I. INTRODUCTION

The Parker Instrumentation Valve Technical Guide will help you select the best valve for your instrumentation system application. Selecting the proper valve requires careful consideration of many factors. These factors include, but are not limited to, service pressure and temperature, flow rate, pressure drop, the flow media's fluid and chemical properties, packing design, seat design, actuation alternatives, special cleaning, compliance with technical standards, and integration within your instrumentation system.

Flow analysis is an important aspect in selecting the proper valve. Accordingly, the Parker Instrumentation Technical Guide presents engineering formulae for flow analysis of gases and liquids.

It is historically reported the first control valve was a bamboo plug valve made in China about 2000 B.C. Today, valves serve five primary functions: to start and stop flow, to regulate and throttle flow, to prevent backflow, to regulate pressure, and to relieve excessive pressure.

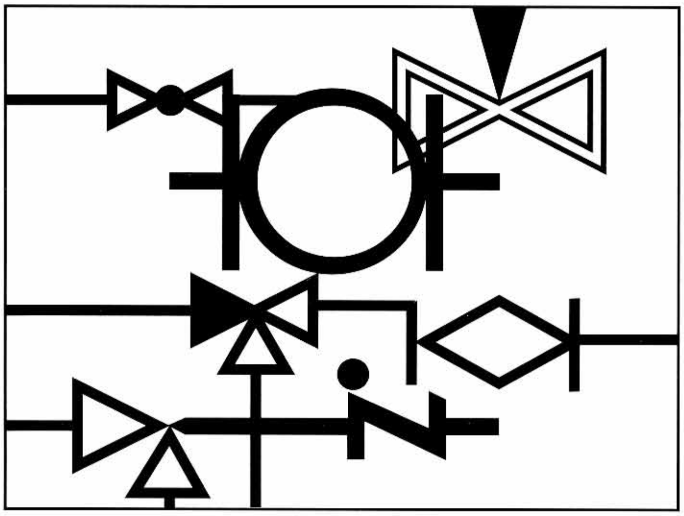
Every industrial plant, power plant or research facility requires not only the large valves and piping that carry the main flow of fluids, but also a maze of small valves for the purpose of linking the primary flows with instruments and controls. Instrumentation valves have functional counterparts with larger general service valves. However, owing to their size, details of design and applications are unique.

This section reviews the fundamental factors to be considered in selecting an instrumentation valve. Some of the most important criteria required for valve selection are listed below. The relative importance of each factor will change for each valve application.

Flow Media
Pressure and Temperature Considerations
Seat Designs
Stem Packing Designs
Actuator Designs
Cleaning Requirements and Options
Codes and Standards
Flow Calculations and Valve Sizing

One must clearly recognize that failure, improper selection or improper use of any valve or instrumentation product can cause personal injury and property damage. Furthermore, while this Valve Technical Guide seeks to help you select the best valve for your instrumentation system application, the information presented by this Valve Technical Guide may not be complete for your specific valve selection.

It is important that you analyze all aspects of your application and review the information concerning the instrumentation products in their current respective product catalog. Due to the variety of operating conditions and applications for Parker Hannifin instrumentation valves, the user, through its own analysis and testing, is solely responsible for making the final selection of the products and systems and assuring that all performance and safety requirements of the application are satisfied.



ON THE COVER:

Seven valve symbols often used in engineering schematics are shown on the cover of IVD's Technical Guide. Starting from the top right hand corner and moving down and around in a clockwise direction they are:

Needle Valves
Plug Valves
Check Valves
Angle Valves
3-Way Valves
Ball Valves
Globe Valves

II. FLOW MEDIA

A) Flow Characteristics

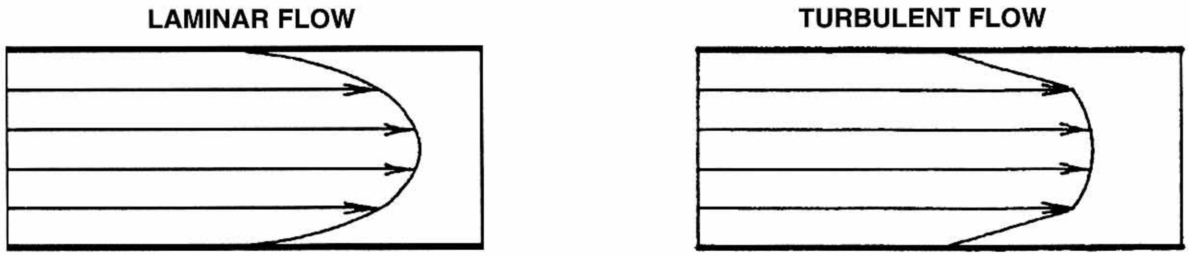
Flow media characteristics are an important factor in valve selection analysis. The principle aspects include fluid properties, chemical reactivity or toxicity and abrasiveness. Valves can often dramatically change the flow, not only directly within the valve, but also quite a distance downstream of the valve. Furthermore, changes in the fluid's properties caused by temperature or chemical changes may also dramatically alter the flow characteristics.

Pressure drop is a key criteria in valve selection. Increased pressure drop across a valve means higher costs for pressurizing the fluid system. Higher pressure drops decrease a valve's life expectancy, and may even damage the rest of the fluid system. High pressure drops across open valves should be avoided. Examples of the problems often caused by high pressure drops are discussed later. The geometry of a valve's internal flow path is the key factor in estimating its potential pressure drop. Straight (inline) internal flow paths create significantly less pressure drop than flow paths that change direction. For example, inline Ball and Plug valves have lower pressure drops than valves with angle bodies, such as Needle or Diaphragm valves. A measure of a valve's potential pressure drop is the C_v (flow coefficient) factor.

Flow rate and velocity are closely related to pressure drop. Increasing the flow rate or velocity to compensate for a low C_v carries the penalty of increased pressure drop and higher costs. This makes sense of course, because more power (i.e., energy or money) is required to push the extra fluid through the valve. The C_v value, by definition, is the flow rate a valve will allow, in gallons of water per minute at 60° F with a pressure drop of one psi.

Turbulence is another important factor in proper valve selection. The degree of turbulence depends upon the flow rate and velocity, as well as the fluid's viscosity, which in turn is controlled by the fluid temperature. It is important to remember as the temperature increases, the viscosities of all liquids decrease, while the viscosities of all gases increase. The classic Moody Diagram can be used to estimate turbulence in a fluid system. Viscosity will be discussed in greater detail later. Internal surface finish of pipe or tubing also affects turbulence. Most of the instrumentation and control lines utilize tubing rather than piping, with the natural advantages of dimensional accuracy and smooth internal surface finishes. As a general rule, tubing is more compatible than pipe with instrumentation valves and accessories. It offers better interior cleanup, and the special instrumentation connection methods offered for tubing result in less interior residue in the form of chips, weld slag, and so forth.

The degree of turbulence in a system depends upon the velocity profile of the flow stream. Figure 1 illustrates the velocity profile of laminar and turbulent flow. Laminar flow is characterized by a parabolic profile, where the relatively large viscous forces cause the fluid to slow as it passes near the pipe walls. In turbulent flow, the inertial forces are large in relation to the viscous forces. Therefore, turbulent flow exhibits a more uniform velocity profile. Flow analysts use the Reynolds number (N_R) to describe fluid turbulence. This dimensionless number is the ratio of the fluid's momentum to the opposing drag (friction) forces in the fluid system.



LAMINAR FLOW

TURBULENT FLOW

REYNOLDS NUMBER USUALLY LESS THAN 2000
SLOW MOVING FLUIDS OR FLUIDS WITH
EXTREMELY HIGH VISCOSITY SUCH AS
GREASE, PAINTS, AND HONEY

REYNOLDS NUMBER USUALLY GREATER THAN 4000
FAST MOVING FLUIDS OR FLUIDS WITH
EXTREMELY LOW VISCOSITY SUCH AS
LOW TEMPERATURE GASES

Figure 1 Laminar and Turbulent Flow
Reynolds number (N_R) above 4,000 may indicate turbulent flow

Noise is generated by all fluid systems. Valves are a natural source for noise in fluid systems, since noise is generated by flow restrictions, and most valves inherently restrict flow. Many factors affect the noise generated by a valve. These include the type of valve, how far the valve is open, flow characteristics, size and length of pipe or tubing adjacent to the valve, fluid system materials of construction, presence of thermal pipe insulation, how many and what types of surfaces the sound might be reflected from, and whether the fluid is a liquid or gas. The OSHA Act of 1970 limits the noise that people may be exposed to. Remedies for excessive noise include changing the flow characteristics (i.e., reducing flow rates and/or pressure drops), placing valves in series or parallel configurations to reduce the pressure drop experienced by any single valve, or limiting the actual transmission or reflection of sound waves. However, excessive noise in a fluid system is frequently a symptom of dangerous flow conditions. Therefore, it is important to investigate all potential causes of the noise before considering noise abatement devices to muffle the sound.

Waterhammer derives its name from the hammering sound which happens when a shock wave encounters a flow restriction in a liquid flow system. This phenomena can cause severe damage to pumps, turbines, instruments and even piping supports. Proper valve selection can minimize the generation of waterhammer. The key is to avoid quick opening and closing of the valve in systems with either high flow velocities or differential pressures. The use of Ball or Plug valves with automatic actuators (i.e., electric or pneumatic) must be cautiously reviewed in these applications. Prudence is demanded since Ball and Plug valves can potentially generate powerful shock waves because of their quick opening characteristics, even when used with manual actuators (i.e., handles). Using automatic actuators with Ball or Plug valves increases the risk that dangerous shock waves will be generated by the valve's accelerated opening or closing.

Flashing and cavitation merit special consideration in valve selection. Both phenomena may damage fluid systems, and valves often contribute to this problem. Evidence of these include vibration, an intermittent ticking, hiss, roar, or the worst case of a churning gravel sound. Cavitation is especially dangerous if the liquid flow stream contains sand or metallic particles. Decreasing the pressure drop or the inlet pressure sometimes reduces the potential of flashing or cavitation.

Flashing and cavitation are associated with gas bubbles in a liquid flow stream. They occur in high-speed liquid flow when bubbles form around the valve's seat area. An energy balance exists between the liquid velocity and pressure in the flow stream. If the velocity increases, the pressure usually decreases. The velocity increase reduces the available energy required to maintain the flow pressure. Subsequently, the flow pressure drops as it is starved of energy. Bubbles form if the flow pressure falls below the liquid's vapor pressure, literally causing the liquid to boil. Flashing and cavitation often occur immediately downstream of a valve's seat area. The reduction in flow area sharply increases the speed of the liquid flow stream, which reduces the pressure and causes bubbles to form as the liquid boils.

What ultimately happens to the bubbles determines if one is dealing with flashing or cavitation. Flashing means the bubbles simply drift downstream, causing minor erosion, noise or vibration in the fluid system. Cavitation is potentially more dangerous. The bubbles violently collapse after a short period of time. All of the energy stored in the bubbles' surface tension implodes to the bubbles' center, but is then reflected back in a powerful microjet of energy. These millions of destructive bubbles literally blast away pieces of the valve's components. Pitting and accelerated corrosion often accompany cavitation. Super-cavitation occurs when the downstream fluid line is almost filled with bubbles. Violent vibration may result when these bubbles explode downstream. Air aspiration (the introduction of atmospheric air into the flow stream) will not prevent cavitation, but sometimes reduces the bubbles' destructive explosion.

Wire drawing deserves special attention, especially with two-phase flow applications. Two-phase flow is simply liquids and gasses mixed together, such as wet stream or carbonated beverages. It is similar to flashing and cavitation, except that the gas bubbles never dissolve back into the liquid. What makes two-phase flow so potentially damaging is the perpetual presence of either gas bubbles or liquid droplets in the flow stream. These bubbles and/or droplets can rapidly cut flow channels through a valve's seating area. In fact, wire drawing gets its name from the thin linear flow channels around the valve's seat or stem that look like a wire was drawn or pulled through the valve's seat area.

Wire drawing is usually caused by high pressure two-phase flow. If a high pressure drop across a valve cannot be avoided, then the seat materials must be highly abrasion resistant. Wire drawing is amplified if the flow stream contains sand or metallic particles. Decreasing the pressure drop across a valve or the inlet pressure sometimes reduces the potential of wire drawing. Wire drawing can also be reduced by an ultra-tight seat seal. Selecting the right seat geometry can also reduce the potential of wire drawing. Evidence indicates that a conical seat geometry with a narrow sealing surface often provides very tight sealing.

B) Fluid properties

Compressibility is probably the most important fluid property. It determines whether the fluid behaves as a liquid or a gas. Flow equations for liquids and gases are radically different in most cases. Accordingly, the fluid's compressibility determines what flow equations should be used in the flow analysis.

Fluid type is of tremendous importance when dealing with liquids. Fluid types are divided into Newtonian and Non-Newtonian liquids. The distinction involves how a liquid's viscosity changes with temperature and pressure. Viscosities of Newtonian liquids change with temperature and with pressure. All other fluids are considered Non-Newtonian. Newtonian liquids are typically pure or low molecular weight liquids such as water, alcohol, oils, or cryogenic liquids. Non-Newtonian liquids include polymers, high molecular weight liquids, slurries, greases, drilling muds, printer's ink, foods such as ketchup and ice cream, crude oils at low temperature, paints and lacquers, and glue. Special flow equations must be used for Non-Newtonian liquids for accurate analysis results.

Chemical reactivity or toxicity often demands the highest attention in valve selection. The two factors that determine a valve's leak integrity are it's materials of construction and the valve's design. Unfortunately, all man-made valves leak, regardless of their materials of construction or design. It's merely a question of how soon a leak will occur, taking into account the leak rate, time in service, pressure, fluid properties, and so forth. This is the realistic view that all experienced valve design or application engineers have regarding the subject of valve leak integrity. Please note temperature and pressure can greatly increase the reactivity, corrosion potential, or toxicity of some chemicals – even those which are considered harmless at ambient temperature and pressure.

Instrumentation valve components are fabricated from a wide variety of materials including metals, thermoplastics, elastomers and ceramics. Moreover, scores of different lubricants or coatings are used to reduce friction and wear. Assembling the proper material defense against chemical attack is a challenging aspect of sound valve selection. Each material and lubricant must be chemically compatible with the flow media.

Abrasiveness of the flow media is usually a minor factor in valve selection. However, it can cause serious problems if not properly dealt with. Abrasion occurs when the flow media contains solid particles which are harder than the materials from which the valve is made. This type of flow media is commonly known as a slurry. The resultant damage depends upon the particles' velocity, size, impact angle, and relative hardness with respect to the valve's wetted components. Abrasion can also accelerate corrosion if the surface layer of a component part is damaged.

