swagelok

Typical VCR Assemblies

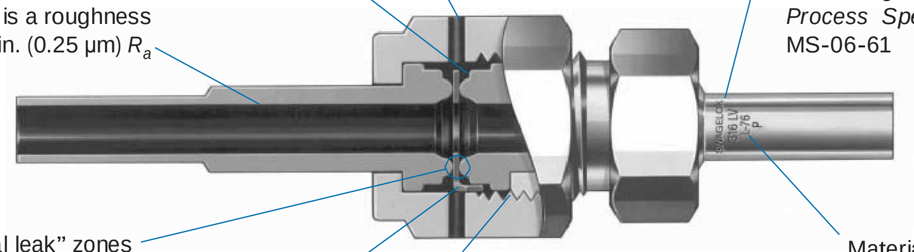


Features

- Swagelok® VCR fittings offer the high purity of a metal-to-metal seal, providing leak-tight service from vacuum to positive pressure.
- The seal on a VCR assembly is made when the gasket is compressed by two beads during the engagement of a male nut or body hex and a female nut.

Plating

- VCR female nuts are silver plated. Avoid chemical processes used for cleaning, electropolishing, and passivation that will remove plating.
- If the plating is damaged or removed, thread galling may occur, damaging fitting components and preventing a proper seal.



Materials of Construction

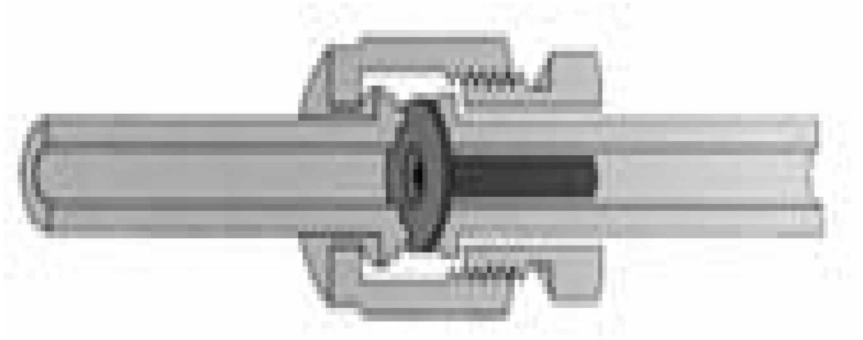
Material	Designator	Specification
316 stainless steel	SS	Bar stock: ASME SA479 ASTM A276 Forged shapes: ASME SA182 ASTM A314
316L stainless steel	316L	Bar stock: ASME SA479 ASTM A276 Forged shapes: ASME A182
316L VAR (vacuum arc remelt) stainless steel	6LV	
Nickel	NI	ASTM B162
316L stainless steel	SS	ASTM A240, ASTM A167
Copper	CU	ASTM B152

Pressure Ratings

- All ratings comply with calculations in accordance with ASME Code for Pressure Piping B31.3, Process Piping.
- To determine pressure ratings in accordance with ASME B31.1, Power Piping, multiply psig rating by 0.94.
- Working pressure ratings determined at room temperature with gasket materials shown.

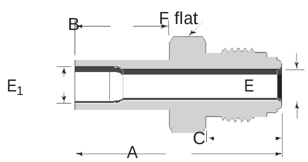
Components	Material	Temperature, °F (°C)
Fittings	316 stainless steel	1000 (537)
	316L stainless steel	
	316L VAR stainless steel	
Gaskets	316L stainless steel	1000 (537)
	Nickel	600 (315)
	Copper	400 (204)

GAS LINE FILTER WITH INTEGRAL VCR GASKET



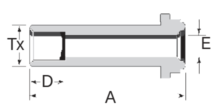
¼, 3/8, ½ INCH VCR COMPARISON

Bodies



Tube Size	VCR Size	Ordering Number	Dimensions						Working Pressure		
			A	B	C	E	E_1	F	Ni	SS	Cu
Dimensions, in. (mm)									psig (bar)		
3/8	1/4	6LV-4-HVCR-1-6TB7	1.68 (42.7)	0.75 (19.1)	0.62 (15.7)	0.25 (6.4)	0.31 (7.9)	5/8	3300 (227)	3300 (227)	3300 (227)

Socket Weld

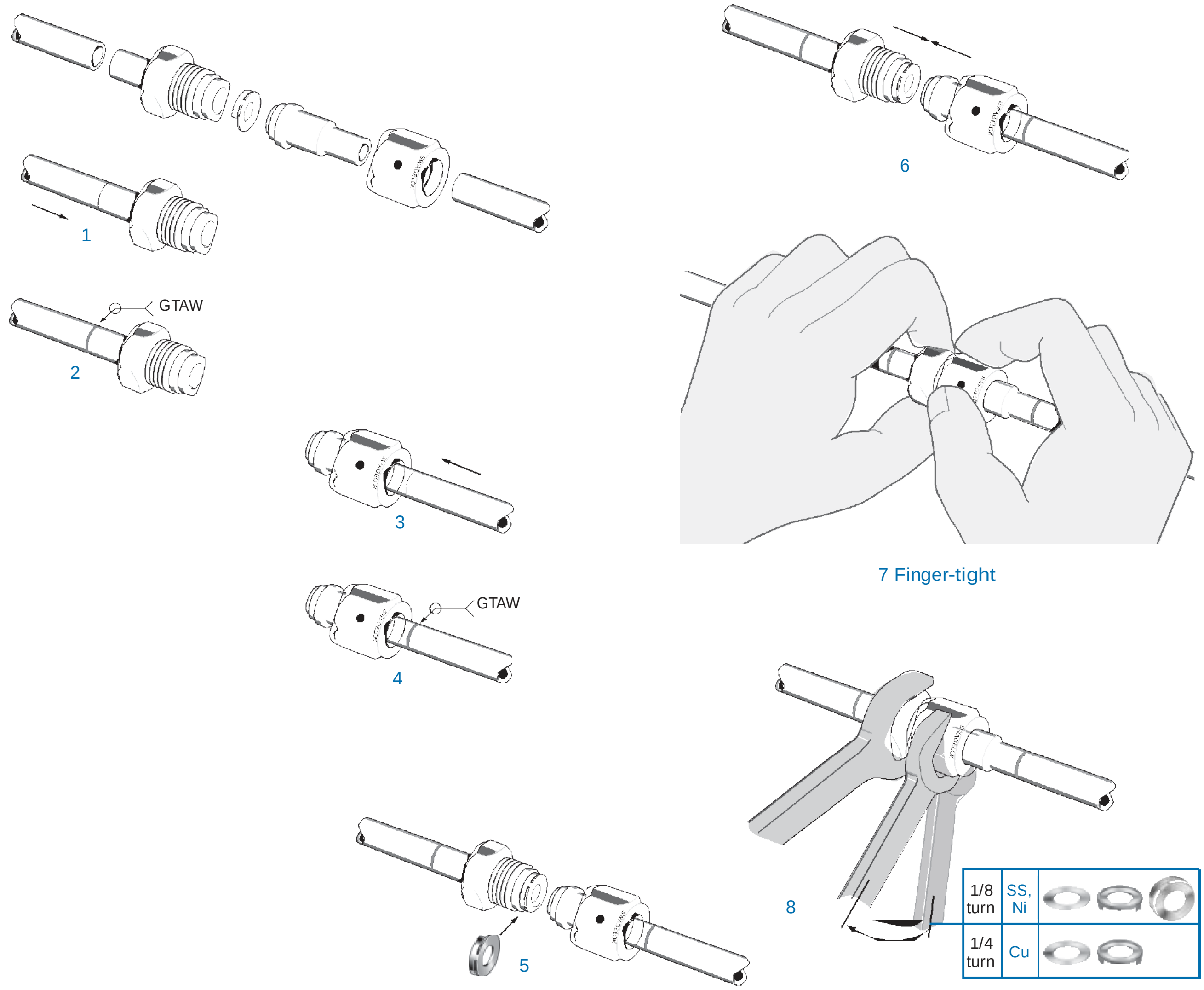


Tube Socket Size	VCR Size	Ordering Number	Dimensions				Working Pressure		
			A	D	E	Tx	Ni	SS	Cu
Dimensions, in. (mm)							psig (bar)		
1/16	1/8	SS-1-VCR-3①②	0.70 (17.8)	0.10 (2.5)	0.05 (1.3)	0.13 (3.3)	9000 (620)	9000 (620)	7200 (496)
1/8	1/8	SS-2-VCR-3②	0.70 (17.8)	0.10 (2.5)	0.09 (2.3)	0.20 (5.1)	7100 (489)	7100 (489)	7100 (489)
1/4	1/4	SS-4-VCR-3	1.31 (33.3)	0.28 (7.1)	0.18 (4.6)	0.35 (8.9)	5500 (378)	5500 (378)	5500 (378)
3/8	1/2	SS-6-VCR-3③	1.50 (38.1)	0.31 (7.9)	0.28 (7.1)	0.60 (15.2)	3500 (241)	4300 (296)	2800 (192)
1/2	1/2	SS-8-VCR-3	1.50 (38.1)	0.38 (9.6)	0.40 (10.2)	0.60 (15.2)	3000 (206)	3000 (206)	2400 (165)
5/8	5/8	SS-10-VCR-3	1.56 (39.6)	0.41 (10.4)	0.50 (12.7)	0.72 (18.3)	2800 (192)	2800 (192)	2200 (151)
3/4	3/4	SS-12-VCR-3	2.00 (50.8)	0.44 (11.2)	0.62 (15.7)	0.88 (22.4)	2800 (192)	2800 (192)	2200 (151)
1	1	SS-16-VCR-3	2.22 (56.4)	0.62 (15.7)	0.87 (22.1)	1.19 (30.2)	2400 (165)	3000 (206)	1900 (130)

① Uses 1/8 in. gasket and nut.
② Not designed for gasket retainer assembly.
③ Uses 1/2 in. gasket and nut.

- **Note:**
- Most OEM MFC manufacturers have a 3/8 inch VCR and a ½ inch VCR option.
- A 3/8 VCR fitting may be a 3/8 tube with a ¼ inch VCR nut or a 3/8 inch tube with a ½ inch VCR nut.
- There is *NO* 3/8 VCR fitting.
- A ½ inch VCR option will be a ½ inch VCR nut and a ½ *OR* a 3/8 inch tube size.