The best strategies against internal abrasion are to minimize turbulent flow, keeping the flow path as straight as possible, and decreasing the pressure drop across a valve. Decreasing the pressure drop or the inlet pressure sometimes reduces the potential of erosion. Low flow velocities, which reduce turbulent flow, also help to minimize erosion. Selecting the right seat geometry can also reduce the potential of erosion. Ball and Plug valves usually offer a reasonably straight internal flow path which reduces abrasive damage.

III. PRESSURE AND TEMPERATURE CONSIDERATIONS

The most commonly requested information about an instrumentation valve is its pressure and temperature rating (P/T) curve. Selecting the proper valve for a particular pressure and temperature is similar to selecting a valve for service with reactive or toxic chemicals. The materials of construction and lubricants determine how well a valve will perform. Temperature effects the point at which flashing and cavitation occur, the fluid's viscosity and density, the strength and performance of the many different types of materials from which the valve's components are made, and even the chemical reactivity or toxicity of the flow media.

Parker Hannifin IVD subjects every product to rigorous pressure/temperature tests, upon which conservative P/T curves are generated. The P/T performance of Parker Hannifin IVD valves is included in the product catalog for each respective product.

An instrumentation valve's pressure/temperature performance is usually controlled by the non-metallic components. These non-metallic components may include elastomeric or thermoplastic materials (such as a Viton® O-Ring or a Teflon® stem packing), or a lubricant's maximum service temperature. However, even metal components are limited to surprisingly low temperature limits, such as 400° F (204° C) for brass and 700° F (371° C) for 17-4 PH stainless steel. The strength and load-carrying capacities of all materials decrease with temperature, which is why the pressure limits for many plastics and elastomers (such as Teflon®, Kel-F® and Viton®) dramatically decrease around 350°F (176°C).

Degrees F to Degrees C Conversion Table

deg. F	deg. C	deg. F	deg. C	deg. F	deg. C	deg. F	deg. C	deg. F	deg. C	deg. F	deg. C
−70	−57	30	−1	130	54	275	135	550	288	800	427
−60	−51	40	4	140	60	325	163	575	302	850	454
−50	−46	50	10	150	66	350	177	600	316	900	482
−40	−40	60	16	160	71	375	191	625	329	950	510
−30	−34	70	21	170	77	400	204	650	343	1000	538
−20	−29	80	27	180	82	425	218	675	357	1050	588
−10	−23	90	32	190	88	450	232	700	371	1100	593
0	−18	100	38	200	93	475	246	725	385	1150	621
10	−12	110	43	225	107	500	260	750	399	1200	649
20	−7	120	49	250	121	525	274	775	413	1250	677

Conversion Formulas: F = (1.8 x C) + 32   C = (F − 32) / 1.8

PSI to Bar Conversion Table

psi	bar	psi	bar	psi	bar	psi	bar	psi	bar	psi	bar
0	0	80	5.5	250	17.2	800	55.2	4000	275.8	8000	551.6
10	0.7	90	6.2	300	20.7	900	62.1	4500	310.3	8500	586.1
20	1.4	100	6.9	350	24.1	1000	69.0	5000	344.8	9000	620.6
30	2.1	125	8.6	400	27.6	1500	103.4	5500	379.2	9500	655.0
40	2.8	150	10.3	450	31.0	2000	137.9	6000	413.7	10000	689.5
50	3.4	175	12.1	500	34.5	2500	172.4	6500	448.2		
60	4.1	200	13.8	600	41.4	3000	206.9	7000	482.7		
70	4.8	225	15.5	700	48.3	3500	241.3	7500	517.1		

Conversion Formulas: bar = psi x .06895, psi = bar x 14.50377

IV. SEAT DESIGNS

Seat design and performance are crucial aspects of a valve. The seat is the primary flow control element whose performance can be tremendously affected by design factors such as geometry, surface finish, materials of construction, rigidity, and seating force. Flow media aspects such as velocity, flow rate, pressure drop, abrasiveness, chemical reactivity, and cavitation also influence how well a valve seat performs. A variety of seat designs have evolved to successfully handle a broad spectrum of application requirements.

With the simplest design, a rotating stem engages the seat, which most often is integral with the body. This concept is also used with throttling or metering valves. Another common seal combination features a two-piece stem design with an independent lower portion. Because the lower stem does not rotate upon actuation, the seating action is positive and consistent, thereby enhancing the chances for a repetitive tight seal.

As with many integral seat arrangements in instrumentation valves, the stem brinnels (crushes) the seat contact area slightly to accomplish a positive metal-to-metal seal. A certain amount of seat damage is tolerated, as long as it is not in excess of what a reseating and rebrinnelling can overcome. Metal-to-metal seats are required for high temperature service. Whether the stem design can be of the rotating or non-rotating type, depends on some extent on the media being handled. For non-lubricating fluids, such as gas or hot water, a non-rotating lower stem is advised. In the case of lube oil, a simple one piece stem will perform satisfactorily.

When fluid temperatures are below the upper limits for plastics such as Teflon®, an instrumentation valve can employ a plastic stem tip. Currently, the high temperature limits for plastic seated valves are between 300°F and 500°F (149°C and 260°C), depending on the severity of service and the specific design. Overall, plastic seated valves will outperform metal-to-metal seats in non-lubricating medias. In non-lubricating medias, such as dry gas, the plastic seat will deform and seal without excessive damage to the seat or the body that may occur in a dry metal-to-metal application. In lubricating medias, such as oil, the media will assist in minimizing the potential damage to the mating metal surfaces by providing low-friction wear conditions.

A) Ball and Plug Seats

Valves with a Ball or Plug type seat design are enormously popular in instrumentation valve applications. They can offer maximum flow capacity, excellent sealing integrity, seat wear compensation, and quick quarter or half-turn operation.

Several types of Ball and Plug type seats exist. The Parker Hannifin IVD B-Series Ball valve uses a floating ball design. The floating Ball design is considered to be the best design for overall performance due to the ability to respond to pressure fluctuations.

The four primary components in the Ball valve design are the ball, stem, seat and seat retainer. These features are illustrated in Figure 2. The most important aspect of the floating ball design is the linkage between the ball and stem. The top of the ball has a drive tang slot into which the stem's keyed end fits. It is designed so that the ball can be forced against the downstream seat by system pressure.

The seat is usually made of a thermoplastic such as Teflon®. The thermoplastic seat material is much softer than the ball, and the seat material has a tendency to permanently change shape (cold flow) when the ball seals against it. Cold flow is accelerated by either pressure or temperature. Increased pressure helps to crush the seat because the flow stream is pushing against the ball and seat with higher force. Increasing the service temperature also accelerates cold flow, since the thermoplastic's compressive strength is sharply reduced as the temperature increases.

Ball valve Seat materials include a variety of thermoplastics. Proper seat material selection requires careful consideration of temperature, pressure, abrasiveness, chemical reactivity, lubricity, and wear resistance. Parker Hannifin IVD offers a variety of high performance thermoplastics as seat materials in its B-Series Ball valve product line such as Kel-F®, Teflon® and Vespel®.

The seat retainer helps to preserve the seats' crucial sealing geometry. The seat retainer effectively protects the thermoplastic against excessive crushing and cold flow. The relatively soft thermoplastic seat, crimped inside the seat retainer, enables the ball seat to seal better as the pressure increases.

Valves with a Plug-type seat design are used extensively in instrumentation valve applications. This valve offers maximum flow capacity, good sealing integrity, minimal dead space, convenient maintenance, and quick quarter-turn operation.

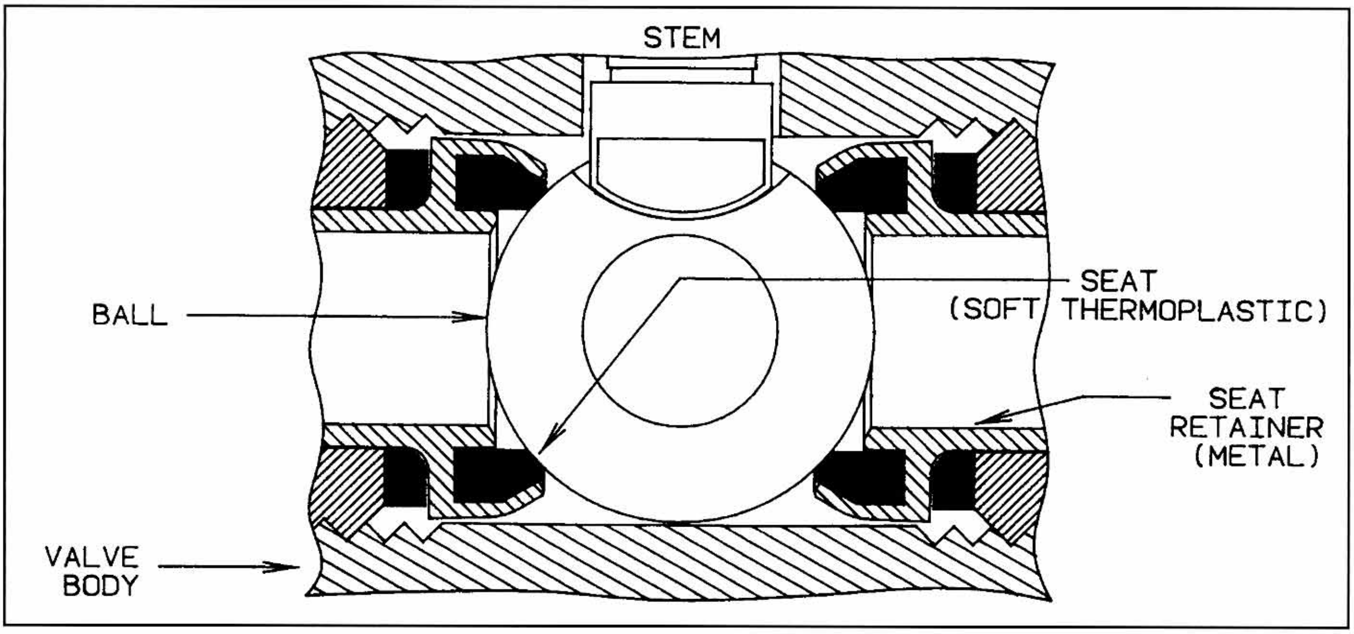


Figure 2 Floating Ball Valve Seat Design
This design features excellent seal integrity and seat wear compensation.

Plug valves are rotary type valves in which a plug-shaped element is rotated to engage or disengage a port hole in the valve body. The three primary components in the Parker Hannifin IVD Rotary Plug valve are the plug, seat, and atmosphere O-Ring seals, illustrated in Figure 3.

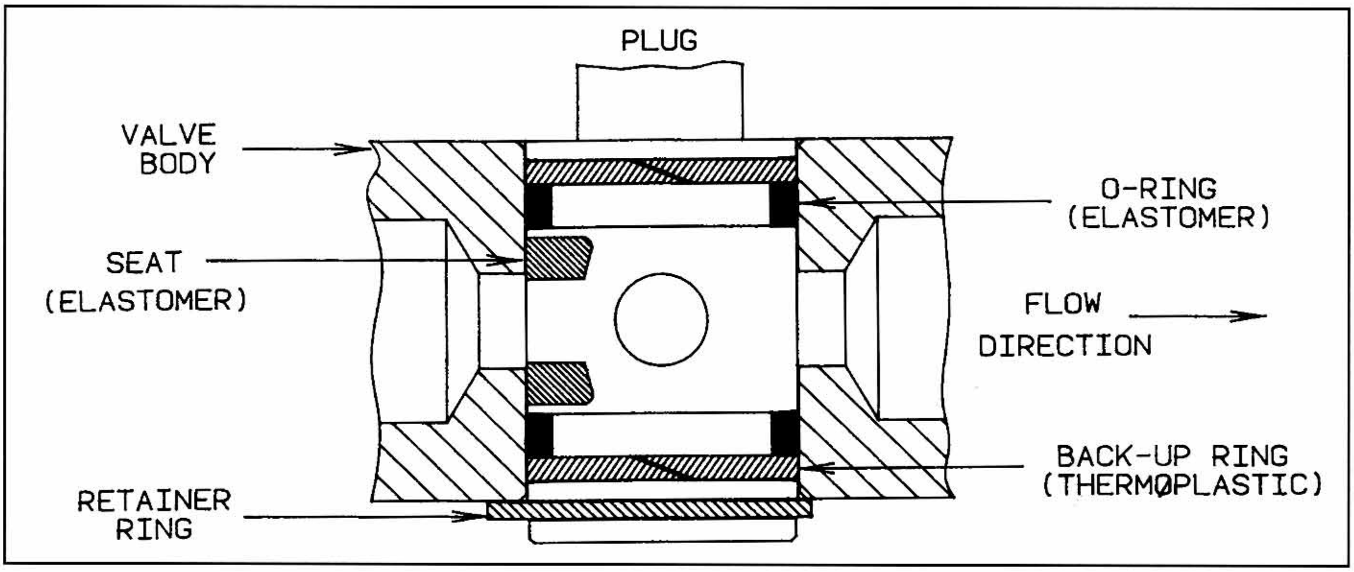
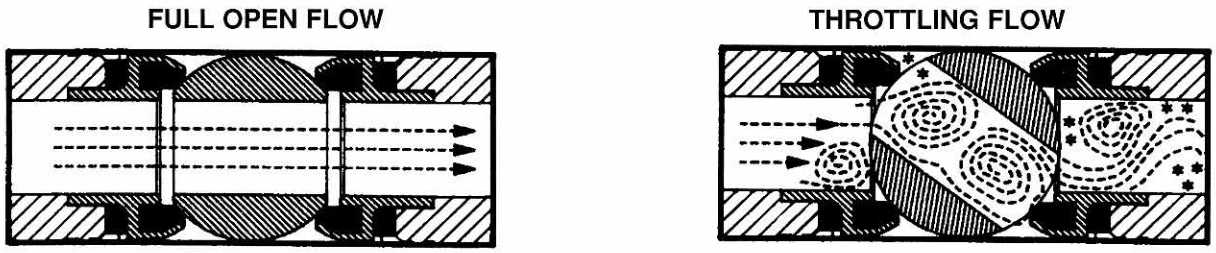


Figure 3 Plug Seat Design
This design offers good seal integrity and minimal dead volume.

Seal materials include a variety of elastomers. Proper seal material selection requires consideration of temperature, pressure, abrasiveness, chemical reactivity, lubricity, and wear resistance. Parker Hannifin IVD offers Viton®, Ethylene Propylene (EPR), and Nitrile elastomers as standard seal materials in its PR-Series Rotary Plug valve product line.