VCR Fitting Installation Instructions



TUBING

Ultrahigh-Purity Stainless Steel Tubing

Ultrahigh-Purity Stainless Steel Tubing

Features

- 316L stainless steel
- Available in sizes from 1/4 to 4 in. outside diameter; metric sizes available upon request
- Coaxial tubing available in sizes from 1/4 to 1 in. outside diameter
- Electropolished internal surface finish of 10 µin. R_a (0.25 µm) max
- Ends prepared for orbital welding
- Rinsed with 18 MΩ·cm DI water
- Purged with filtered nitrogen
- Cleaned and sealed in an ISO Class 4/Federal Class 10 cleanroom
- Marked to indicate size, material type, and heat code

Electric-Traced Bundled Tubing

A simple and economical choice for applications where electric tracing is preferred, Swagelok electric-traced bundled tubing maintains consistent temperatures in long, continuous lengths of impulse and sample lines for freeze protection, temperature maintenance, or viscosity control. The standard self-regulating tracer lowers heat output as the bundle gets warmer. For more precise temperature control, an optional line-sensing thermostat is available.

Features

- Self-regulating electric tracers
- Tinned copper braided shield
- Fluoropolymer tracer jacket
- ATEX, FM®, and CSA® approved tracer for use in hazardous areas
- Maintains process temperatures up to 250°F (121°C)
- One or two process tubes available as standard up to 4 Pre-Insulated Tubing Bundles

Technical Data—Tracer Specifications

- **High-Temperature Tracers**
- High-temperature tracers are used to maintain process temperatures or for viscosity control up to 250°F (121°C). They are also used for freeze protection or if the tracers will be exposed to intermittent temperatures up to 420°F (215°C), such as during steam cleaning.
- **Low-Temperature Tracers**
- Low-temperature tracers are used for freeze protection or maintaining temperatures up to 100°F (37°C) and can be exposed to continuous process temperatures of 150°F (65°C).

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Choice of material:

- Stainless Steel is used in processes with toxic, corrosive and explosive gases.
- Furthermore it is recommended to use stainless steel materials for process operating with high purity gases and for calibration gases with contents in the range of ppm or ppb (eventually electro polished).
- For gas qualities up to 99.0 it is sufficient to use copper pipelines or brass materials
- Research has clearly shown that house Nitrogen and Oxygen supply systems using properly constructed brazed copper pipe is as clean as electropolished stainless steel after initial purging and improves with age.

Benefits of Electropolishing

- Electropolishing produces a number of favorable changes in a metal part which are viewed as benefits to the gas system. All of these attributes translate into advantages depending upon the end use of the product. These include:
  - Brightening
  - Burr removal
  - Total passivation
  - Oxide and tarnish removal
  - Reduction in surface profile
  - Removal of surface occlusions
  - Increased corrosion resistance
  - Increased ratio of chromium to
  - Radiusing of sharp edges
  - Reduced surface friction
  - Stress relieved surface
  - Removal of hydrogen

- Electropolishing produces the most spectacular results on 300 series stainless steels.
- The resulting finish often appears bright, shiny, and comparable to the mirror finishes of "bright chrome" automotive parts.
- Electropolishing produces a combination of properties which can be achieved by no other method of surface finishing.
- Mechanical grinding, belting, and buffing can produce beautiful mirror-like results on stainless steel, but the processes are labor intensive and leave the surface layer distorted, highly stressed, and contaminated with grinding media.
- The passivation methods commonly employed produce clean, corrosion resistant surfaces, but do not achieve the bright, lustrous appearance obtained by electropolishing.
- The corrosion resistance of electropolished stainless steel exceeds that of standard passivation processes.
- Electroplating can produce extremely bright finishes, but the finish is a coating which can chip or wear off.
- Electroplated surfaces may also exhibit hydrogen embrittlement which must be stress-relieved in a separate step.
- Neither passivation nor electroplating can accomplish burr removal.
- Processes are available for chemical deburring and brightening of steel and stainless steel, but these methods cannot match the surface improvement produced by electropolishing.
- The corrosion resistance produced by such processes is decidedly inferior to that produced by electropolishing.

Basic Principle of Electropolishing

- Electropolishing is a process by which metal is removed from a work piece by passage of electric current while the work is submerged in a specially-designed solution.
- The process is essentially the reverse of electroplating. In a plating system, metal ions are deposited from the solution onto the work piece; in an electropolishing system, the work piece itself is dissolved, adding metal ions to the solution.

Figure 1 is an illustration of a typical electropolishing cell. The work piece is connected to the positive (or anodic) terminal, while the negative (cathodic) terminal is connected to a suitable conductor. Both positive and negative terminals are submerged in the solution, forming a complete electrical circuit. The current applied is direct (DC) current.

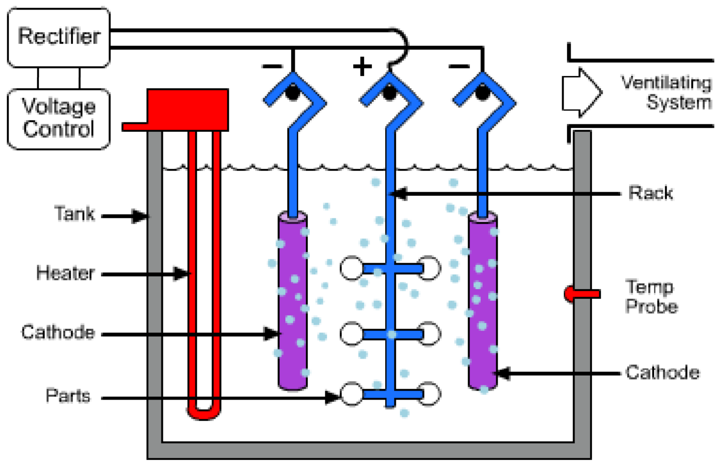


Figure 1: Typical Electropolishing Installation

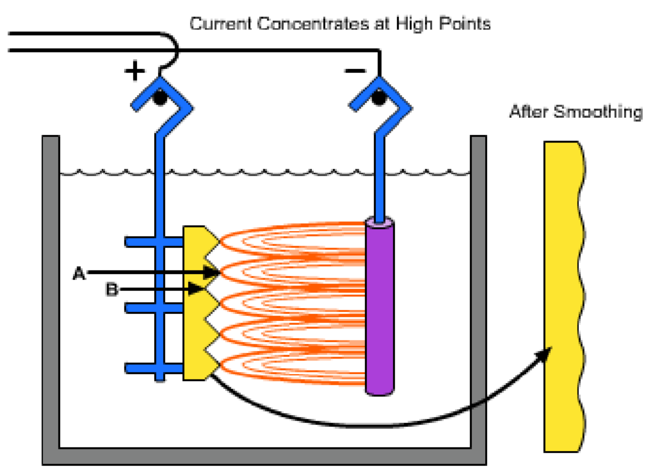
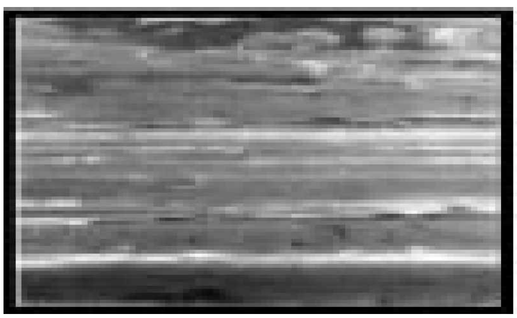


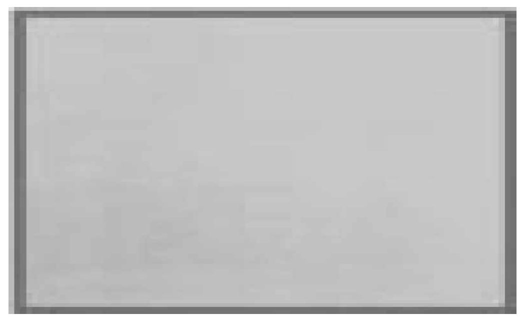
Figure 2: Smoothing by Electropolishing

The quantity of metal removed from the work piece is proportional to the amount of current applied and the time. Other factors, such as the geometry of the work piece, affect the distribution of the current and consequently, have an important bearing upon the amount of metal removed in local areas.

Figure 2 illustrates both high and low current density areas of the same part and notes the relative effects of electropolishing in these two areas.

- The principle of differential rates of metal removal is important to the concept of deburring accomplished by electropolishing.
- Fine burrs become very high current density areas and are, subsequently, rapidly dissolved.
- Low current density areas receive lesser amounts of current and may show significantly lower metal removal.
- In the course of electropolishing, the work piece is manipulated to control the amount of metal removal so that polishing is accomplished and, at the same time, dimensional tolerances are maintained.
- Electropolishing literally dissects the metal crystal atom by atom, with rapid attack on the high current density areas and lesser attack on the low current density areas.
- The result is an overall reduction of the surface profile with a simultaneous smoothing and brightening of the metal surface.
- In the case of stainless steel alloys, an important effect is caused by differences in the rates of removal of the components of the alloy.
- Under equilibrium polishing conditions, the chemical reaction favors preferential removal of iron and nickel atoms, leaving a surface layer consisting principally of chromium and its oxides.
- This phenomenon imparts the important property of "passivation" to electropolished surfaces.


Mill finished tubing


After Electropolishing

MASS FLOW CONTROLLERS

MFC PRINCIPLES

- Mass Flow Controllers (MFCs) are used wherever accurate measurement and control of a mass flow of gas is required independent of pressure change and temperature change

To help understand how an MFC works, it can be separated into 4 main components:

1. a bypass,
2. a sensor,
3. an electronics board and
4. a regulating valve:

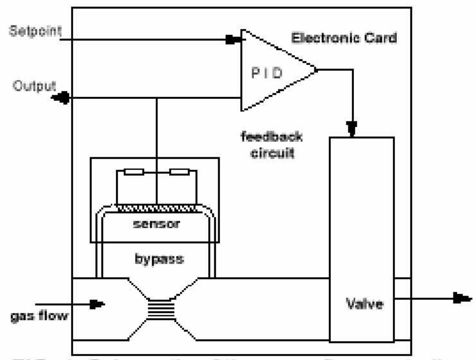


FIG. 1. Schematic of the mass flow controller.

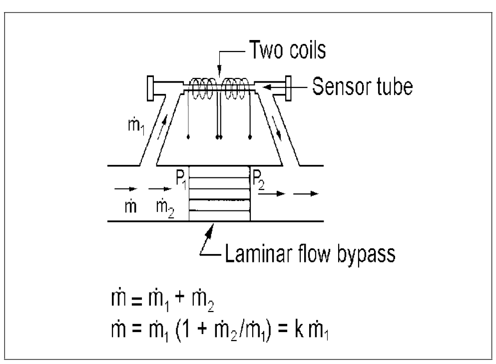
- The bypass, the sensor, and one part of the electronics board are the measurement side of the mass-flow controller and make a Mass Flow Meter.

- The regulating valve and the other part of the electronics board are the controlling side of the mass-flow controller and exist only on a Mass-Flow Controller.

- So every Mass-Flow Controller includes a Mass-Flow Meter.

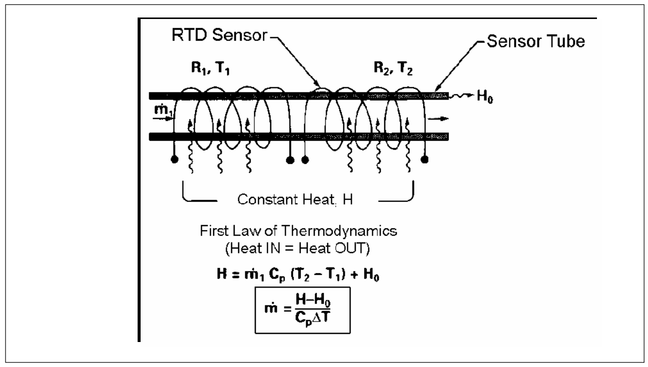
FLOW SENSING PRINCIPLE

- The operating principle of the Thermal Mass Flow Sensor is based on heat transfer and the first law of thermodynamics.
- During operation process gas enters the instrument's flow body and divides into two flow paths.
- One through the sensor tube. The other path through the laminar flow bypass.
- The laminar flow bypass generates a pressure drop, P_1–P_2, forcing a small fraction of the total flow to pass through the sensor tube(m_1).

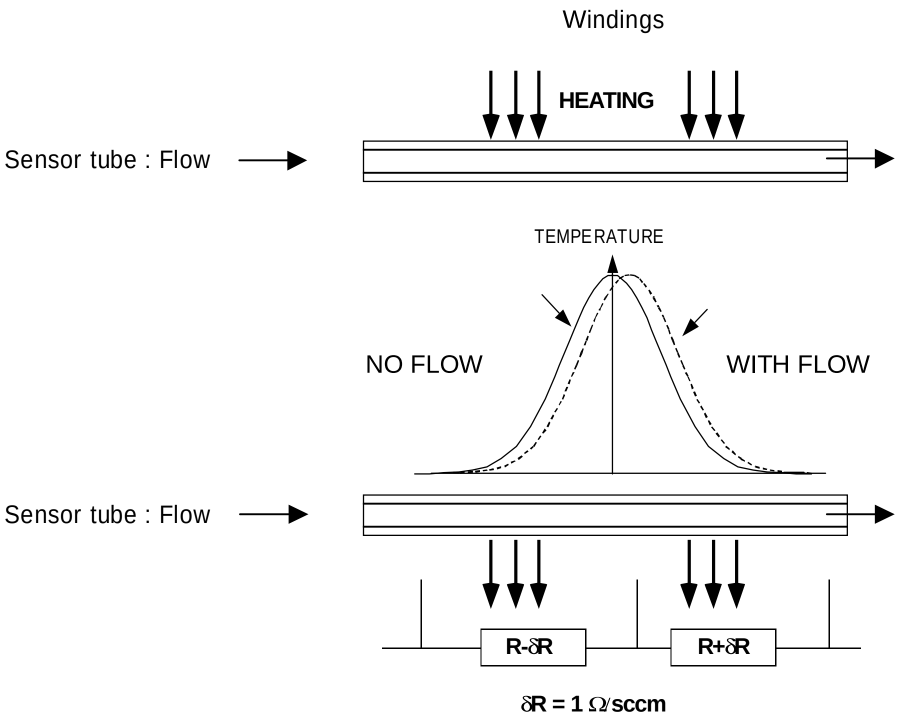


Flow Paths through the Instrument

- Two resistance temperature detector (RTD) coils around the sensor tube direct a constant amount of heat (H) into the gas stream.
- During operation, the gas mass flow carries heat from the upstream coil to the downstream coil.
- The resulting temperature difference (ΔT) is measured by the electronics or microprocessor.
- From this, the electronics or microprocessor calculates the output signal.
- Since the molecules of the gas carry away the heat, the output signal is linearly proportional to gas mass flow.



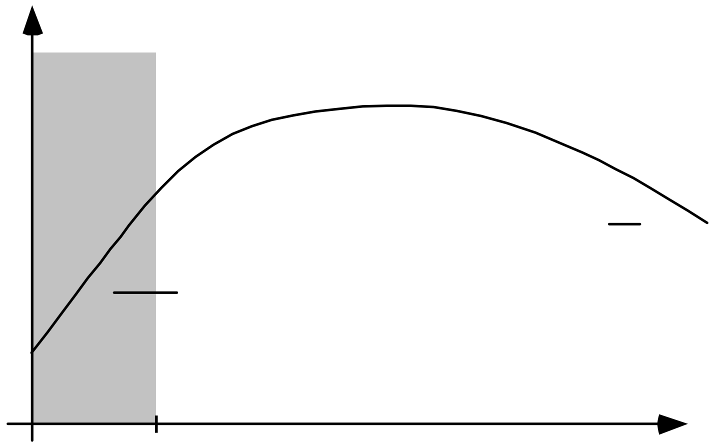
Flow Measuring Principle



Sensor temperature profile

- The mass flow through the sensor tube is inversely proportional to the temperature difference of the coils

- The coils are legs of a bridge circuit with an output voltage in direct proportion to the difference in the coils' resistance; the result is the temperature difference (ΔT).
- Two other parameters, heat input (H) and coefficient of specific heat (Cp) are both constant.
- Through careful design and attention to these parameters, this output signal is made linear over the transducer's normal operating range
- As a result, the measured flow through the sensor tube is directly proportional to the gas flow in the main body.



Linear Range of the Transducer's Output Signal

THE BYPASS

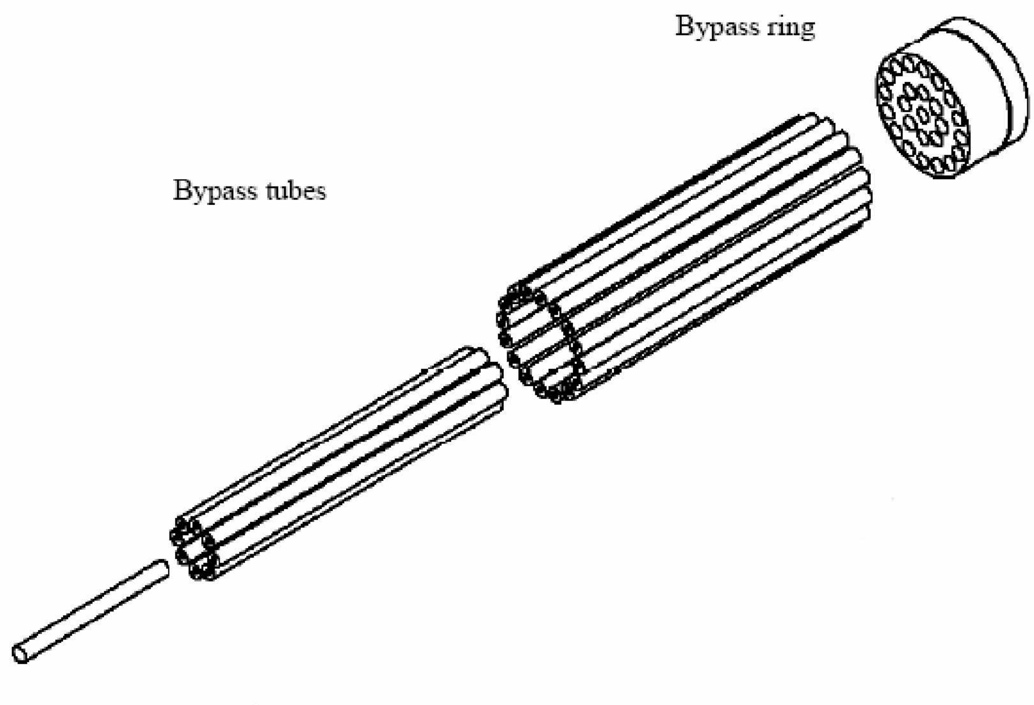
- For flow under 5 sccm the measurement is proportional to the flow with a coefficient which depends on :

  ρ : Volumic mass of the gas
  Cp : specific heat for a constant pressure,
  N : .spin factor. Constant which depends on the molecular structure of the gas and compensates for the temperature dependence of Cp.

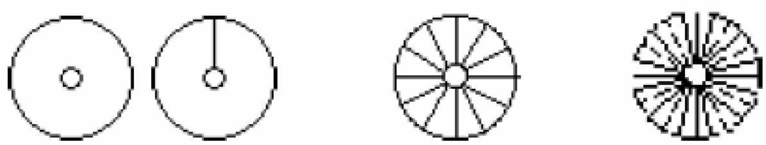
  Value of N :
  1. Monatomic gas 1.04
  2. Diatomic gas 1.00
  3. Triatomic gas .94
  4. Polyatomic gas .88
- For flows higher than 5 sccm, the sensor is at first non-linear.
- Then the measurement starts to decrease with flow because the gas flow is too fast and cools the 2 wound resistance wires instead of cooling the first one and heating the second one.
- This is the reason why a bypass is necessary for higher full scale than 5 sccm.
- Also the fact that the coefficients N and Cp are different from one gas to another explains why mass-flow CANNOT be changed from one gas to another without using a special coefficient to convert the measurement or recalibrate the mass-flow.
- Because of sensor saturation, if flow is ten times the full scale, output will be almost
- "no flow" This will never happen on a mass-flow controller as the valve acts as a restrictor and
- will not allow the gas to flow at ten times the full scale.
- But it can easily happen on a mass flow meter; if there is no restriction in the gas line there is nothing in the mass-flow meter to limit the gas flow.

BYPASS PRINCIPLES

- Acting as a restrictive element, the bypass is composed of a series of capillary tubes (or bypass washers that also come in different slot sizes for different flow ranges).
- The number of tubes or washers and their diameter will depend on the customer's specifications of gas type and flow range.
- For higher flow rates, the bypass tubes are replaced by a screen.



Bypass tubes



Bypass washers (equivalent to several thin tubes)

- The bypass principles are based on the laminar flow theory:
- When flow is laminar, the flow is proportional to the differential pressure between the inlet and outlet of the tube:
- This differential pressure between the inlet and outlet of the tube is dependent upon

1. Volume mass of the gas
2. Viscosity of the gas
3. length of the tube
4. radius of the tube

- So when a sensor tube (radius Rs, length ls) and a bypass tube are in parallel

- The flow in the sensor tube is proportional to the flow in the bypass:
- However, this is true only if the flow is laminar and if the tubes are small enough.
- This is why the bypass is made of several thin tubes instead of only one tube.
- It is important to note that the flow measured thru the sensor of a mass-flow meter or controller is not the total flow, but only one part of the flow split by the bypass.
- Mass flow meters and controllers must be used with clean, filtered gases to avoid clogging in the bypass tubes and sensor tube.