Ball and Plug type seats offer substantially higher flow rates than most other valves, particularly tapered stem (Needle) valves. However, Ball-type seats are usually not recommended for throttling service, where the valve is partially open or closed. Throttling exposes the valve and the downstream fluid system to several potentially dangerous conditions. These may include flashing, cavitation, erosion, noise, and severe mechanical vibration. The flow streams of a fully-open Ball or Plug valve, as well as a valve seat in the throttling position, are illustrated in Figure 4.



FULL OPEN FLOW

BALL IS IN THE FULL OPEN POSITION.
FLOW REGIME MAY BE EITHER LAMINAR OR TURBULENT DEPENDING ON FLUID VELOCITY AND VISCOSITY.

THROTTLING FLOW

THE PARTIALLY OPEN POSITION SHOULD BE AVOIDED.
CAVITATION AND FLASHING PRODUCE MICRO-BUBBLES (*) WHICH MAY CAUSE SEVERE NOISE AND FLUID SYSTEM DAMAGE.

Figure 4 Flow characteristics of a Ball or Plug type Seat
Throttling may cause flashing, cavitation, erosion, noise, and severe mechanical vibration.

B) Tapered Stem Seats

The tapered stem seat is immensely popular in instrumentation valve applications. Of course, valves with a tapered stem are commonly known as Needle valves. Tapered stem valves offer excellent seal integrity for a variety of media applications such as gases, liquids, and slurries. They also function well in an extremely wide range of temperatures, and are available for a broad spectrum of reactive chemical environments. The tapered seat design consists of a valve stem whose downward travel decreases the fluid flowing through a valve's seat area.

Tapered stem designs may be fabricated from either metal or thermoplastic. Proper seat material selection requires careful consideration of temperature, pressure, abrasiveness, chemical reactivity, lubricity, and wear resistance. Thermoplastic tapered stem tips are superior to metal tapered stems for effectively sealing gases or low molecular weight liquids. However, metal stems are usually required for applications where high temperatures or pressures, reactive chemicals, or abrasive flow media are present.

Tapered stem valves offer higher flow resistance than Ball or Plug valves. Needle valves with tapered stem seats require valve bodies with angular internal flow passages. These non-linear flow paths increase the flow resistance and pressure drop across the valve, as compared to either a Ball or Plug valve. The difference in seat geometry makes tapered stem valves much more suited for throttling (adjustment) of flow streams than the Ball or Plug valve.

Several types of specialized tapered seat designs have evolved for instrumentation applications. They include the *Blunt, Regulating,* and *Metering* tapered stem designs. Each of the three basic tapered stem types are designed for a particular application. The Blunt Stem derives its name from the "V" shape of its tapered sealing end. The Blunt stem is tapered at 30 degrees which makes this design excellent for basic flow shut-off applications. The Regulating Stem combines the excellent shut-off characteristics of the Blunt stem with the ability to provide coarse regulation of the fluid flow stream. This is accomplished with a gradual taper at the stem end. The Metering Stem offers exceptional precision flow stream adjustment.

A tapered stem's performance can be enhanced by selecting either a metal or soft-seat stem tip design. The selection depends upon several flow media characteristics, including but not limited to, the temperature and corrosiveness, presence of hard particles (such as in a slurry), and whether the flow media is a liquid or gas. Metal stem tips are usually required for temperatures beyond 350°F (176°C), or if the flow media is highly abrasive. Soft-seat stem tips are often selected for use with gases, since the relatively soft thermoplastic tip can seal very tightly against the metal valve seat. Thermoplastics such as Kel-F® and Vespel® are used in such applications.

V. STEM PACKING DESIGNS

Packing design and performance play an important role in valve selection. Valves consist of a control element (such as a ball, plug, or tapered stem seat), and an actuation element. While the Seat is designed to directly control flow through the valve, the Packing limits the leakage between the Seat and Actuation elements. The Packing's performance can be tremendously affected by design factors such as geometry, surface finish, materials of construction, rigidity, and location on the valve stem.

The two fundamental Packing designs found in Parker Hannifin instrumentation valves are Packed and Packless valves. In general, Packed valves are usually quite suitable for most instrumentation applications, while Packless valves are preferred for service with expensive, toxic or reactive chemicals, or where any minute degree of leakage cannot be tolerated.

A) Packed Valves

Packed valves are used successfully in a vast array of instrumentation applications. These include most Needle and Ball valves. However, Packed valves are questionable for protecting against Stem area leaks of expensive, reactive, or toxic chemicals.

Packed valves rely upon the mechanical deformation (crushing) of a relatively soft packing material (Teflon®, Grafoil®, Viton®, etc.) against the valve stem. This squeezing of the relatively soft packing material eliminates all but microscopic gaps (leak paths) between the packing material and valve stem.

Critical factors such as hardness differences and surface finish limit the seal integrity of these packings. In fact, just the normal turning of the valve's Stem breaks the intimate bond between the Stem and Packing, which then may create new leak paths (although they may be extremely small). Accordingly, while Packed valves offer a reasonably high level of seal integrity for most applications, they are nevertheless susceptible to slight leakage under certain conditions, requiring packing nut adjustment.

The performance and capabilities of a Packed valve depends upon the location of the packing on the valve stem (with respect to the power threads), and the material from which the packing is fabricated. Packed valves are available in two basic configurations. These are known as "Packing above threads" (PAT) and "Packing below threads" (PBT). These configurations are illustrated in Figure 5.

The PAT *(Packing Above Thread)* design is suitable for service with most liquids and gases. It is available with the V-Series and SN-Series tapered-stem (Needle) valves offered by Parker Hannifin IVD.

The PBT *(Packing Below Thread)* design protects the flow stream from thread lubricant contamination or washout, keeps corrosive chemicals from damaging the stem's power threads, and allows a non-rotating lower stem design for superior sealing. It is available with the U-Series Union Bonnet and PBT-Series tapered-stem (Needle) valves, as well as the PV-Series Rising Stem Plug valve product lines offered by Parker Hannifin IVD.

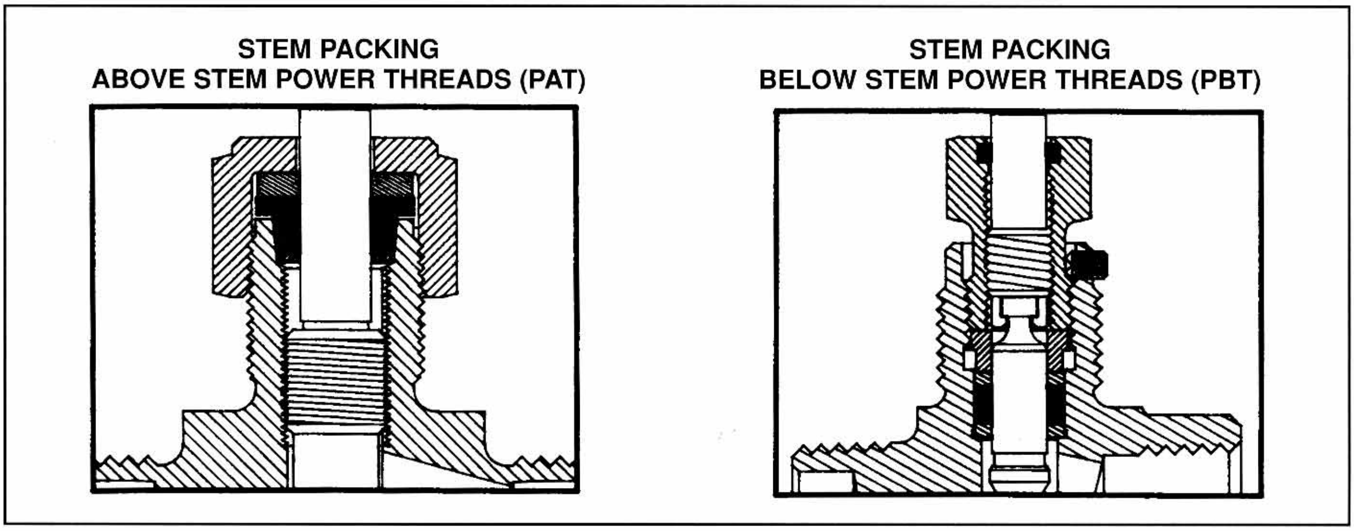


Figure 5 Packing Configurations (PAT and PBT)
The PAT (Packing Above Thread) design is suitable for service with most liquids and gases.

Of course, the performance and capabilities of a Packed valve depends upon the material from which the packing is fabricated as well as the location of the packing on the valve stem (PAT versus PBT). The three basic stem packing materials offered by Parker Hannifin IVD are plastics, elastomers and Grafoil®.

The type of valve application dictates what Packing material should be used. Three factors that demand prudent consideration are the temperature, chemical reactivity of the flow media and the actuation frequency.

Grafoil® is recommended for most high temperature applications. Furthermore, it is chemically resistant to attack from nearly all organic and inorganic fluids, with the exception of highly oxidizing acids and chemicals. This excellent chemical compatibility generally exists across Grafoil's® entire temperature range.

Thermoplastics and elastomers may be suitable for applications where service temperatures are less than 500°F (260°C). Parker Hannifin IVD offers Delrin®, PEEK® (virgin and carbon-filled), Rulon®, Teflon®, UHMWPE, Vespel® and other high-performance thermoplastics as Packing materials in its variety of product lines. Available elastomers include Nitrile, Ethylene Propylene (EPR), Fluorocarbon (Viton®), Kalrez® and other high-performance elastomers as O-Ring materials. It is important to remember that all materials have a chemical "Achilles heel", that is all are susceptible to accelerated chemical attack by at least one chemical compound. Increasing the service temperature may also weaken a material's ability to withstand reactive chemicals. Accordingly, prudent material selection of thermoplastics or elastomers is required in every valve selection analysis.

Most applications only require that the proper Packing material be selected. However, some applications demand that the valve's actuation frequency also be considered. In general, the applications requiring higher actuation frequencies require elastomeric Packing materials to minimize the frequency of stem packing adjustment. The underlying reason is the difference in the resiliency between elastomers, and the thermoplastic and Grafoil® materials. The valve stem and body cavity (in which the Packing is located) have microscopic surface scratches which are potential leak paths. However most thermoplastics, elastomers and Grafoil® are resilient enough such that their deformation can fill these microscopic gaps. The problem arises when the valve stem is actuated. This actuation causes the Packing and stem to slide against each other, which may cause leakage as the microscopic gaps are uncovered. Elastomers are able to refill the microscopic gaps much faster than either thermoplastics or Grafoil®. Accordingly, elastomers are generally superior for applications requiring high frequency actuation.

B) Packless Valves

Packless valves (Bellows and Diaphragm) are becoming increasingly popular in instrumentation valve applications. They are used when stem leakage cannot be tolerated, including such applications as toxic, corrosive, ultra-clean, flammable, or very expensive flow media. The Packless valve offers excellent sealing integrity and a variety of actuation options. Packless valves use a completely different stem sealing concept than the mechanical crushing method used by packed valves. The Packless concept calls for a hermetically-sealed barrier between the valve Seat and Stem mechanisms. Hermetic seals commonly achieve a seal integrity of 10^{-9} cc of helium per second or less.

Bellows and Diaphragm valves offer different performance features due to their respective designs. Bellows valves typically offer higher flow rates than Diaphragm valves, can better control flow, and are more adaptable to remote actuation in high pressure applications. A typical Bellows valve is illustrated in Figure 6.

The HP and P-Series Bellows valves offered by Parker Hannifin IVD are world-class quality products. Among the design features that elevate the P-Series Bellows valve product line are an externally-pressurized bellows, which allows faster purge times and reduces entrapment zones within the flow area, compared to an internally pressurized bellows design. Moreover, longer cycle life is obtained with an externally pressurized bellows because of a more uniform stress distribution in the bellows. These features make the HP and P-Series Bellows valves an excellent choice for applications that require a critical service Packless valve.

Diaphragm vales offer distinctly different features. These features include low internal volume, few entrapment zones, fast purge times and quarter-turn actuation. A typical Diaphragm valve is illustrated in Figure 7.

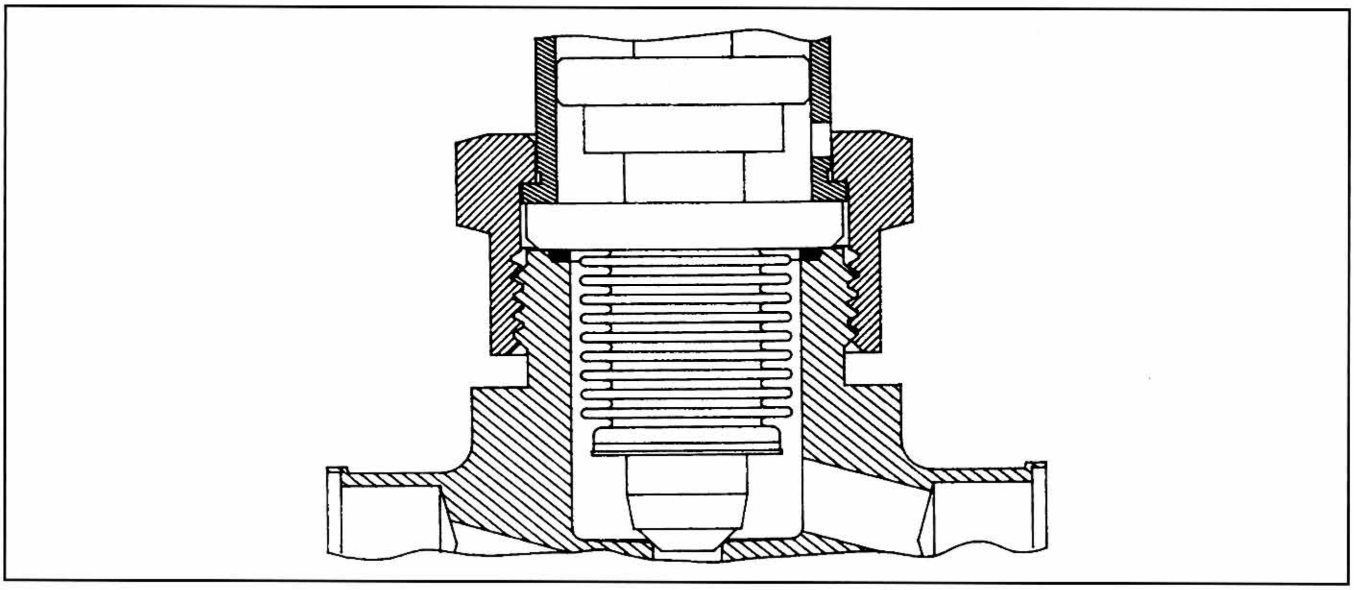


Figure 6 Bellows Valve Stem Seal Configuration
Bellows valves offers a variety of tapered stem designs for multi-turn, toggle, and remote actuation options.

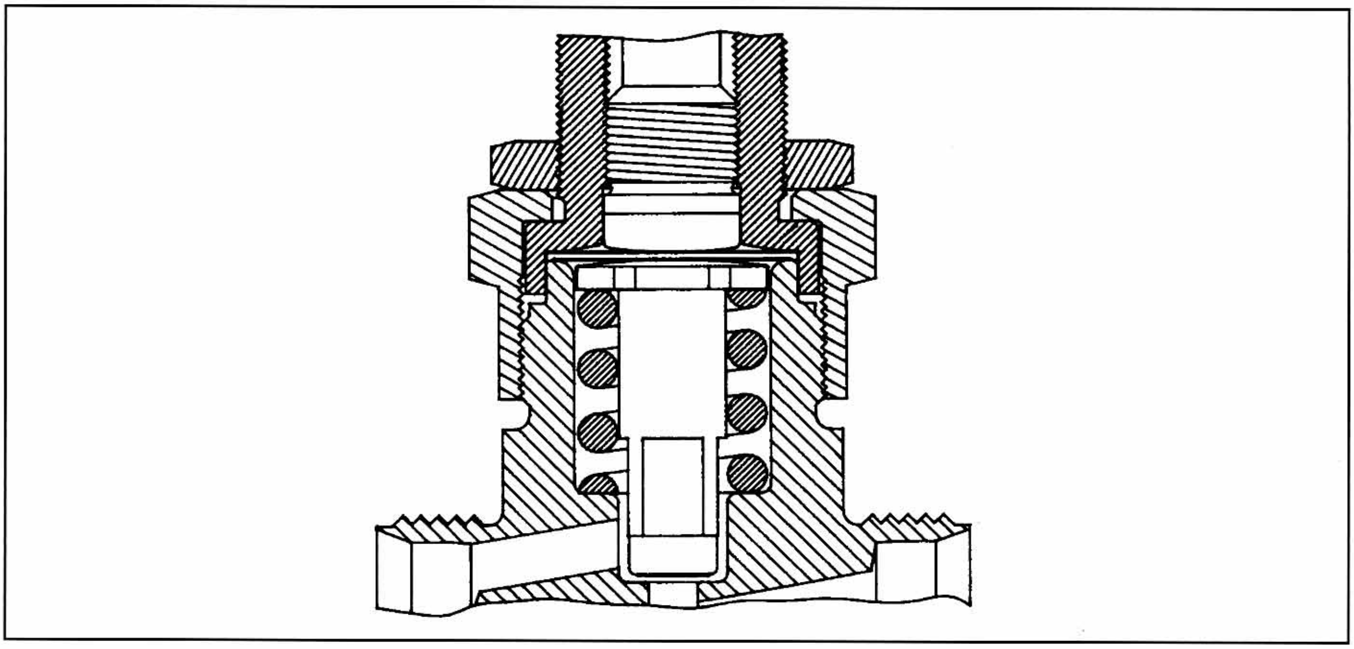


Figure 7 Diaphragm Valve Stem Seal Configuration
Diaphragm valves offer a variety of stem designs for quarter-turn and multi-turn options. These valves are ideal for applications requiring low particle generation and low internal volume.

VI. ACTUATOR DESIGNS

Selecting the right Actuator is another important step in choosing the right design for your valve application. The Actuator choice is important because the Actuator directly links the valve's Operator (either a person or a control system) and the valve's Seat (which directly controls the flow media). In fact, the Seat and Actuator are usually the two most important considerations in selecting a valve.

Just as valves are available with two basic Packing designs (Packed and Packless), two basic valve Actuation options exists. These are the Manual and Automatic options. Advantages and disadvantages apply to both the Manual and Automatic options.

A) Manual Actuation

Multi-Turn Handles are commonly used in flow regulation and shut-off applications. Round and T-Bar handles may be used interchangeably, except with soft-seat tapered stems such as a Kel-F® seat. The reason is higher torques are possible with T-Bar handles, which may result in crushing the thermoplastic soft-seat material. Vernier handles are found almost exclusively on Metering valves, where they may provide the operator with a visual indication of how far open a valve is.

Quarter-Turn Handles are used in shut-off applications; are associated exclusively with Ball, Plug and Quarter-Turn Diaphragm valves; and, usually provide directional indication. In addition, some Quarter-turn product lines feature a Lock-Out device for securing the handle in either the open or closed position.

Lever Handles are also known as "toggle" handles, and feature rapid shut-off control. They are usually quite valuable in simple "on/off" applications.

For most instrument valves, plastic handles provide the best choice and options, and are designed to deliver the required loads for proper shut-off torques. With quarter-turn ball valves, the tendency is to shape the plastic handle to include a point, indicating the valve position. Color coding of handles is common and an important feature for instrumentation valves. The matching of color for fluid or line purposes has advantages, especially when a large number of valves are clustered closely together. Instrumentation piping and tubing are harder to mark or color than larger piping, so that the colored handle is often the best way to identify the lines.

B) Remote Actuation

Selecting a Remote Actuator demands close attention to the details regarding your application. There are many aspects to consider. These considerations include, but are not limited to, safety, reliability, system performance, cost and inaccessibility of the valve and actuator. Of course, the relative importance of these aspects are different for each valve application, and thus prudence is demanded in selecting any Remote Actuator. However, all Remote Actuators must reliably perform the following functions:

1) Move the valve seating element (ball, plug or tapered stem) to the desired position.
2) Hold the valve seating element in the desired position against the flow stream's forces.
3) Seat the valve seating element by applying enough force or torque.
4) Provide the required rotational travel to move the valve seat from the open to closed positions.
5) Provide the required operating speed for proper actuation frequency.

Pneumatic and Electric Actuators

Pneumatic Actuators are the work horses of the instrumentation industry. Their long history of reliable, robust and safe service has earned them a reputation for excellent performance. Pneumatic Actuators are powered by compressed air, which is not only commonly available in most instrumentation environments, but also contributes to the non-explosive characteristics of Pneumatic Actuators. Pneumatic Actuators are available in fail-open (normally open), fail-closed (normally closed) and fail-as-is (double acting) configurations.

Pneumatic Actuators are superior to Electric Actuators for applications requiring high actuation frequencies. This is because Pneumatic Actuators have no duty cycle, whereas Electric Actuators usually have a duty cycle rating. This means that Pneumatic Actuators can cycle continuously. Electric Actuators, on the other hand, with a duty cycle of 25 percent, mean they should be at rest 75 percent of the time.

Stalling is an area where Pneumatic Actuators are superior to Electric Actuators. Stalling occurs when the actuator still has power applied to it (either air pressure or electric current), but it has reached the rotation limit for its current actuation cycle. Stalling in electric actuators is often caused by a mis-application, where the actuator is sized below a required torque. Electric Actuators tend to overheat when the motor stalls. Overheating due to stalling can seriously decrease an Electric Actuator's life expectancy, and even worse, potentially contribute to fire or explosion. Pneumatic Actuators are safer than Electric Actuators, with respect to stalling, because Pneumatic Actuators never overheat in a stalled condition.

Electric Actuators are commonly used where it is impractical to locate and properly maintain the requisite air supply required by Pneumatic Actuators. Moreover, Pneumatic Actuators are sometimes susceptible to clogged air lines in low temperature applications (caused by frozen condensate). Electric Actuators have their special niche applications, and the increasing dominance of computer-based process control systems insures the use of Electric Actuators will grow considerably.

Pneumatic Actuators are often more cost-effective than Electric Actuators because of their rugged design based on the safety of air-operation. Pneumatic Actuators are inherently explosion proof because no sparks or high temperatures are generated. Furthermore, they are not sensitive to wet environments. Electric Actuators in harsh environments may require NEMA enclosures.

Double-Acting Rotary Pneumatic Actuators require pressurization to either close or open the valve. The piston is coupled to the actuator shaft via a rack and pinion gear drive, which produces the desired rotary valve stem motion. Spring-Return Rotary Pneumatic Actuators require pressurization of only one actuator port to either close or open the valve. The spring-return module automatically reverses the valve stem position when the actuation pressure is removed.

Piston Pneumatic Actuators produce linear motion, as opposed to the rotating motion produced by the Rotary Pneumatic Actuator. The Piston design requires pressurization to open or close the valve, depending upon the desired mode. The valve's internal spring forces the valve to a desired position when the actuator pressure is removed, in normally-open or normally-closed designs.

VII. CLEANING REQUIREMENTS AND OPTIONS

Many valve applications require special cleaning with respect to either media compatibility or particle generation. These are frequently found in applications such as life support systems and pharmaceutical and semiconductor manufacturing. Parker Hannifin IVD has always strived to provide instrumentation valves for these crucial applications. This effort is reflected in the Parker Hannifin IVD C3 and C4 cleaning specifications, which are based upon cleaning processes ES8003 and ES8004, respectively.

A) Cleaning for Oxygen Service

Oxygen systems require careful design and cleanliness considerations. Meticulous cleaning is one basic essential in preventing or contributing to oxygen fires. Accordingly, Parker Hannifin IVD has established strict procedures to ensure proper cleanliness levels for valves to be placed in oxygen service. Valves for oxygen service are processed under Parker Hannifin IVD ES8003 and are identified by a "C3" in the valve's product nomenclature.

Users and designers of oxygen systems should refer to the guide materials available from organizations such as the *Compressed Gas Association* (CGA), the American Society for Testing and Materials (ASTM), the *American National Standards Institute* (ANSI), the *American Welding Society* (AWS) and the *National Fire Protection Association* (NFPA).

Valve selection and use also requires careful consideration. Guidelines emphasize that valves must be opened slowly. Accordingly, both the valve selection and operating procedures must be thoroughly investigated. By the nature of their design, full flow, quarter-turn valves such as Ball or Plug valves are quick to open and can induce high velocities. These high velocities can, in turn produce adiabatic compression and a resulting source of momentary heat ignition energy. This heat can ignite organic contaminants, plastics and small metallic particles in the form of burrs or loose chips.

Parker IVD's cleaning process ES8003 has been developed to remove or prevent contaminates such as burrs and metal filings, machining oils, human oils, lint, dust and hydrocarbons from entering oxygen systems from valves. In addition, valves requiring lubrication for function are lubricated only with those compatible for oxygen service.

Copies of ES8003 are available upon request from IVD, and all product lines can be ordered cleaned to this specification. The user should evaluate the procedure and determine if it meets the needs for the application.

Cleaning Requirements & Options

B) High Purity Cleaning

Semiconductor process technology has demanded ultra high levels of cleanliness. Microscopic particle contamination can wreck havoc in a semiconductor manufacturing process. Furthermore, these processes are demanding cleaner systems as the size of microchip circuitry decreases each year. In fact, the entire clean room industry has developed in response to meeting the ever demanding needs of these industrial processes.

All Packless valves are supplied with a special cleaning process which is similar to the C3 oxygen service cleaning specification. For more demanding applications, these valves are available with a High Purity cleaning level. Valves cleaned to the High Purity standard are processed under Parker Hannifin IVD ES8004, and are identified by a "C4" in the valve's product nomenclature. Details of the ES8004 cleaning process are available upon request.

With this cleaning, all operations are conducted in a Class 100 Clean Room as defined in Federal Standard 209. In simple terms, the room environment cannot exceed 100 particles of any contaminant greater than 0.5 microns in size, in any given cubic foot of room air. The human eye cannot see particles of this size. Cleaning technology here involves the use of high pressure 18 megohm deionized water equipment to shear away any contaminants on the wetted surfaces of components. Laser-based particle counting is used to measure the cleanliness prior to shipment, and a special double-bagged packaging (consisting of a nitrogen-purged inner nylon bag with an outer protective polyethylene bag) is used to preserve the cleanliness of the component until it is opened at the user's facility.

Codes & Standards

VII. CODES AND STANDARDS

Instrumentation valve selection requires valves meet standards established to protect the valve user from products which are made from inferior materials or designed to less than acceptable criteria. Until 1987, there were no definitive industry standards specifically devoted to instrumentation valves. ANSI B31.1, entitled "Power Piping", referenced instrumentation in paragraph 122.3. Unfortunately, the document was of little value beyond recommended guidelines for materials and wall thickness determinations.

In the 1980's, the *Manufacturers Standardization Society of the Valve and Fittings Industry* (MSS) created a committee in which Parker IVD participated, to develop the first standard for instrumentation valves. Entitled *MSS SP-99,* this document was the first of its kind to specifically address the instrumentation market.

Unlike larger process valves which have numerous ANSI design specifications such as ANSI B16, the purchaser of instrumentation valves was left to reply on the manufacturer for sound design engineering and appropriate test qualification. This still remains the case, but *MSS SP-99* forms the basis for common practice among the responsible parties involved.

MSS SP-99 applies to small valves and manifolds developed for and primarily used in instrument, control and sampling piping systems. It addresses steel and alloy valves of one inch nominal pipe size and smaller. In its current form, the Standard Practice does not deal with brass valves. The document requires all pressure boundary components to be manufactured from materials identified in it. In addition, material certifications, identifying chemical analyses and mechanical properties, must be obtained for all pressure boundary parts.

The design requirements in *MSS SP-99* deal principally with end connections. Familiar ANSI standards for pipe threads, pipe socket welds and pipe buttwelds are incorporated by reference. Requirements for tubing remain the responsibility of the manufacturer. That is, mechanical tube fittings, tube socket welds and tube buttwelds are to be designed in accordance with the manufacturer's standard. *MSS SP-99* adopted ASME qualification requirements for end connections welded to the valve body. All welds must be performed in accordance with the *ASME Boiler and Pressure Vessel Code, Section IX.*

The most noteworthy item within *MSS SP-99* is the new *Cold Working Pressure* rating system (abbreviated CWP). Valves manufactured in accordance with this practice shall have Cold Working Pressure ratings established by hydrostatic burst qualification tests. The CWP rating of a valve is determined based upon 1/4 of the lowest burst pressure recorded for three production test valves, factored by the ratio of specified to actual tensile strengths of the pressure boundary materials.

The formula for calculating CWP is:

$$\text{CWP} = (0.25) \times (\text{Lowest Burst Pressure in three tests}) \times \frac{\text{Material Tensile Strength (specified)}}{\text{Material Tensile Strength (actual)}} \qquad \text{(EQ. 1)}$$

IX. FLOW CALCULATIONS AND VALVE SIZING GUIDELINES

Selecting the right valve size is the final touch in proper valve selection. It is as important as picking the proper Seat, Stem Packing and Actuator Designs. This section introduces you to the basic aspect of fluid flow analysis for instrumentation valves. Examples of flow calculations illustrate the fine points of prudent valve selection, and show the practical applications-orientated side of the Instrumentation Valve Technical Guide.