CONTROL PRINCIPLES

- The electronics board compares the amplified mass flow rate value (measured by the sensor) to the desired set point.
- This comparison generates an error signal that controls the regulating valve.
- The difference is used to drive the control valve.
- The control valve will proportionally open or close until the output is equal to the set point.
- Note that valve can be normally open or normally closed.
- This is the position that the valve will be in when the mass-flow controller is not connected to a power supply.
- The valve can be actuated by a
    1. magnetic solenoid,
    2. Piezo electric actuator, or
    3. thermal element
- The response time of the valve itself is almost instantaneous.
- In practice, however, the response time of the mass-flow controller is limited by the response time of the sensor and the time to move the valve.
- As a sensor is based on thermal exchange, it takes 0.2 to 2 sec. for the sensor to measure a gas change.
- Several techniques allow us to increase this response time and allow us to get the best mass-flow response time.
- Present state of the art response is below 0.5 seconds.

● The specification on mass flow controller valve closure references the amount of gas that will leak past the control valve when a zero flow set point is given and a specified pressure differential applied across the device.

● In this case the gas does not leak out of the flow device but past the valve and into the downstream flow path.

● This is not usually a problem with elastomer seal devices since the amount of leakage is essentially zero, but with metal seals positive shutoff is not possible because the sealing surfaces are metal-to-metal with a limited amount of closure force available.

● The manufacturers specify an accepted leak through rate, usually in percent of full scale or in mv output (50 mv equals 1% full scale on a 5 volt full scale output device). Since this is actually the measurement of a gas leak through an orifice (the gap in the valve seat) it is also very dependent on the density of the gas used for the test.

● While most manufacturers of metal seal controllers use 1% of full scale as their specification (largely because some of the larger gas panel suppliers have adopted this as their specification) there are some that are unable to meet this specification and in some cases the specification for leakage is not referenced directly at all in their performance data, possibly because it is much higher than their competitors. In these cases the issue is indirectly addressed by a statement in the performance spec that the device should not be used as a positive shutoff.

● It is usually possible to achieve much better results than the published specification with a new device (depending on the gas density) since the sealing surfaces are new and unblemished by use.

● As the valve is subjected to the forces and wear of many closures there is inevitable wear on the surfaces that can cause deterioration in the effective closure and a gradual increase in the leakage rate over time. When such a device is returned for service it is possible that, although the closure has degraded appreciably, it will still meet the specification but will not be as good as it was when new. Unless there is some reason to believe that the valve closure required is better than the specification the device is not adjusted as long as it meets the published value.

● Since the valve leakage spec is referenced as a percent of full scale the leak rate will be proportional to the full scale flow of the device, which means that the valve leakage on a 100 sccm device could be 10 times that of a 10 sccm device and still meet factory specs.

● A test based solely on a specific rate of rise in downstream pressure over time will selectively fail the higher flow device since it is looking for a specific flow rate as opposed to a flow rate at a certain percent of full scale. If your process is setup to pass/fail on valve closure tests results that are much lower than the factory spec or run higher differential pressures expect higher failure rates (even on new devices) and repair costs to replace valve components on older devices with some run time on them.

● If you have been using elastomer type devices and are switching to metal seal devices it would be wise to modify your testing procedures for valve closure and install positive shutoff valves up and downstream of your flow devices.

● In summary metal seal flow controllers are not positive shutoff devices and are not claimed to be. There are factory specifications for the accepted leak rate that are considered acceptable although not always experienced, especially on new devices. Lack of knowledge about valve leakage issues and what your process requires can cause undue incoming test failures and repair costs.

SYSTEM ANALYSIS

GAS PANELS AND SUPPLIES

- Every gas system has a source of gas which is usually:
    - ü Gas bottle of high pressure gas
    - ü Gas bottle of low pressure gas or liquid
    - ü Canister of liquid

- This gas must be controlled through a system of valves and regulators to:
    - ü Reduce the pressure of the gas in the bottle to a safe and useable pressure for

the equipment.
- ü Allow the gas to be turned off
- ü Allow bottle changes
- ü Allow residual atmosphere to be purged from the system

- The basic gas bottle system is a simple regulator with input and output pressure gauges, with a shut off valve and connection for the bottle.
  - ü Simple and effective for inert gases
  - ü Allows some atmosphere to be introduced into the gas stream
  - ü System is susceptible to damage from handling and contamination
  - ü Cannot be used for corrosives, Toxics, etc.

Contamination of inert gas:

- Contamination by air (humidity) during commissioning of the system or after changing cylinder will be removed by multiple purging with changing pressures (up to 10 bar increase/relief) using dry Nitrogen or other inert gases.
- Contamination caused by inappropriate piping material or inappropriate valves and regulator can be avoided by:
  - ü use of diaphragm or bellows sealing in pressure regulators and valves
  - ü use of gases with higher purity
  - ü suitable piping (eventually electro polished)
  - ü reduction of the internal volume of the system
  - ü use of orbital welding with Argon atmosphere
  - ü continuous purging and sealing of the piping system
  - ü Helium leak test of the system
  - ü use of VCR connections

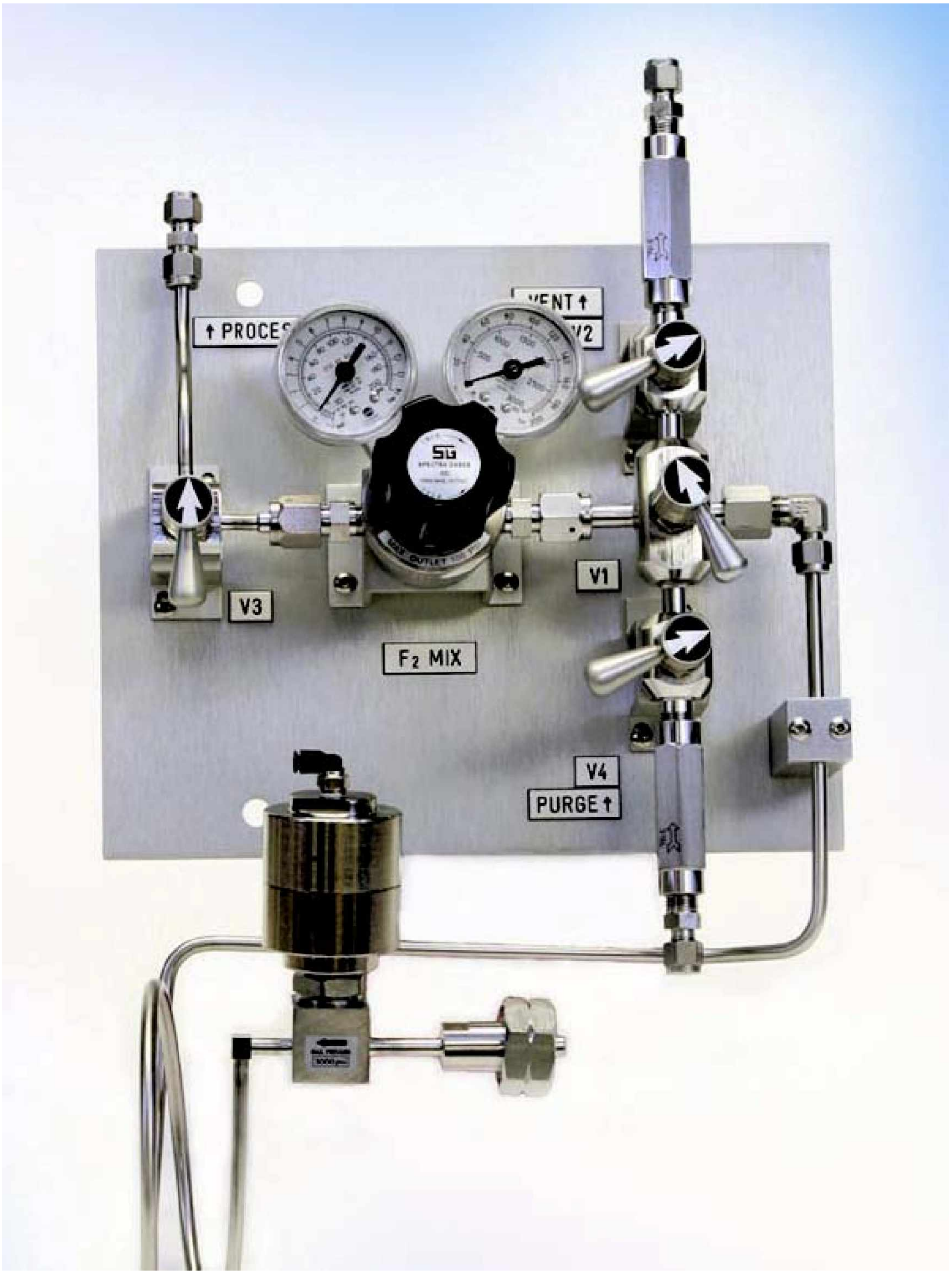
Purging:

- For gases with contents of corrosive ingredients or for gas qualities of 99.9.0 or better it is also recommended.
- For toxic, corrosive and explosive gases a purging device or pressure growing purging by pressurization cycles or by continuous system purging is necessary.