There are two ways to analyze flow through tubing and valves; using a graphical method (i.e. picking a number from an engineering chart) or using a simple customized equation. Regardless if you're using an engineering chart or a customized equation, there are only five or six easy-to-find values needed, depending on if you're working with liquids or gases, respectively. These values can be rearranged within an equation to solve for any single unknown value.

Engineering Scope of the Instrumentation Technical Guide

This document **isn't** designed as an engineering textbook on advanced fluid mechanics. Although it can be very helpful in many general flow applications encountered with instrumentation valves, there are situations where the formulas and graphs contained herein **simply don't apply** if extremely accurate solutions are required. You should always consult the best available engineering advice if you have any doubts about whether these formulas apply to analyzing your specific application.

The information contained in this work has been obtained by Parker Hannifin IVD from reliable and recognized sources. However, validating both the accuracy and completeness of this information is the sole and exclusive responsibility of the user. Parker Hannifin IVD shall not be responsible for any errors, omissions, or damages arising out of the use of this information. Parker Hannifin IVD is supplying information but is not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

Types of Fluid Flow:

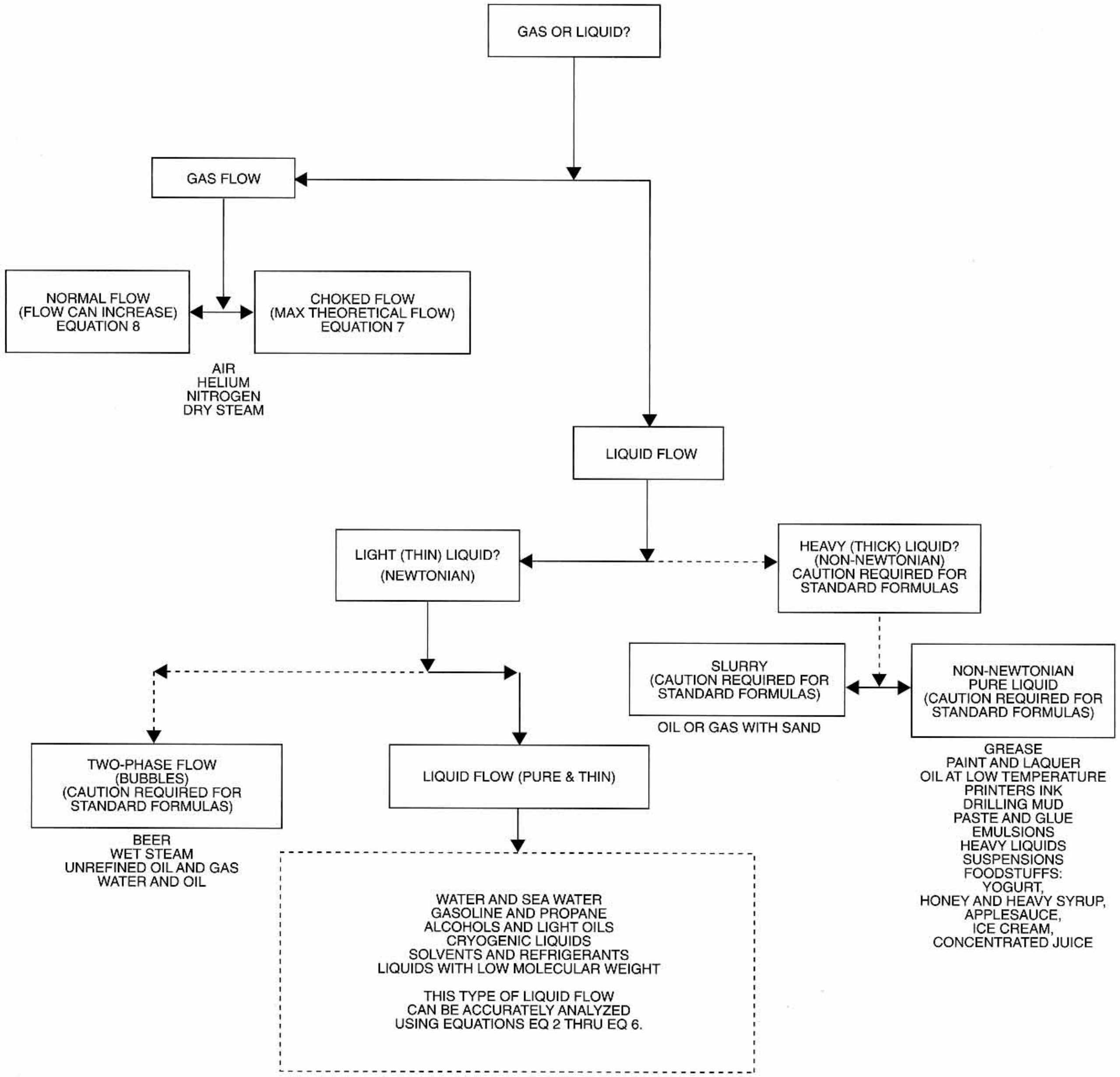
Now, there's a very important point about the flow formulas and graphs presented in this Parker Hannifin Instrumentation Valve Technical Guide. These are based on ideal theoretical conditions. While that's not a major issue for gas flow calculations, it does make a difference for accurate liquid flow calculations.

The four (4) basic types of liquid flow are:

Type of Liquid Flow	Characteristics	Examples
General	Thin, Pure Liquids	Water, Gasoline, Light Oils, Solvents
Two-Phase Flow	Bubbles mixed with Liquids	Beer, Wet Steam, Unrefined Petroleum
Slurry	Solid Particles mixed with Liquids	Water and Sand, Fluidized Beds
Non-Newtonian	Heavy, Thick Liquids	Grease, Printer's Ink, Paint, Honey, Yogurt

The liquid flow formulas and graphs herein are based on ideal turbulent flow of thin pure liquids. The other three (3) types of liquid flow (**Two-Phase, Slurries, and Non-Newtonian**) can be analyzed using these formulas and graphs. However, the decision of using these formulas and graphs with the other fluid types depends upon the degree of accuracy required in the flow analysis. The amount of error will depend on how different the other fluid type is from the general fluid type.

A **Valve Flow Equation Selection Guide** is presented in Figure 8. It helps select the proper flow equations for gas and liquid flow. This flowchart not only shows the basic types of gas and liquid flow, but also the specific type of liquid flow best analyzed by the equations and graphs presented herein.



NOTE: THE OTHER TYPES OF LIQUID FLOW REFERRED TO IN THIS FLOW CHART MAY BE ANALYZED USING EQUATIONS EQ 2 THROUGH EQ 6. HOWEVER, AN UNACCEPTABLE LARGE MARGIN OF ERROR MAY BE PRESENT, DEPENDING ON THE FLUID'S TEMPERATURE, DENSITY, VISCOSITY, OR THE PRESENCE OF BUBBLES (SUCH AS BEER) OR SOLID PARTICLES (SUCH AS SAND).

Figure 8 Valve Flow Equation Selection Guide
The liquid flow equations and graphs presented in this Instrumentation Technical Guide are based on **Thin and Pure liquids only,** *which do not contain bubbles or solid particles, or are thick or heavy liquids.*

A) Liquid Flow Calculations

This section shows how to analyze liquid flow for instrumentation valves, using both *customized* formulas and graphical methods. The **Formula Method** is presented first since it is more accurate than the **Graphical Method.** Before we continue, however, the *Specific Gravity (Sg)* of various liquids is presented, since this fluid property is required for both the Formula and Graphical Methods.

Table 1
Specific Gravity (Sg) of Various Liquids

Liquid	Sg	Liquid	Sg	Liquid	Sg
Acetaldehyde	0.782	Diethyl ether	0.714	Naphthalene	1.145
Acetic Acid	1.049	Ether	0.736	Nitric Acid, 60%	1.370
Acetone	0.790	Ethyl acetate	0.900	Nitrobenzene	1.203
Acid Sulfuric, 87%	1.800	Ethyl bromide	1.450	Nonane-n	0.700
Alcohol butyl	0.810	Formic acid	1.221	Octane-n	0.700
Alcohol ethyl	0.789	Freon	1.490	Oil, Vegetable	0.910
Alcohol, Methyl	0.796	Fuel Oil No. 1	0.850	Oil, Mineral	0.880
Ammonia	0.662	Gasoline	0.710	Pentane-n	0.630
Aniline	1.022	Glycerine	1.260	Quenching oil	0.870
Oil SAE 10-70	0.910	Glycol, ethyl	1.125	Rapeseed oil	0.910
Beer	1.010	Heptane-n	0.684	Sugar 20%	1.080
Benzene	0.879	Hexane-n	0.660	Sugar 40%	1.180
Bromine	2.900	Kerosene	0.800	Turbine oil	0.910
Butyric acid	0.959	Linseed Oil	0.930	Turpentine	0.861
Carbolic acid	1.080	Mercury	13.54	Water (fresh)	1.000
Castor Oil	0.960	Methyl iodide	2.280	Water (sea)	1.030
Chloroform	1.489	Milk	1.030	Xylene-O	0.870

Formula Method

The *customized* formulas for analyzing liquid flow are:

FLOW RATE (GPM):
$$Q = C_V\sqrt{\frac{P_1 - P_2}{S_g}} \qquad \text{(EQ. 2)}$$

FLOW COEFFICIENT:
$$C_V = Q\sqrt{\frac{S_g}{P_1 - P_2}} \qquad \text{(EQ. 3)}$$

PRESSURE DROP (PSIG):
$$\Delta P = \left[\frac{Q}{C_V}\right]^2 \times S_g \qquad \text{(EQ. 4)}$$

INLET PRESSURE (PSIG):
$$P_1 = P_2 + \left[\frac{Q}{C_V}\right]^2 \times S_g \qquad \text{(EQ. 5)}$$

OUTLET PRESSURE (PSIG):
$$P_2 = P_1 - \left[\frac{Q}{C_V}\right]^2 \times S_g \qquad \text{(EQ. 6)}$$

Liquid Flow Calculation Example 1:

A Biotech Fluid System designer needs a quarter-turn shut-off valve to flow approximately 10 GPM (Q), with an inlet pressure (P_1) of 3000 psig and an outlet pressure (P_2) of 2900 psig. The flow media is clean water at room temperature. She selects a **6A-PR4-BNT-SS** Parker IVD **PR-Series Rotary Plug Valve.**

Let's see if the valve size she selected provides her required flow rate (Q).

FLOW RATE (GPM) : $Q = C_V\sqrt{\frac{P_1 - P_2}{S_g}}$ (EQ. 2)

Q = UNKNOWN : FLOW RATE, GPM

C_V = 1.20 : FLOW COEFFICIENT (REFER TO THE PARKER IVD VALVE BULLETIN)

S_g = 1.00 : FLUID SPECIFIC GRAVITY (RATIO OF FLUID DENSITY COMPARED TO WATER DENSITY) (REFERENCE FLUID SPECIFIC GRAVITY TABLE ON PAGE 19)

P_1 = 3000 : INLET PRESSURE, PSIG

P_2 = 2900 : OUTLET PRESSURE, PSIG

$Q = 1.20\sqrt{\frac{(3000 - 2900)}{1.00}}$: PLACE ALL VALUES INTO THE EQUATION

$Q = 1.20 \times \sqrt{\frac{(100)}{1.00}}$: $P_1 - P_2 = 100$ (THIS IS THE PRESSURE DROP)

$Q = 1.20 \times \sqrt{(100)}$: $100 \div 1 = 100$

$Q = (1.20) \times 10$: THE SQUARE ROOT OF 100 IS 10

Q = 12.0 GPM (GALLONS PER MINUTE) : OBTAIN THE FINAL SOLUTION

Liquid Flow Calculation Example 2:

A **Chemical Engineer** needs an ultra high integrity air-actuated valve for his liquid chromatograph system in an oil company R&D lab which analyzes new types of gasoline. He selects an **8BW-P8K-12AC-SS** Parker air-actuated **P-Series Bellows Valve** with welded ports. He needs to size this valve to flow 14.5 GPM (Q) of gasoline with inlet and outlet pressures of 375 and 25 psig, P_1 and P_2 respectively.

Let's see how easily he compares the flow coefficient (C_V) value of his **8BW-P8K-12AC-SS** Parker Bellows valve, whose $C_V = 0.93$, with the flow coefficient required to flow gasoline at the above flow rate (Q = 14.5 GPM) and pressures ($P_1 = 375$ and $P_2 = 25$ psig).

FLOW COEFFICIENT : $C_V = Q\sqrt{\dfrac{S_g}{P_1 - P_2}}$ (EQ. 3)

C_V = UNKNOWN : FLOW COEFFICIENT

Q = 14.5 : FLOW RATE, GPM

S_g = 0.71 : FLUID SPECIFIC GRAVITY (RATIO OF FLUID DENSITY COMPARED TO WATER DENSITY) (REFERENCE FLUID SPECIFIC GRAVITY TABLE ON PAGE 19)

P_1 = 375 : INLET PRESSURE, PSIG

P_2 = 25 : OUTLET PRESSURE, PSIG

$C_V = 14.5\sqrt{\dfrac{.71}{(375 - 25)}}$: PLACE ALL VALUES INTO THE EQUATION

$C_V = 0.65$: MINIMUM REQUIRED C_V TO OBTAIN 14.5 GPM

He refers to the flow data selection of the Parker IVD Packless Valve Bulletin. He sees that an 8BW-P8K-12AC-SS bellows valve (air actuated) has a C_V value of 0.93. He selects this valve because it's 0.93 C_V is larger than the calculated value.

Liquid Flow Calculation Example 3:

A **Semiconductor Fluid System designer** needs a high performance check valve for an ammonia system. His required flow rate is 2.25 GPM (Q). He selects a Parker **4V1-CO4L-1-KZC-SS CO-Series Check Valve.**

Let's see how easily he calculates the pressure drop ($P_1 - P_2$) across the **4V1-CO4L-1-KZC-SS** check valve, whose $C_v = 0.32$ and which is flowing 2.25 GPM of ammonia.

Please note that the *customized* liquid pressure drop equation (EQ. 4) uses only the flow rate (Q), valve flow coefficient (C_v), and fluid specific gravity (S_g); it does not require either the inlet (P_1) or outlet (P_2) pressures in order to calculate the pressure drop.

PRESSURE DROP : $\Delta P = \left[\dfrac{Q}{C_V}\right]^2 \times S_g$ (EQ. 4)

Q = 2.25 : FLOW RATE, GPM

C_V = 0.32 : FLOW COEFFICIENT (REFER TO THE PARKER IVD VALVE BULLETIN)

S_g = 0.662 : FLUID SPECIFIC GRAVITY (RATIO OF FLUID DENSITY COMPARED TO WATER DENSITY) (REFERENCE FLUID SPECIFIC GRAVITY TABLE ON PAGE 19)

$\Delta P = \left[\dfrac{2.25}{0.32}\right]^2 \times [0.662]$: PLACE ALL VALUES INTO THE EQUATION

ΔP = 33 PSIG : THE PRESSURE DROP FROM A 2.25 GPM FLOW RATE

WATER FLOW CALCULATION CURVES

Valve $C_v = 1.0$ Specific Gravity = 1.00
P_1 = Inlet (Upstream) Pressure P_2 = Outlet (Downstream) Pressure

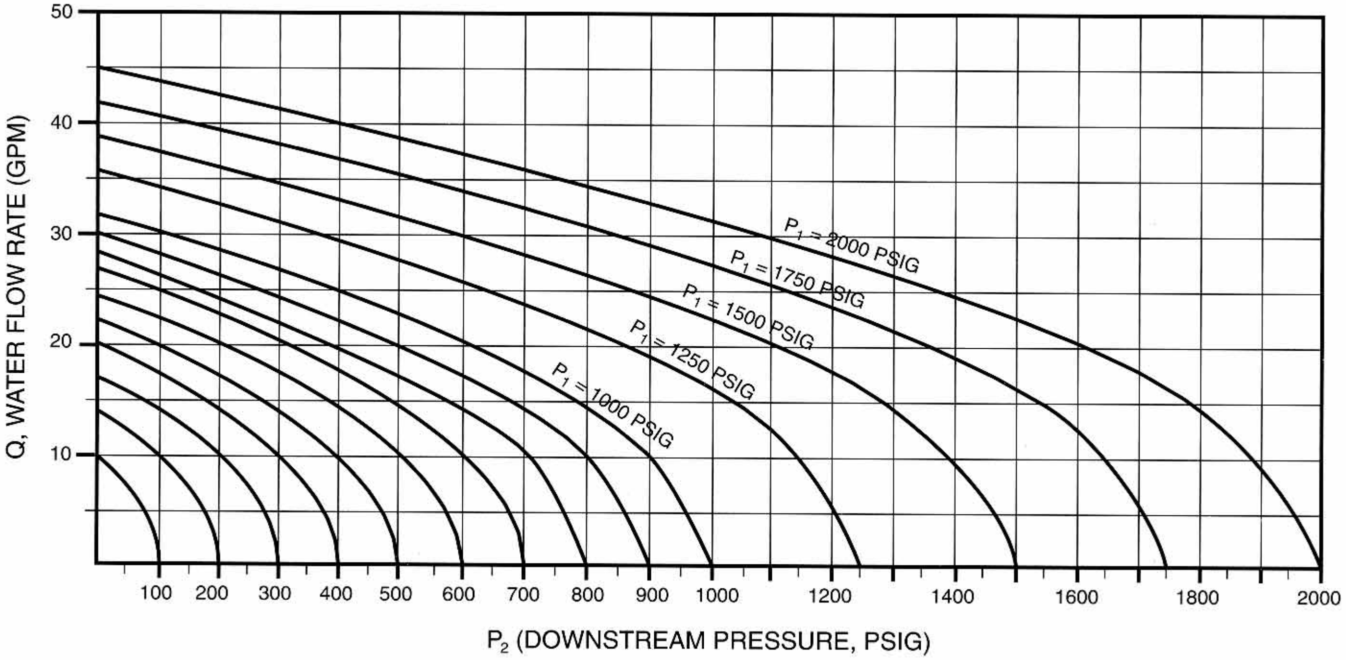


Figure 9 Water flow calculation curves, zero to 2000 psig

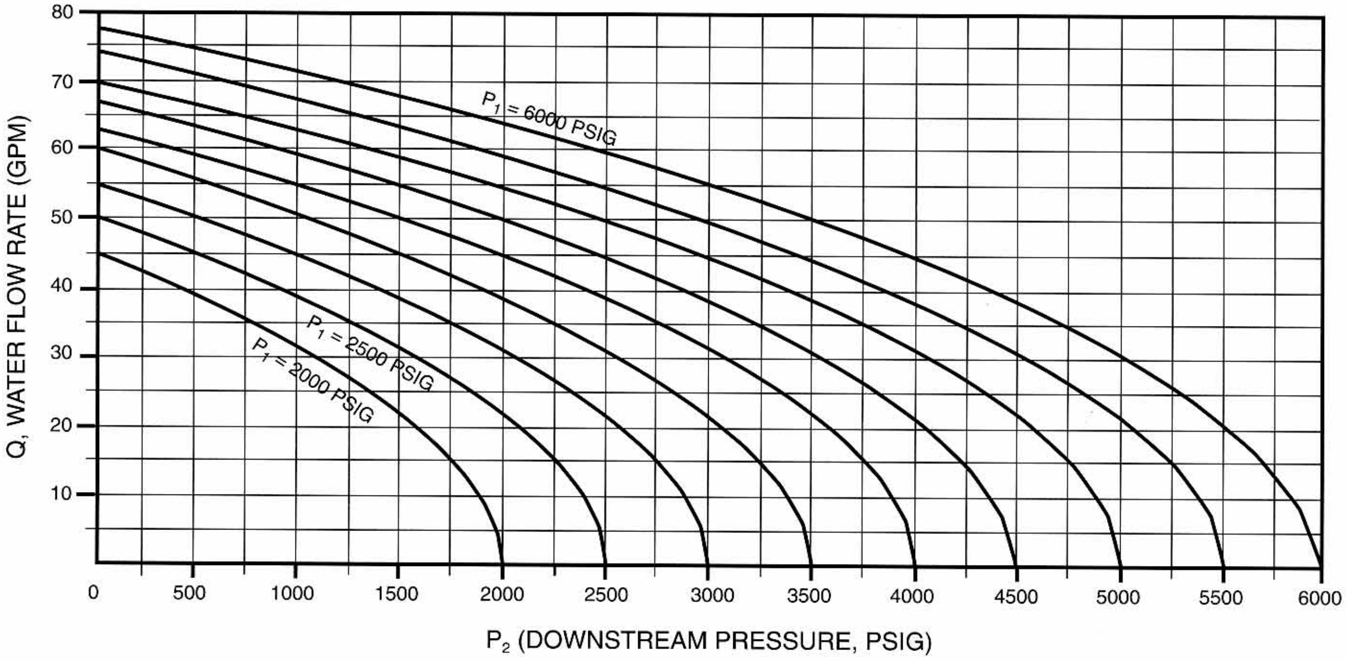
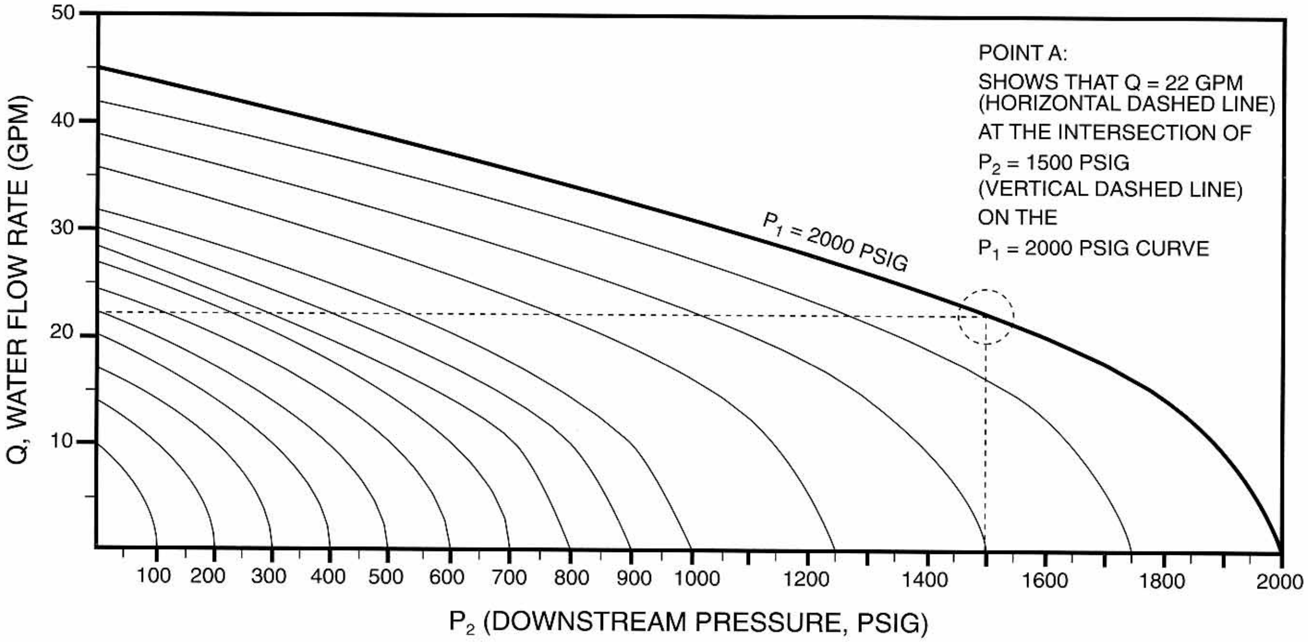


Figure 10 Water flow calculation curves, 2000 to 6000 psig

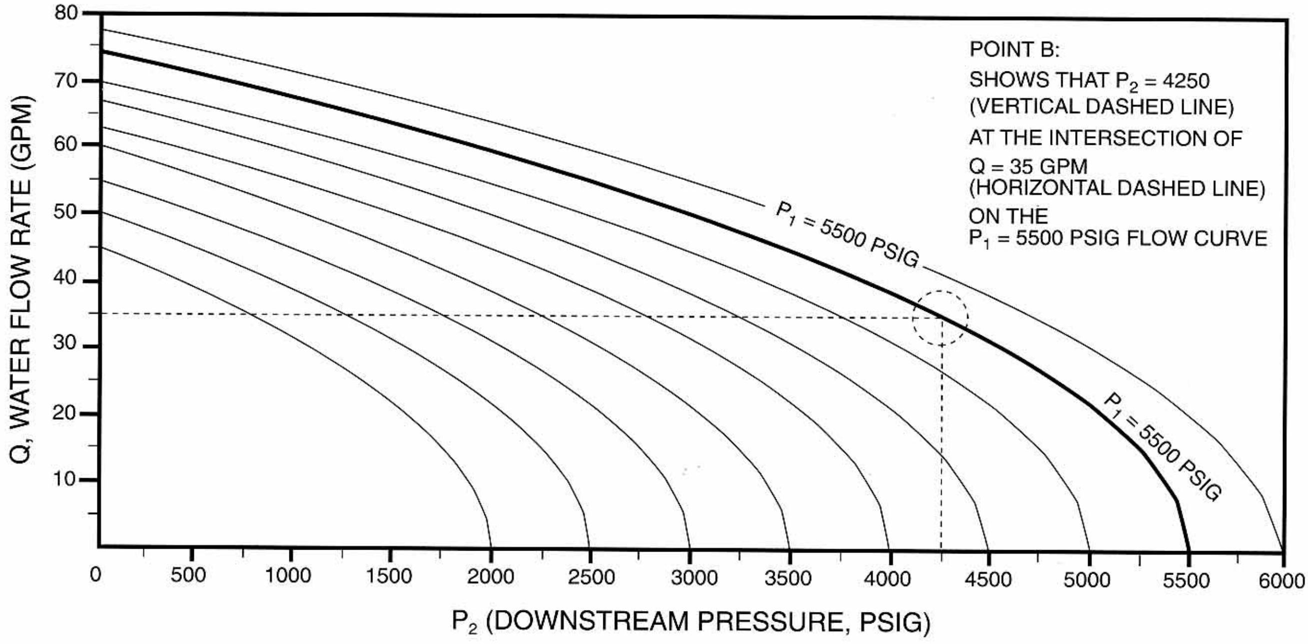
Liquid Flow Calculation Example 4:

A **piping designer** needs to find the *flow rate* (Q) for water flowing at 2000 psig inlet (P_1) and 1500 psig outlet (P_2) pressure, through a valve whose flow coefficient (C_v) is 0.73. **Point-A** on the chart shows the flow rate is 22 GPM (Q) for a valve whose C_v = 1.00. The candidate valve has a **C_v of 0.73.** Multiply the 22 GPM by the 0.73 to find the *effective flow rate* of **16 GPM.**



Liquid Flow Calculation Example 5

One needs the *pressure drop* ($P_1 - P_2$) for acetic acid **(Sg = 1.049)** flowing through a valve with C_v = 1.00, at 35 GPM (Q) and 5500 psig upstream pressure (P_1). **Point-B** on the chart shows that the downstream pressure (P_2) is about 4250 psig. The *pressure drop* ($P_1 - P_2$) is 5500 – 4250 = 1250 psig. This figure is *approximately accurate* since acetic acid's Sg (1.049) is very close to water's 1.00. **The use of graphical methods for solving liquid flow problems are not recommended when specific gravities (Sg) depart from unity.**



B) Gas Flow Calculations

This section shows how to analyze gas flow for instrumentation valves, using both **customized** formulas and graphical methods. The **Formula Method** is presented first since it is more accurate than the **Graphical Method.** Before we continue, however, the *Specific Gravity (Sg)* of various gases is presented, since this fluid property is required for both the Formula and Graphical Methods.