Purging for corrosive gases:

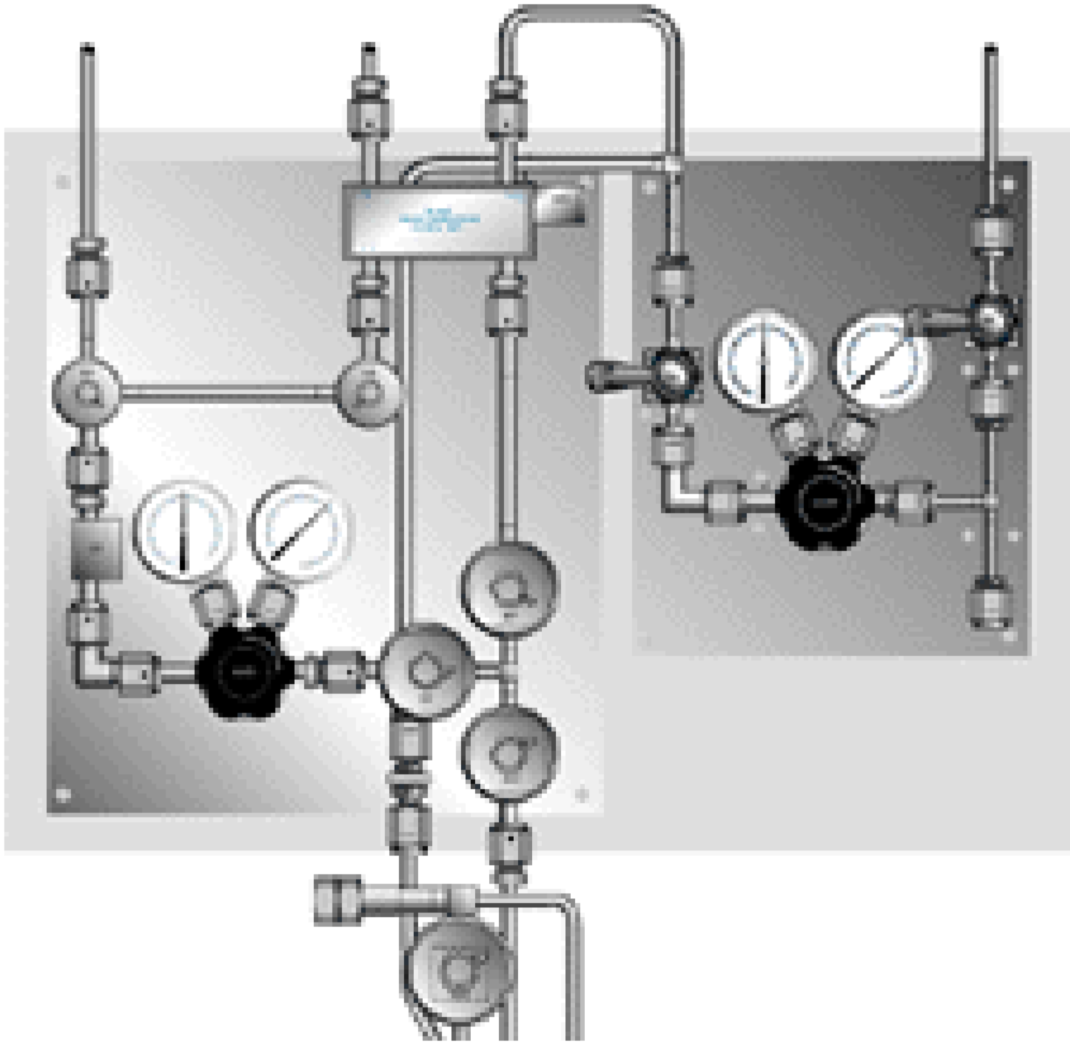
- If using corrosive gases which are connected to point of use systems, the contamination with humidity and/or Oxygen (air) has to be avoided.
- In order to avoid traces of moisture (H_2O < 5 ppm) the choice of material and the use of purging gas (Argon or Nitrogen) with a content of H_2O of less than 2 ppm is very important.
- Furthermore the purging method (multiple vacuum/pressure range alternations) plays an important role.
- Typical cycle purging required to reduce contaminates below 2 ppm is >50 cycles

5 VALVE GAS PANEL WITH PIGTAIL SHUTOFF VALVE



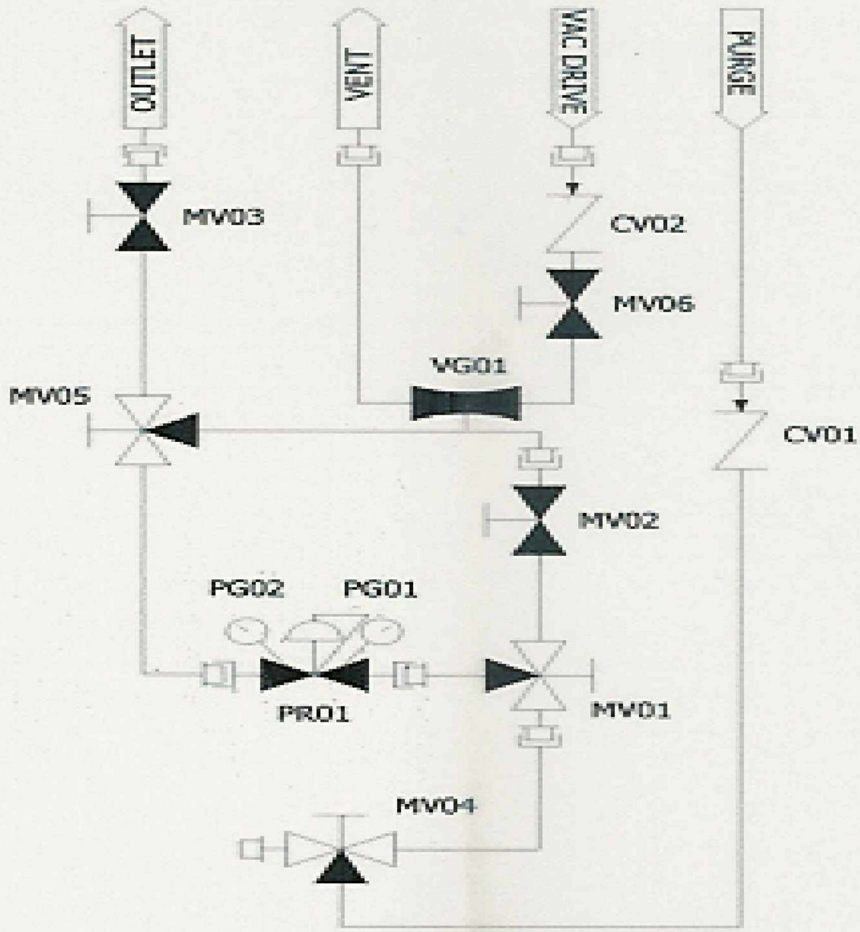
- ü 5 Valve panel allows the use of cylinder gas and an inert gas to purge the system
  - ü This reduces atmospheric contamination to a very low level during cylinder change outs
  - ü Use of a pigtail shut off allows the gas bottle to be shut down in the event of a line failure or system emergency
  - ü System can be set up to allow a small exit purge from the pigtail during a bottle change out to prevent CGA contamination.
  - ü Regulator, Gauges and lines are engineered to suit the type of gas and use rate.

6 VALVE GAS PANEL WITH PURGE PANEL ATTACHED



- 6 Valve panel allows the use of an inert gas and a vacuum generator to purge the system
  - This reduces atmospheric contamination to a very low level during cylinder change outs
  - Use of a pigtail shut off allows the gas bottle to be shut down in the event of a line failure or system emergency, triggered by an excess flow switch on the outlet line.
  - System can be set up to allow a small exit purge from the pigtail during a bottle change out to prevent CGA contamination.
  - Regulator, Gauges and lines are engineered to suit the type of gas and use rate
  - Inert purge panel shown in the picture for easy access to the purge gas.
  - Vacuum generator uses inert gas flow to generate approx 100 TORR vacuum level.
  - Cycle purging from 30 psi to Vacuum will achieve < 2 ppm contaminate levels after 50 cycles.

6-Valve



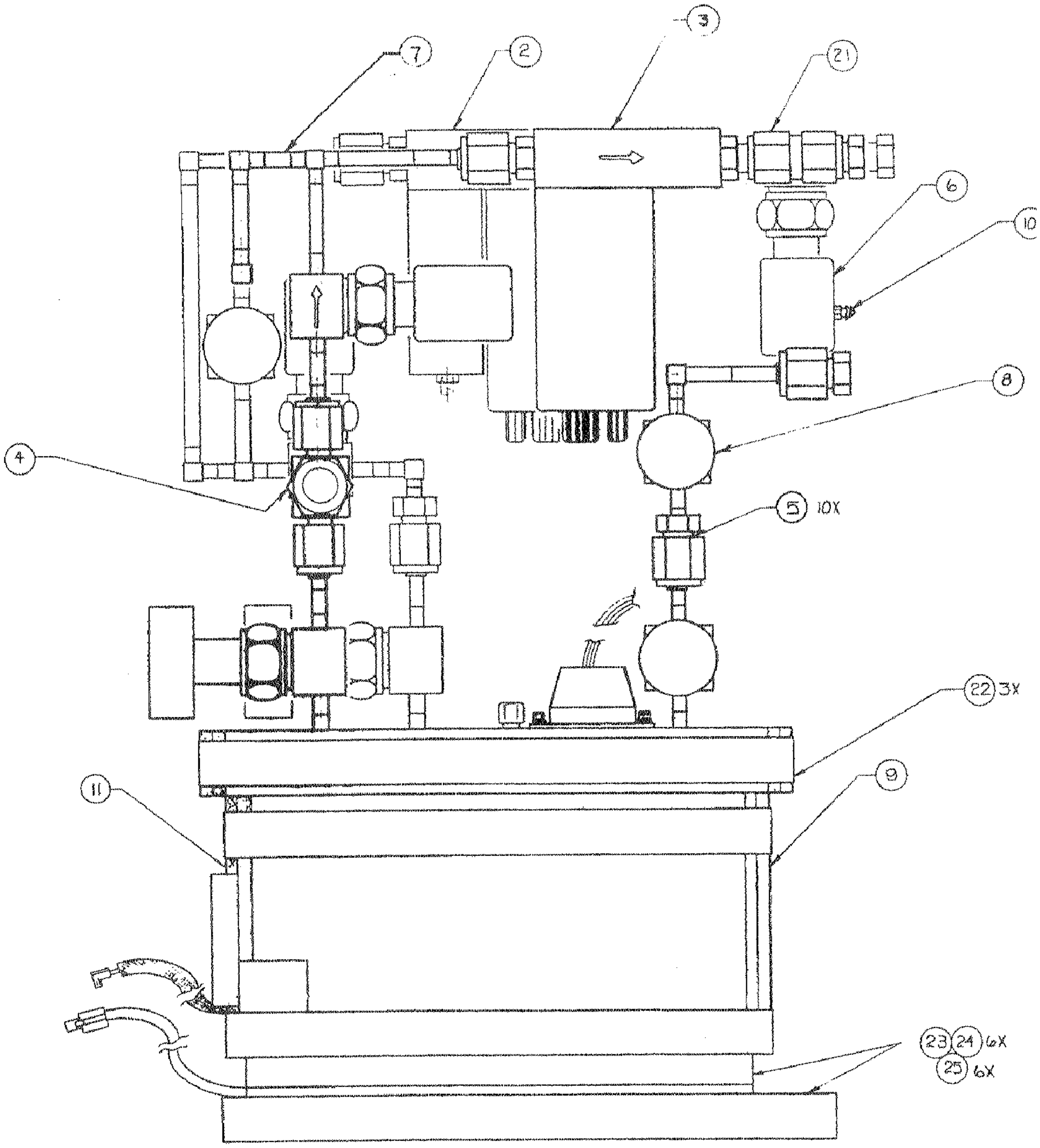
- Adds High Pressure Vent Valve [MV02]
- Adds Process Outlet Isolation Valve [MV03]
- Adds Purge Inlet Iso. Valve [MV04]
- Adds Purge Inlet Check Valve [CV01]
- Adds DEEP PIGTAIL PURGE capability
- Adds LOW PRESSURE VENT & venturi EVAC CAPABILITY [MV05, VG01, MV06, CV02]