Table 2
Specific Gravity (Sg) of Various Gases

Gas	Sg	Gas	Sg	Gas	Sg
Acetylene	0.905	Chlorine	2.480	Methyl Bromide	3.270
Air	1.000	Diborane	0.950	Methyl Chloride	1.740
Alcohol, Ethyl	1.590	Ethane	1.040	Naphtalene	4.430
Alcohol, Methyl	1.110	Ether	2.550	Nitrogen	0.967
Allene	1.40	Ethylene	0.974	Nitrous oxide	1.530
Ammonia	0.590	Fluorine	1.310	Octane	3.943
Argon	1.379	Helium	0.138	Oxygen	1.105
Arsine	2.695	Heptane	5.520	Pentane	2.491
Benzene	2.695	Hexane	2.071	Phosphine	1.183
Bromine	5.520	Hydrogen	0.069	Phosgene	0.420
Butane	2.071	Hydrogen Chloride	1.270	Propane	1.547
Carbon Dioxide	1.520	Hydrogen Sulfide	1.189	Silane	1.114
Carbon Disulfide	2.630	Krypton	2.898	Sulfur Dioxide	2.210
Carbon Monoxide	0.970	Methane	0.555	Water (Steam)	0.620

Formula Method

The *customized* formulas for analyzing gas flow *(Normal and "Choked")* are:

NORMAL FLOW'S CRITICAL PRESSURE DROP RATIO: $\frac{P_1}{P_2} < 1.89$ **: FLOW RATE LESS THAN THEORETICAL LIMIT** **(EQ. 7)**

FLOW RATE (SCFM) (NORMAL FLOW) : $Q = 16.05 \times C_V \sqrt{\frac{(P_1^2 - P_2^2)}{T\,(^\circ R) \times S_g}}$ **(EQ. 8)**

FLOW COEFFICIENT (NORMAL FLOW) : $C_V = Q \times (0.0623) \sqrt{\frac{T\,(^\circ R) \times S_g}{(P_1^2 - P_2^2)}}$ **(EQ. 9)**

CHOKED FLOW'S CRITICAL PRESSURE DROP RATIO: $\frac{P_1}{P_2} > 1.89$ **: FLOW RATE AT THE THEORETICAL LIMIT** **(EQ. 10)**

FLOW RATE (SCFM) (CHOKED FLOW) : $Q = 13.63 \times C_V \times P_1 \sqrt{\frac{1}{T\,(^\circ R) \times S_g}}$ **(EQ. 11)**

FLOW COEFFICIENT (CHOKED FLOW) : $C_V = \frac{Q \times (0.0734)}{P_1} \sqrt{T\,(^\circ R) \times S_g}$ **(EQ. 12)**

NOTE: P_1 AND P_2 ARE IN UNITS OF PSIA

Gas Flow Calculation Example 1:

A **Chemical Engineer** needs to calculate the flow rate (Q) of Argon gas at 600° F (T), flowing through a Parker **8W-U12LR-G-SS Union Bonnet valve,** with inlet and outlet pressures of 1700 and 1500 psig, P_1 and P_2 respectively.

Let's see how easily she checks to see if the valve size selected provides her required flow rate (Q) of high-temperature Argon gas. **Remember that she must use both absolute pressures (psia) and absolute temperature (degrees R) in her calculations.**

FIRST, CHECK IF FLOW IS EITHER NORMAL OR "CHOKED". THIS DETERMINES WHAT FORMULA TO USE.

$$\frac{P_1}{P_2} = \frac{1700 \text{ PSIG} + 14.7}{1500 \text{ PSIG} + 14.7} = \frac{1714.7 \text{ PSIA}}{1514.7 \text{ PSIA}} = 1.13$$

1.13 IS LESS THAN THE CRITICAL 1.89 VALUE. THIS MEANS THE GAS FLOW RATE IS LESS THAN THE THEORETICAL MAXIMUM. THEREFORE, USE FLOW EQUATION 8 FOR NORMAL GAS FLOW.

FLOW RATE (SCFM):

$$Q = 16.05 \times C_V \sqrt{\frac{(P_1^2 - P_2^2)}{T\,(°R) \times S_g}} \qquad \text{(EQ. 8)}$$

Q = UNKNOWN : FLOW RATE, SCFM

C_V = 1.10 : FLOW COEFFICIENT (REFER TO THE PARKER IVD VALVE BULLETIN)

P_1 = 1714.7 : INLET PRESSURE (MUST USE ABSOLUTE PRESSURE : 1700 PSIG + 14.7 = 1714.7 PSIA)

P_2 = 1514.7 : OUTLET PRESSURE (MUST USE ABSOLUTE PRESSURE : 1500 PSIG + 14.7 = 1514.7 PSIA)

T = 1059.67 : TEMPERATURE (MUST USE ABSOLUTE TEMPERATURE : 600°F + 459.67 = 1059.67°R)

S_g = 1.379 : ARGON SPECIFIC GRAVITY (RATIO OF ARGON DENSITY COMPARED TO AIR DENSITY) (REFERENCE GAS SPECIFIC GRAVITY TABLE ON PAGE 24)

$$Q = 16.05 \times 1.10 \sqrt{\frac{(1714.7)^2 - (1514.7)^2}{1059.67 \times 1.379}}$$

: PLACE ALL VALUES INTO THE EQUATION REMEMBER TO USE ABSOLUTE PRESSURE AND TEMPERATURE

$$Q = 17.655 \sqrt{\frac{645{,}880}{1{,}461.285}}$$

: SIMPLIFY TERMS INSIDE AND OUTSIDE OF THE SQUARE ROOT SYMBOL

$$Q = 17.655 \times 21.024$$

: 645,880 ÷ 1,461.285 = 441.995
THE SQUARE ROOT OF 441.995 = 21.024

Q = 371 SCFM

: OBTAIN THE FINAL SOLUTION

Gas Flow Calculation Example 2

A **Semiconductor Process Engineer** is replacing a diaphragm shut-off valve in an existing computer chip manufacturing facility. The process uses Phosphine (PH_3) gas at 600° F. The gas runs in a 1/4-inch Parker **VacuSeal** tubing line, supplying an inlet pressure (P_1) of 3000 psig to the shut-off valve. He selects a **4V1-DP4R-SSP-C4** Parker ***DP-Series Diaphragm valve,*** which is specially cleaned to the Parker IVD C4 cleaning specification.

His process needs a minimum flow rate of 325 SCFM (Q). He decides to use the gas equations for **"Choked"** flow, since **"Choked"** flow represents the maximum possible flow rate.

He knows that **"Choked"** flow occurs when $P_2 = (P_1 / 1.89)$, as derived from EQ. 10. He also rembembers that P_1 and P_2 must be given in terms of absolute pressure *(Psia = Psig + 14.7).*

Therefore, he divides his P_1 inlet **absolute** pressure (3000 + 14.7 = 3014.7) by 1.89 to obtain the required outlet pressure (P_2) for maximum flow. P_2 is calculated to be 1595 psia (which is equal to 1580.3 psig).

He now knows that he needs an inlet pressure (P_1) of 3014.7 psia and an outlet pressure (P_2) of 1595 psia for his gas flow to be **"Choked" (eg. flowing at the maximum theoretical flow rate).** All he has to find out if the **4V1-DP4R-SSP-C4** Diaphragm valve can flow 325 SCFM (Q) with $P_1 = 3014.7$ and $P_2 = 1595$ psia.

Let's see how he checks to see if the flow coefficient (C_V) of his Parker valve accommodates his process flow rate requirement of 325 SCFM (Q). **Remember that he must use both absolute pressures (psia) and absolute temperature (degrees R) in his calculations.**

FLOW RATE (SCFM):

$$Q = 13.63 \times C_V \times P_1 \sqrt{\frac{1}{T\ (°R) \times S_g}} \qquad \text{(EQ. 11)}$$

Q = UNKNOWN : FLOW RATE, SCFM

C_V = 0.31 : FLOW COEFFICIENT (REFER TO THE PARKER IVD VALVE BULLETIN)

P_1 = 3014.7 : INLET PRESSURE (MUST USE ABSOLUTE PRESSURE : 3000 PSIG + 14.7 = 3014.7 PSIA)

P_2 = 1595.0 : OUTLET PRESSURE (MUST USE ABSOLUTE PRESSURE)

T = 1059.67 : TEMPERATURE (MUST USE ABSOLUTE TEMPERATURE : 600°F + 459.67 = 1059.67°R)

S_g = 1.183 : PHOSPHINE SPECIFIC GRAVITY (RATIO OF PHOSPHINE DENSITY COMPARED TO AIR DENSITY) (REFERENCE GAS SPECIFIC GRAVITY TABLE ON PAGE 24)

$$Q = 13.63 \times 0.31 \times 3014.7 \sqrt{\frac{1}{1059.67 \times 1.183}}$$

: PLACE ALL VALUES INTO THE EQUATION REMEMBER TO USE ABSOLUTE PRESSURE AND TEMPERATURE

$$Q = 12{,}738 \sqrt{\frac{1}{1{,}253}}$$

: SIMPLIFY TERMS INSIDE AND OUTSIDE OF THE SQUARE ROOT RADICAL SYMBOL

$$Q = 12{,}738 \times 0.028$$

: THE INVERSE OF 1,253 IS 0.0008
THE SQUARE ROOT OF 0.0008 = 0.028

$$Q = 359 \text{ SCFM}$$

: OBTAIN THE FINAL SOLUTION

AIR FLOW CALCULATION CURVES

Valve Cv = 1.0 Temperature = 80°F (540°R) PSIA = PSIG + 14.7
P_1 = Inlet (Upstream) Pressure P_2 = Outlet (Downstream) Pressure
Specific Gravity = 1.00

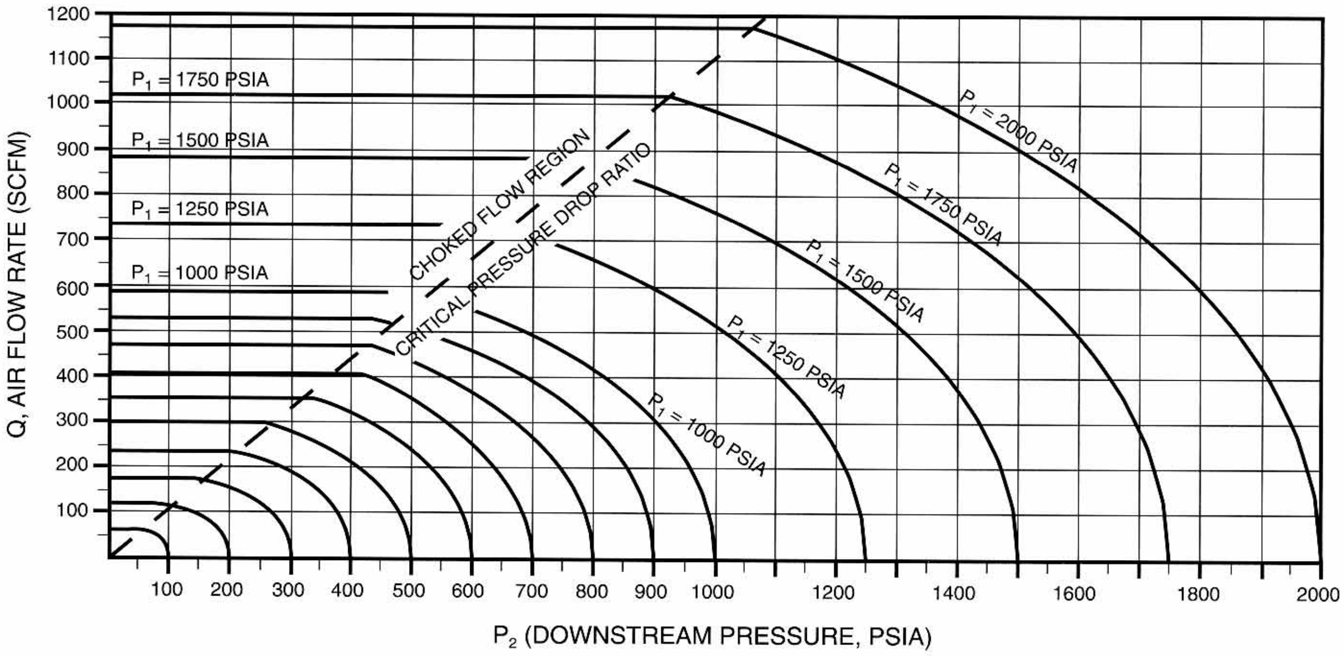


Figure 11 Air Flow Calculation Curves, zero to 2000 PSIA

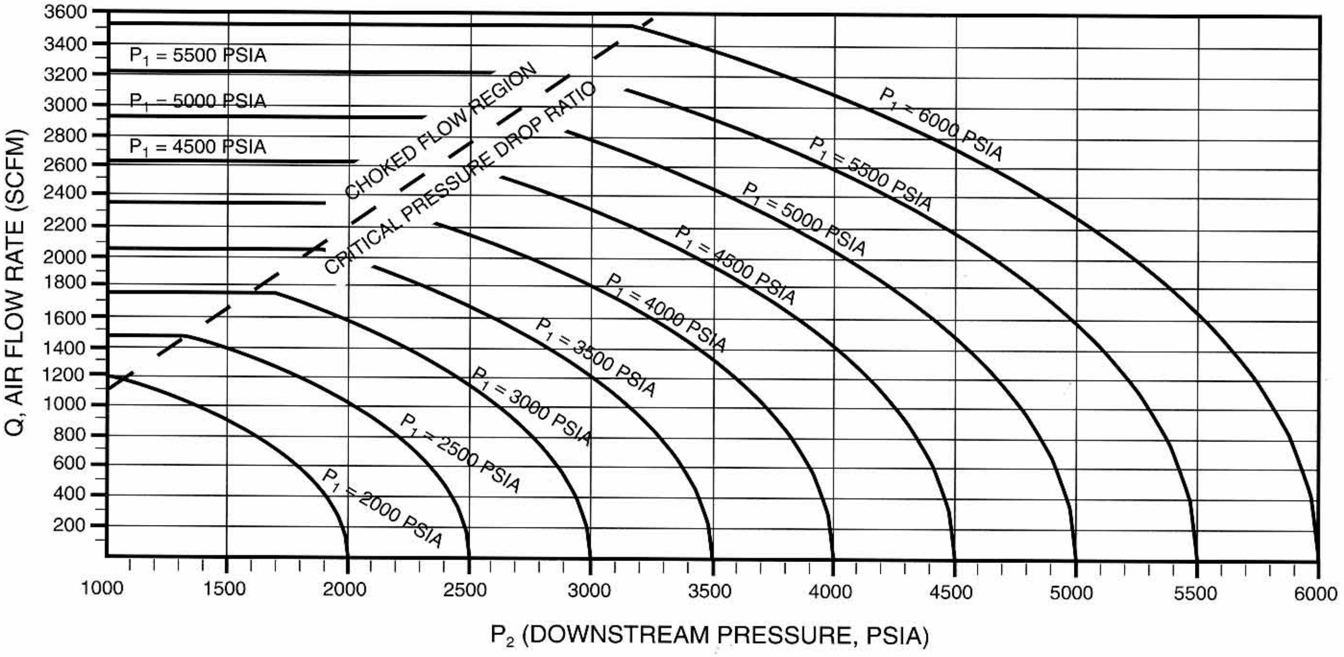
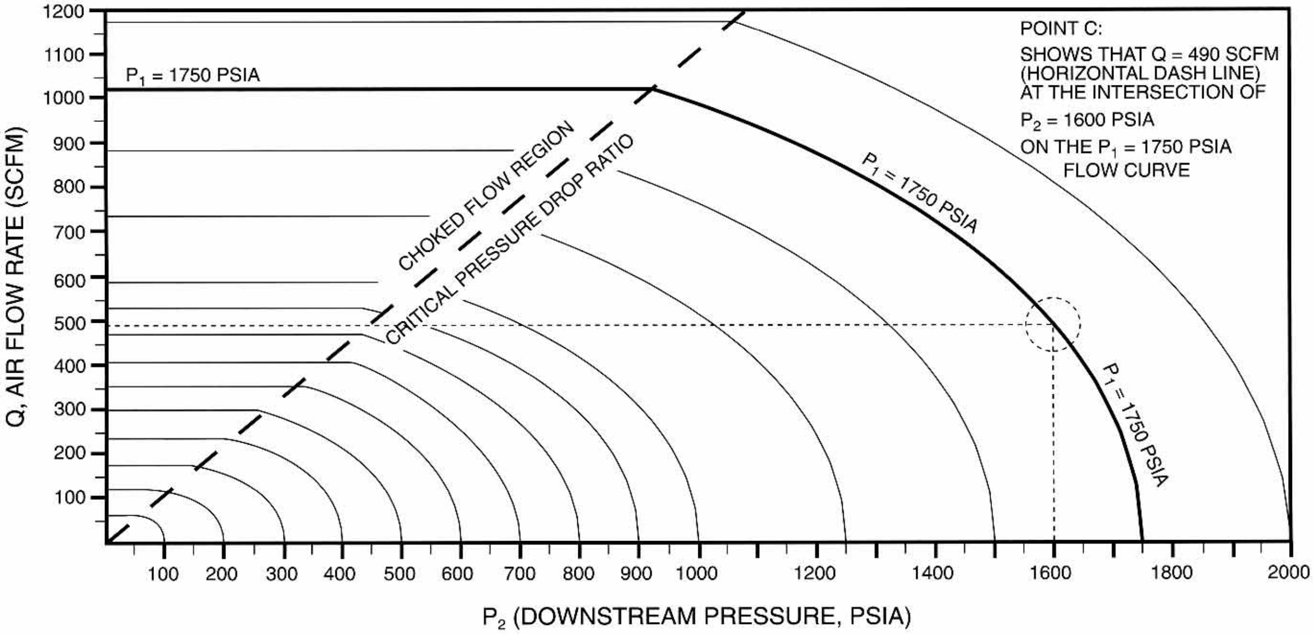