Ultrahigh-Purity Stainless Steel Tubing Gas Line Design and Installation

Features

■ Tubing is 316L stainless steel, Electropolished internal surface finish of 10 µin. R_a (0.25 µm) max to reduce corrosion, chemical attack, outgassing, particle generation.
■ Coaxial tubing used for highly toxic or corrosive gas lines to contain and detect leakage.
■ Coaxial tubing terminations can be open to the exhausted gas enclosure, capped and pressurized with a leakage detection gauge, or capped and evacuated with vacuum gauge.
■ All fittings and junctions are orbital welded
■ Purged with filtered nitrogen
■ Cleaned and sealed in an ISO Class 4/Federal Class 10 cleanroom
■ Installed with slope to allow drainage if used for a condensable gas
■ Filters, gas line diameter, valve sizing, and regulator size must be selected for the gas and the flow range in use. If for multiple machines or chambers then size accordingly.
■ Electric-Traced Tubing for condensable gases with self regulating heat or regulated with a controller.
■ Machine internal gas lines MUST follow the same rules such as:

- ü Liquid source lines must be sloped to allow condensable drain back
- ü Liquid source gas line, filters, and valves must be heat traced if required
- ü Heat tracing and insulation must be complete, no gaps, even the smallest area of lower temperature will cause condensation.
- ü Lines must be of sufficient size to allow the full pressure at the MFC inlet.
- ü Filters must be of the correct type and size.
- ü Remember that single source and multiple users will cause problems.
- ü The normal temperatures for a heated gas line system should be set up in the following manner:
    1. If required, heat the gas source to achieve sufficient system pressure.
    2. Heat the gas panel and gas lines to a higher temperature than the bottle.
    3. Heat the MFC to a temperature higher than the gas line.
    4. Ensure that gas lines slope so condensate in the lines will run back to the bottle or to a trap in the line.
    5. Ensure that the gas lines and ALL components in the line, are heated equally. A cold spot will cause condensation. If condensed gas enters the MFC, it will usually indicate a very low flow due to clogging of the sensor.
    6. Purging will often eliminate condensate from the MFC, but not always.
    7. Typical temperatures will be 20 to 40 degrees at the source, 10 Deg. Higher for the gas line, and 10 to 30 degrees higher for the MFC. A standard MFC can be heated to 40 degrees C MAXIMUM. Special heated MFC's are available for higher temperatures.
    8. Many MFC's can be calibrated to a pressure inlet of 5 PSI to allow lower source temperatures.
    9. Deviation from an MFC's calibrated temperature will cause a calibration error of roughly 1% for each 10 degrees of change.



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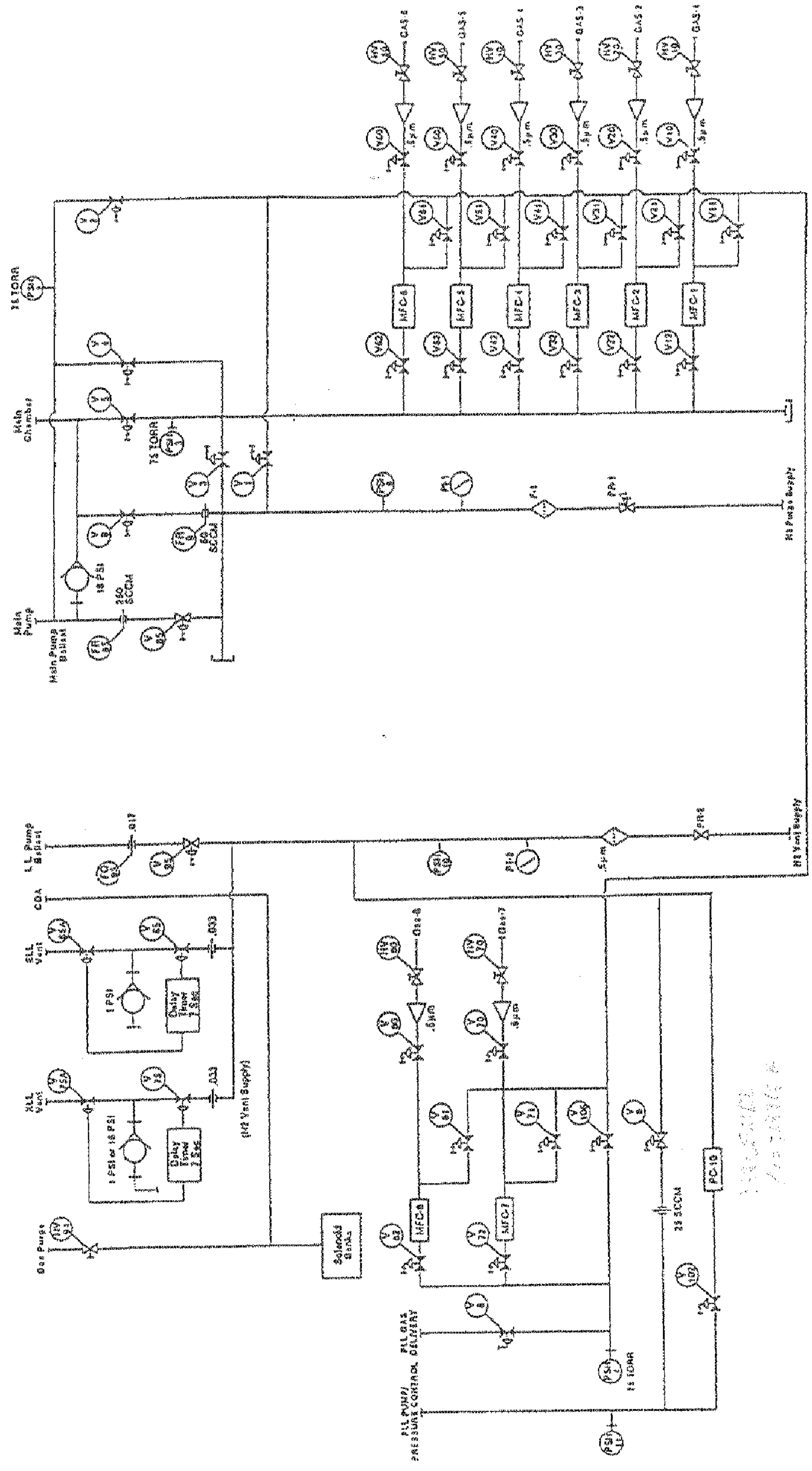
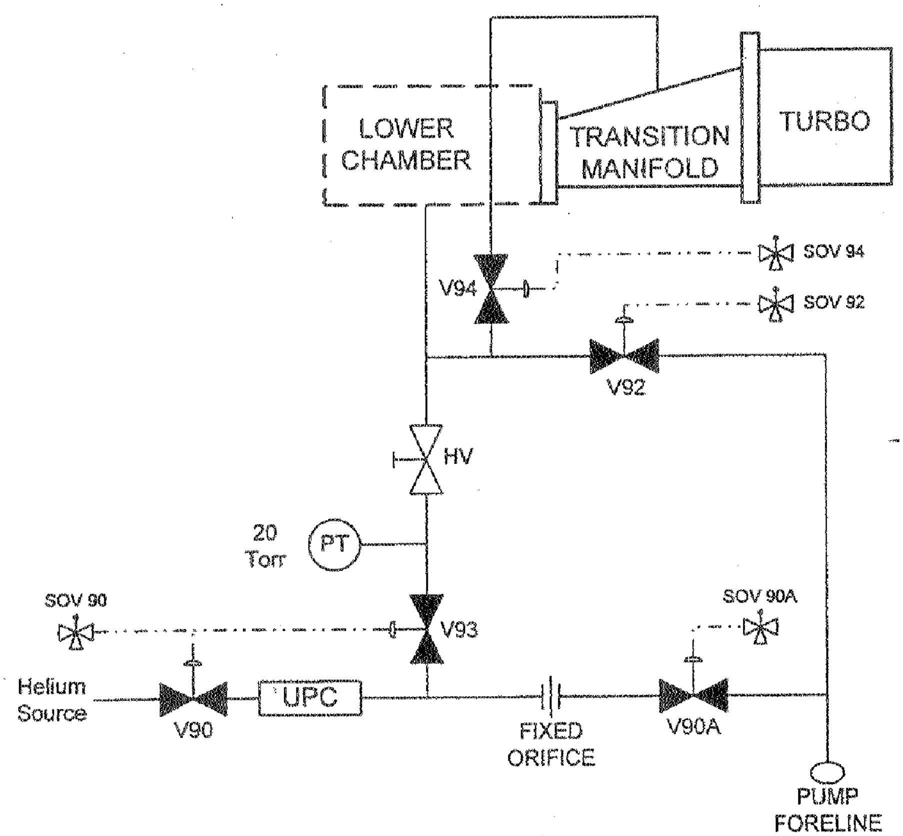
A typical liquid source system (AMAT P-5000)

Item 2	High flow MFC
Item 3	Low flow MFC
Item 4	MFC Inlet filter
Item 6	MFC Outlet valve
Item 8	Liquid canister fill valve
Item 9	Canister heater jacket

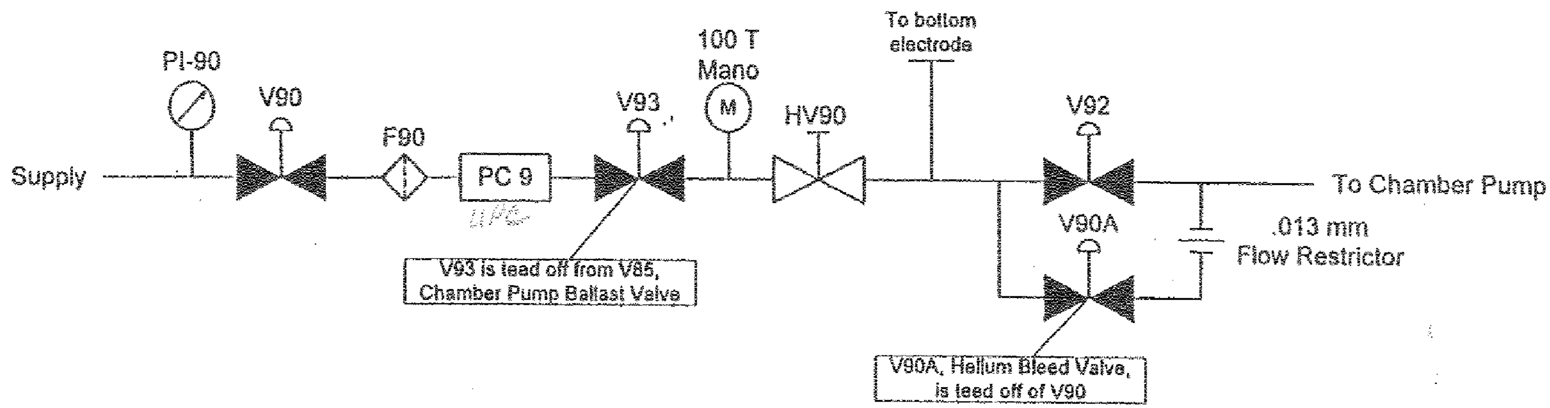
A typical etch gas system (Lam 4600)



Helium Backside Cooling gas system Version 1



V90A opens first for at least 15 seconds, evacuating any pressure build-up behind V93 due to a potential slow leak past the UPC. V90A stays open whenever "Load and Process" is "Active". This provides a constant flow for the UPC (pressure controller) and provides for smoother pressure control. Upon a Helium-on command, V90 and V93 open and after 1 second the set-point is sent to the UPC. A 20 Torr manometer feedback is used by the UPC to control the pressure. When the Helium set-point is set to zero, V90 and V93 close, the zero set-point is sent to the UPC, and V92 opens. V92 stays open until the "Threshold Pressure" (configurable from 0 to 1 Torr) has been reached. At this point V92 closes and V94 opens to complete the evacuation. V94 stays open until the next Helium-on command.



1. When the START button is pushed, V85, the normally open Chamber Pump Ballast Valve, closes and V93 opens. V93 is teed off from V85 and is used during chamber leakback rate checks to isolate the helium PC.
2. When the recipe commands a helium pressure setpoint, the V90 solenoid is energized opening V90, Helium Primary Valve, and V90A, Helium Bleed Valve.
3. The helium pressure controller, PC 9, maintains the helium pressure under the wafer using the 100T manometer for control feedback. V90A maintains a constant helium flow to aid in pressure control.
4. When the rceipe commands the helium pressure to turn off, V90 and V90A close, and V92, Helium Dump Valve, opens to allow the helium under the wafer to be pumped out.
5. Steps 2, 3, and 4 continue until all wafers are processed and the system returns to the idle state. At that time V85 will reopen and V93 will close.

Helium backside Cooling Gas System, Version 2

PROBLEM SOLVING

PROBLEM SOLVING

During the progress of this presentation you will have thought of some questions about the things you have learned. Many of those questions we will cover in the following topics, others we will try to cover as time permits. All of the questions cover ideas and problems that we have all encountered so they are important to the learning process. We all learn from our mistakes and the mistakes of others. We also learn from a careful analysis of the systems and how those systems work. We will do our best here to cover every conceivable problem but there will be many that will be unique and even surprising, be prepared for those.

CONTAMINATION:

- Contamination is a very serious issue and can cause:
    - ü Process problems
    - ü Corrosion
    - ü Damage to the MFC
    - ü Perforation of valve bellows and diaphragms
    - ü Particle generation
    - ü Destruction of filters
    - ü Loss of regulator control
    - ü Loss of sensors

- Causes of contamination can be varied but may include:
    - ü Air in the gas system
    - ü Moisture in the gas system
    - ü Inadvertent connection of the wrong type of gas bottle
    - ü Corrupted gas in the bottle
    - ü Leaking fittings
    - ü Pinholes or micro cracks in valve diaphragms or bellows
    - ü Inadvertent opening of the gas system to atmosphere
    - ü Incorrect gas line heating
    - ü Incorrect gas line installation
    - ü Installation of components that were either improperly cleaned or not cleaned

- ü Dusting of Silane or Silane based gas systems
- ü Perforated flex lines
- ü Installing new components in an improperly cleaned, contaminated system.
- ü Normal use can also cause contamination as many gases leave residues.

- Things to remember to prevent contamination:
  - ü When changing a gas bottle, the CGA fitting will be exposed to air and any residual gas in that fitting will react and form a contaminate which will stay in the system unless cleaned out or prevented. This contaminate will then enter the gas stream and travel to the process chamber. The CGA fitting has a bottle side as well.
  - ü If a component such as a valve or MFC is removed and it shows signs of contamination, corrosion, etc. then the rest of the system is most likely also contaminated the same way.
  - ü If new or refurbished components are installed in this system then they will immediately become re-contaminated. Your work will be wasted.
  - ü Filters will trap contamination, when cleaning a contaminated system…replace the filter .
  - ü If you have a system that is having flow problems after cleaning, did you replace the filter ?
  - ü Always double check the gas bottle you are installing to ensure it is correct.
  - ü Never assume someone else has done something that was supposed to be done, always check. Verify, Verify, Verify.
  - ü Always leak check a system prior to turning on the gas supply.
  - ü Always leak check a system after work is performed on the system.
  - ü Always purge and evacuate a gas system from the gas bottle to the chamber prior to turning on the gas.
  - ü Use O-rings and seals that are compatible with the gas and the process.
  - ü Use MFC’s that are calibrated for the gas in use

PURGING:

- Purging is a very process and if not properly done can cause:
  - ü Process problems
  - ü Corrosion
  - ü Damage to the MFC
  - ü Perforation of valve bellows and diaphragms
  - ü Particle generation
  - ü Destruction of filters
  - ü Loss of regulator control
  - ü Loss of sensors

- Results of improper purging can be varied but may include:
  - ü Air in the gas system
  - ü Moisture in the gas system
  - ü Pinholes in valve diaphragms or bellows
  - ü Dusting of Silane or Silane based gas systems
  - ü Perforated flex lines
  - ü Contamination new components in an improperly purged, contaminated system.

- Things to remember for correct purging:
  - ü When changing a gas bottle, the CGA fitting will be exposed to air and any residual gas in that fitting will react and form a contaminate which will stay in the system unless cleaned out or prevented. This contaminate will then enter the gas stream and travel to the process chamber. Manual cleaning and subsequent cycle purging will prevent this.
  - ü If a component such as a valve or MFC is removed and it shows signs of contamination, corrosion, etc. then the rest of the system is most likely also contaminated the same way. Clean the SYSTEM, as a whole and then purge prior to using.
  - ü If new or refurbished components are installed in this system then they will immediately become re-contaminated. Your work will be wasted, purge correctly.
  - ü Filters will trap contamination, when cleaning a contaminated system…replace the filter , and then purge correctly.
  - ü If you have a system that is having flow problems after cleaning, did you replace the filter and purge correctly?
  - ü Always double check the gas bottle you are installing to ensure it is correct and then purge after installation.

- ü Never assume someone else has done something that was supposed to be done, always check. Verify, Verify, Verify.
- ü Always leak check a system and purge prior to turning on the gas supply.
- ü Always leak check a system and purge after work is performed on the system.
- ü Always purge and evacuate a gas system from the gas bottle to the chamber prior to turning on the gas.

- Purging basics:
  - ü Purging is the process of replacing air and moisture in a contained system with an inert gas or a vacuum.
  - ü Purging may be done in two ways:
    1. Using a constant flow of Ar/N2 or other gas for a set period of time.
    2. Using a “cycle” method with alternating vacuum or low pressure with system pressurization using the inert gas.
  - ü Purging with a constant flow has limitations and is only marginally effective in the short term. Long term constant purge is more effective but uses a lot of gas.
  - ü Constant purge allows much of the gas trapped outside the direct flow path to remain in the system.
  - ü Cycle purging, with the use of a vacuum, causes the trapped gases to escape the voids and flow into the gas stream.
  - ü Cycle purging also uses much less gas to achieve a much lower contamination level.
  - ü Cycle purging without a vacuum is more effective than a constant purge but is less effective than cycle purging with a vacuum.
  - ü A “Typical” gas system may take up to 150 cycles of vacuum-pressure before it is considered “clean”.
  - ü A small gas panel may take as few as 25 cycles till “clean”.
  - ü A gas system usually requires purging prior to opening as a prerequisite for component replacement. Often this is not possible due to clogging of gas system components such as filters, MFC’s, or valves.
  - ü Purging with a clog may require some “creative” methods and may require purging from the gas panel as well as from the tool.
  - ü Purging cannot remove:
    1. Corrosion
    2. Dusting
    3. Many liquids such as HCL residue, TMP, TMPI, etc.
    4. Residual polymers which form on valve seats and other areas.

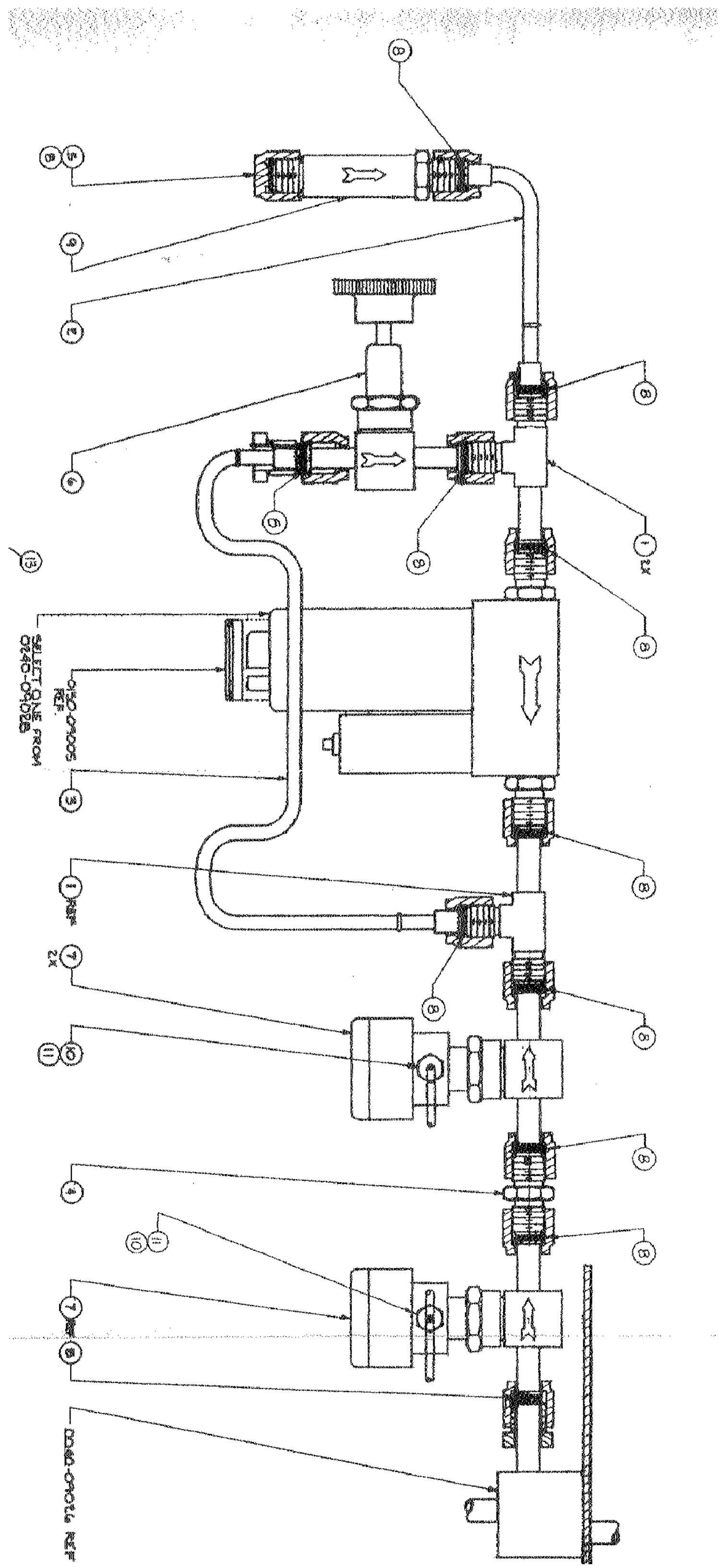
FLOW PROBLEMS AND CAUSES:

- There are many flow problems and these include:
    - ü Low flow
    - ü High flow
    - ü Flow that starts normal and slowly drops
    - ü No flow
    - ü Flow that starts low and slowly increases
    - ü Flow that fluctuates
- We will look at the known and most likely causes of flow problems.
- Gas lines:
    - ü Gas in a system must flow through many components such as the gas line.
    - ü If the gas line is too small, the flow will be reduced simple due to line friction.
    - ü A line may have too many systems connected to it and when the number of devices turned on gets too high the pressure becomes too low.
    - ü A line may also become restricted due to corrosion or contamination.
    - ü A line can also become damaged due to work on other systems, crimping.
- Filters:
    - ü A clogged or partially clogged filter is a source of many gas system problems.
    - ü Completely clogged filters are fairly easy to spot since there is no flow at all, a purge will not pass even when the end of the filter is disconnected.
    - ü A partially clogged filter is more difficult because sufficient gas may flow to fill the gas line prior to the MFC so flow will start normal, then as the restricted filter has insufficient flow to supply the demand, pressure drops as does flow.
    - ü This problem is usually diagnosed as a bad MFC but the voltage at the top of the MFC will be normal in and reduced output according to actual flow.
    - ü A pressure gauge at the MFC inlet will indicate a pressure drop over time.
    - ü Teflon filters can also perforate with sufficient pressure difference, this allows free flow of gas but with the contamination blocking the filter in the gas stream.
- Valves:
    - ü Most gas systems contain several valves and most are air operated.
        1. Air operated valves require a minimum pressure to open or shut.
        2. If the operating air pressure is too low the valve may not open at all or may open only fractionally.
        3. If a valve opens only part way it may limit the gas flow and cause a low flow or a “flow that starts normal then drops” condition.
    - ü Improper valve opening can have several causes:
        1. Air supply regulator set too low or pressure gauge is inaccurate.
        2. Pneumatic solenoid valve is clogged or does not open all the way.
        3. The air line to the valve is crimped or leaking

4. The air fittings at either end of the line are damaged or loose.
5. The air piston is loose, O-ring worn, or piston is sticking (very common)

ü Improper valve opening can appear to be an MFC problem or a filter clogged.

1. The voltages at the top of the MFC will be normal for the actual flow of the MFC.
2. Input pressure to the MFC will be low.
3. Purge flow through the valve will be low or zero.
4. There may be an obvious leak in the air line or fittings.
5. This can be a very difficult problem to locate, particularly if the problem is within the valve air operator mechanism.



A typical “Gas Stick” from a machine gas panel. (AMAT P-5000)

- Mass Flow Controller:
  - ü Mass Flow Controllers are very complex and delicate devices, as such they have many possible failure modes.
  - ü Most MFC's are analog devices, some are digital, but nearly all require a standard input and output voltage which make troubleshooting very easy.
  - ü The input command for flow is a zero to five (0-5) volt signal linear with flow.
    1. At 5 volts input, the flow is 100% of whatever that device was calibrated for.
    2. At 2.5 volts input the flow is 50% of whatever that device is calibrated for.
    3. So, when you need to measure the flow, do so at the input to the MFC and calculate a percentage; very simple.
  - ü The output signal is also a zero to five (0-5) volt signal and has the same properties as the input.
  - ü Operating power to most devices is ±15 Volts DC, Device net powered MFC's are supplied power through the DN connector and is +12 to 24 VDC.
  - ü Low flow from an MFC may be caused by:
    1. Low input pressure (see above for causes)
    2. Input restriction (see above for causes)
    3. Output restrictions (see above for causes)
    4. Low input signal voltages due to poor connections, zero offset, system calibration errors, low supply voltages, etc.
    5. Contamination
    6. Swelling of the valve tip (caused by incompatible gas).
    7. Clogging from particulates or corrosion products.
    8. MFC failure
  - ü High flow from an MFC may be caused by:
    1. Contamination
    2. Input signal error due to zero offset, system calibration errors, etc.
    3. MFC failure
    4. High input pressure
  - ü Erratic, oscillating, jumping, or cyclic flow can be caused by:
    1. Input pressure too high or too low
    2. Using a gas the MFC is not calibrated for.
    3. System flow restrictions (see above for causes) .
    4. Incorrect operating voltages
    5. Poor connections or system calibration.
    6. Contamination
    7. Other MFC's connected to the same gas line.
    8. Gas lines too small for the flow

9. Regulator failure, regulator size too small, or poor control
10. MFC failure
11. If this is a liquid source system, check the line and MFC heaters, heater coverage, cold spots, line elevations, etc.
12. If liquid reaches the MFC then flow will be erratic.

ü Stable but incorrect flow:

1. MFC calibration (one year between calibration is recommended)
2. Incorrect MFC mounting position
3. Incorrect gas for the MFC calibration
4. contamination
5. Zero offset error
6. Connections
7. System calibration errors
8. Power supply voltages incorrect.

- Regulators:

ü Most gas systems contain several regulators.

1. The function of a regulator is to give a specific output pressure independent of flow.
2. If the flow exceeds the rated flow of the regulator then pressure will drop significantly as flow increases.
3. If the regulator does not seal well, then pressure will rise to equal input pressure even with no flow

ü Improper regulator function can have several causes.

1. Pressure gauge is inaccurate
2. Regulator internal valve is clogged or does not open all the way.
3. Poorly manufactured or contaminated/worn valve seat and stem allows excessive leakage.
4. The air fittings at either end of the regulator are damaged or loose and leaking.
5. The regulator valve is loose, O-rings worn, or valve is sticking (very common)

ü Improper regulation can appear to be an MFC problem, valve problem, or a filter clogged.

1. The voltages at the top of the MFC will be normal for the actual flow of the MFC.
2. Input pressure to the MFC will be high, changing, or low.
3. There may be an obvious leak in the gas line or fittings.
4. Gauges often stick at the position they have been in for a long time. This gives a false indication of line pressure and can easily

give an incorrect diagnosis. Vary the pressure to check the gauge prior to assuming the regulator is operating correctly.

- System calibration:
  - ü The most often overlooked area of gas flow accuracy and control is the system in which the gas system is installed.
  - ü Even if the MFC is correctly calibrated and installed, the gas system is in perfect condition, and the operation appears normal, flow can be incorrect.
  - ü When operating a system, it will indicate a specific gas flow for each gas depending on the system setup, recipe, and process step.
  - ü At this moment each MFC will receive a signal telling it how much gas to flow, if any.
  - ü This signal is an exact voltage or digital signal proportional to the amount of gas required.
  - ü If the zero of the MFC is offset, then the total gas flow will be offset by that same amount.
    1. That is, if zero has been offset to -20 millivolts, then gas flow will be the actual flow plus 20 millivolts (0.4%).
    2. If the zero is +100 millivolts then the actual flow will be low by 100 millivolts (2%).
    3. Most MFC's are specified to zero at +2 to +15 millivolts.
  - ü In a typical control system, the digital signal from the computer is changed to the zero to five volt signal required by the MFC through an A to D convertor system or board.
  - ü This board is normally calibrated manually for the zero and the 5 or 10 volt upper limit, or it may be calibrated by the computer using an on board measurement. Procedures are in the OEM system maintenance manuals.
  - ü If the A to D board is out of cal then the voltage to and from the MFC will not be converted to an accurate digital signal and the MFC will appear inaccurate.
  - ü If there are voltage drops at the connections from the MFC through the A to D system, then the cal will be inaccurate and the MFC will appear faulty.
  - ü Measurements taken at the very top connector of the MFC will help verify calibration of the MFC and the system.
  - ü Remember, 5 volts = 100% flow, at the top of the MFC.
  - ü NEVER offset the MFC zero or calibration to compensate for a system error.
  - ü This will destroy the MFC calibration and your recipe will not be accurate.
- Methods used to check flow calibration:
  - ü The ONLY accurate method of checking flow calibration is on a test bench with calibrated test equipment.
  - ü Checking calibration in situ by “rate of rise” is an approximation and is only accurate to ±10%.

- ü Checking flow accuracy by flowing gas into a chamber and expecting to achieve a certain pressure is even less accurate and depends on the pump, pump lines, chamber and all other system components being in the exact condition they were during the initial "standard" calibration.
- ü Each gas will create a different pressure in a chamber and this pressure will depend on chamber volume, throttle valve operation, pump line condition, pump condition, chamber temperature, etc.
- ü Checking MFC calibration by using the pressure in a chamber at a set gas flow is '*at best*' , <u>a guess</u> and studies have eliminated this method for most users.
- ü In line flow standards are an excellent reference for checking gas flow but several things must be considered in use:
  1. The flow standard must be calibrated initially and on a regular basis, one year or less is recommended.
  2. The gas measured must be used with the correction factor if different from the calibration of the MFC.
  3. There are several different correction factors depending on MFC model and the MFC manufacturer.
  4. The flow standard is susceptible to the same problems as an MFC.