Figure 12 Air Flow Calculation Curves, 2000 to 6000 PSIA

Flow Calculations & Valve Sizing Guidelines

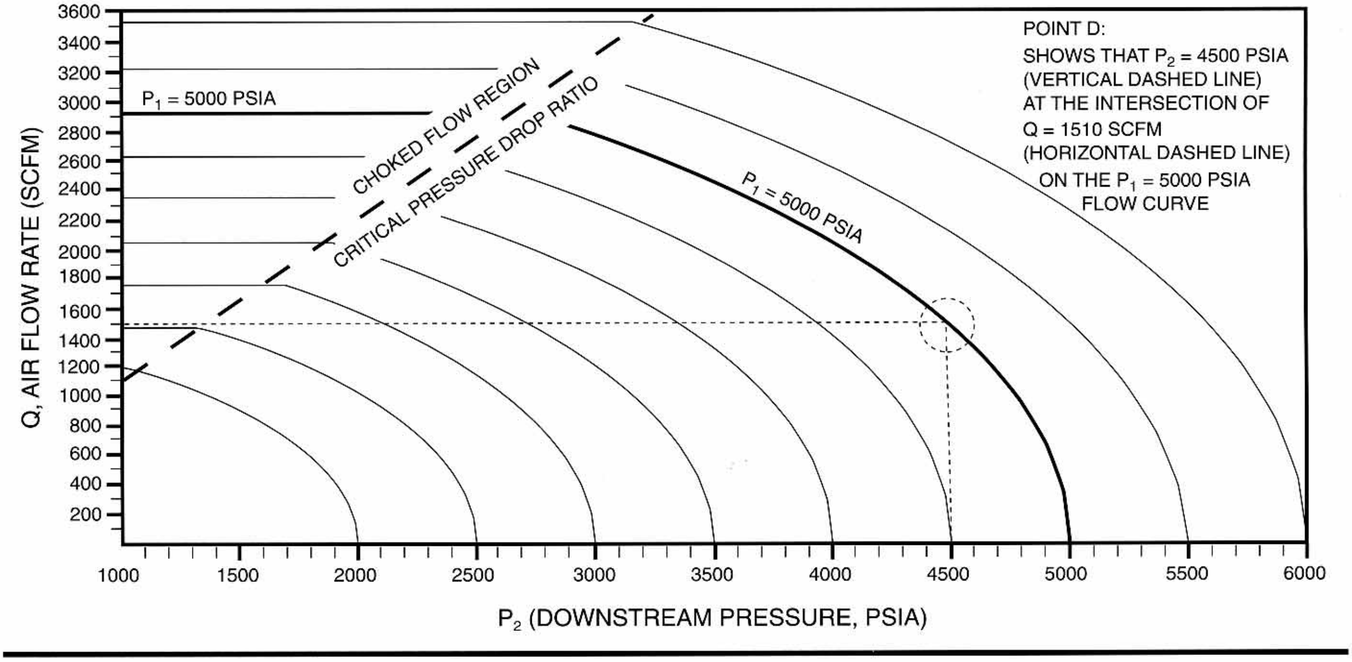
Gas Flow Calculation Example 3

A **Hyperbaric Diving System Designer** needs to find the **flow rate** (Q) for **Air** flowing at 1750 psia inlet (P_1) and 1600 psia outlet (P_2) pressure, and 80° F. He selects a Parker SB-Series Swing-Out Ball Valve whose flow coefficient (C_v) is 32. **Point-C** on the chart shows the flow rate is 490 SCFM for a valve whose C_v = 1.00. Since his valve has a C_v of 32, he multiplies the 490 SCFM by 32 to find the **effective flow rate** of **15,680 SCFM.**



Gas Flow Calculation Example 4

One needs to find the *pressure drop* ($P_1 - P_2$) for nitrogen **(Sg = 0.97)** flowing through a valve with C_v = 1.00, at 1510 SCFM, 5000 psia upstream pressure (P_1), and 80° F. **Point-D** on the chart shows that the downstream pressure (P_2) is about 4500 psia. The *pressure drop* ($P_1 - P_2$) is 5000 – 4500 = 500 psi. This figure is *approximately accurate* since nitrogen's Sg (0.97) is very close to air's 1.00, and the temperature is 80° F. **The use of graphical methods for solving gas flow problems are not recommended when specific gravities (S_g) depart from unity or when temperatures vary from 80° F.**



X. FLUID COMPATIBILITY TABLE

The following table is intended as a guide to the user in the selection of materials for fluid compatibility. The information in the table is based on fluids at **room temperature** unless otherwise specified. The compatibility ratings are intended only as general guides. Factors such as solution concentration, temperature, degree of agitation, and presence of impurities influence the compatibility ratings. **No one material can be expected to be compatible with the wide variety of fluids found in the world today. Users must test under their own operating conditions to determine the suitabiity of any material in a particular application. Do not assume the chemical compatibility of any elastomer or plastic in your application, including fluids such as water.**

Valve **internal components,** in contact with the fluid should carry an **"A" rating. Body materials** in direct contact with the fluid can, in many cases, carry a **"B" rating** because the rate of corrosion is not fast enough to become a serious problem.

EXPLANATION OF RATINGS

A = Satisfactory
B = Fair
C = Poor
D = Unsatisfactory
Blank = No Information

A "B" or "C" rating for a plastic or elastomer often indicates that the fluid will swell the material at room temperature without chemically degrading it. When such swelling occurs, valve performance can be jeopardized.

Carpenter 20 is a registered trademark of Carpenter Technology.
Viton is a registered trademark of DuPont.
Vespel is a registered trademark of DuPont.
17-4 PH is a registered trademark of Armco Steel.
Monel is a registered trademark of International Nickel.
Teflon is a registered trademark of DuPont.
Teflon PFA is a registered trademark of DuPont.
Delrin is a registered trademark of Dupont
PEEK is a registered trademark of the ICI Corporation.
Kel-F is a registered trademark of the 3M Corporation.
Grafoil is a registered trademark of Union Carbide.
Kalrez is a registered trademark of DuPont.
Hastelloy is a registered trademark of the Cabot Corporation.

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Acetaldehyde	C	C	A		A	A	A	C	B	D	C	C	A	B		A	A	A	D
Acetamine	B	B	B				A	A				B				A	A	A	
Acetate Solvents	B	A	A			A	A	D		D	A	D	D			A	A	A	
Acetic Acid, aerated	D	D	A			A	A	C		C		C	D	B	A	A	A	A	
Acetic Acid, Air Free	B	D	A	A	A	A	A	C		D		C	D	B	A	A	A	A	
Acetic Acid, crude	C	C	A	A	A	B	A	D		D		D	D	B	A	A	A	A	
Acetic Acid, glacial			D	A			A	B	B	D	A	D	D	B	A	A	A	A	
Acetic Acid, pure	C	D	A	A	A	D	A	D		D	A	D	B	B	A	A	A	A	C
Acetic Acid, 10%	C	C	A	A	A	B	A	D	B	D	A	C		B	A	A	A	A	A
Acetic Acid, 80%	C	C	A	A	A	B	A	D	C	D	A	D	D	B	A	A	A	A	C
Acetic Acid Vapors	D		D	D	B	C	A	D			A			B		A	A	A	
Acetic Anhydride	D	D	B	B	B	B	A	D	B	D	A	B	C		A	A	A	A	C
Acetone	A	A	A	A	A	A	A	D	A	D	A	D	A	A	A	A	A	A	A
Other Ketones	A	A	A	A	A	A	A	D	D	D		D	A			A	A	A	
Acetyl Chloride	A		C			B	A	D	D	A	A	D	D			A	A	A	
Acetylene	B	A	A	A	A	A	A	A	A	A	A	B	A	A		A	A	A	
Acid Fumes	D	D	B		B			C				B	D		A	C	A	A	
Acrylonite	A	A	A		B	A	A	D	D	C		D	D	A		A	A	A	
Air	A	A		A	A	A	A	A	A	A		A	A	A	A	B	A	A	A
Alcohol, Amyl	B	B	A		B	B	B	C	A	B		C	A	A		A	A	A	
Alcohol, Butyl	B	B	A		A	A	A	B	C	A		B	A	A		A	A	A	
Alcohol, Diacetone	A	A	A		A	B	A	D	B	D		C	A	A		A	A	A	
Alcohol, Ethyl	B	B	B		A	B	A	A	A	A		B	A	A		A	A	A	A
Alcohols, Fatty	B	B	A		A		A	B				B	A	A		A	A	A	
Alcohol, Isopropyl	B	B	B		A	B	B	C	A	A		B	A	A		A	A	A	
Alcohol, Methyl	B	B	A		A	A	A	B	A	C		A	A	A		A	A	A	
Alcohol, Propyl	A	B	A		A	A	A	B	A	A		B	A	A		A	A	A	
Alumina	A		A			C	A	A	A			A	A	A		A	A	A	
Aluminum Acetate	D		A	B	B	B	B	B	A	D	A	B	D			A	A	A	A
Aluminum Chloride dry	B	C	C		D		B	A	A	A	A	A	A	A	A	A	A	A	A
Aluminum Chloride solution			D	C	B	B	A	A		A	A	A	D	A	A	A	A	A	A
Aluminum Fluoride		D	C			B	A	A	A	A	A	A	C			A	A	A	A
Aluminum Hydroxide	A	D	A	B	B	B	B	A	A	A	A	A	C			A	A	A	A
Aluminum Nitrate	D		C		B	C	B	A	A	A	A	A	D			B	A	A	
Aluminum Oxalate			D		A	B	A				A						A	A	A
Alum (Alum. Potassium Sulphate)	D		B	C	B	C	A	A	A	D	A	A	D			A	A	A	A
Aluminum Sulfate	C	D	B	A	B	C	A	A	A	A	A	A	D	A		A	A	A	A
Amines	B	B	A	A	A	B	B	D	B	D	A	B	C	B		A	A	A	
Ammonia, Alum			A		A		A	B				B	C	D		A	A	A	
Ammonia, Anydrous Liquid	D	A	A	A	A	B	A	B	A	D	A	A	D	A	A	A	A	D	
Ammonia, Aqueous	D	A	A		A	B	B	B		A	A	B	D	B		A	A	A	
Ammonia, Gas, hot	D		A		A	B	B	D	B	D	A	B	D			A	A	A	A
Ammonia Liquor			A		A		B							B		A	A	A	
Ammonia Solutions	D	B	A		A	B	B	B	B	D		B	D	B		A	A	A	
Ammonium Acetate	D		B		A	B	B	B	A	D	A	B	D			A	A	A	
Ammonium Bicarbonate	B	C	B		B	B		B	A	A	A	A	A	B		A	A	A	A
Ammonium Bromide 5%			B		B	B					A		A			A	A	A	A
Ammonium Carbonate	B	B	B		B	B		D	A	A	A	A	D			A	A	A	A

Ratings: **A**-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Ammonium Chloride	D	D	C	C	B	B	B	A	A	A	A	A	C	D		A	A	A	A
Ammonium Hydroxide 28%	D	C	B	A	A	D	B	B	B	A	A	A	D	B	A	A	A	A	A
Ammonium Hydroxide (Concentrated)	D	C	B	A	A	C	B	C	A	A	A	A	D			A	A	A	A
Ammonium Monosulfate			A		B	B	B						D				A	A	A
Ammonium Nitrate	D	D	A	A	B	D	B	A	A	A	A	A	D	C		B	A	A	A
Ammonium Oxalate 5%			A		A	B					A		A				A	A	A
Ammonium Persulfate	C		A		A	D		D	A	B	A	C	D		A		A	A	A
Ammonium Phosphate	D	D	B		B	C		A	A	D	A	A	C	A		A	A	A	A
Ammonium Phosphate Di-basic	C	D	B		B	C	B	A	A	A	A	A	A	A		A	A	A	
Ammonium Phosphate Tri-basic	C	D	B		B	C	B	A	A	A	A	A	A	A		A	A	A	
Ammonium Sulfate	C	C	B	B	B	B	B	A	A	D	A	A	B	A	A	A	A	A	A
Ammonium Sulfide	D	D	B		B	B		A	A	D	A	A	A			A	A	A	A
Ammonium Sulfite	C	C	A		B	D		B	B	A	A	A	A			A	A	A	
Amyl Acetate	B	C	B	A	A	B	A	D	C	D	A	D	A	D	A	A	A	A	A
Amyl Chloride	B		A		A	B	B	D	D	A	A	D	A	B		A	A	A	D
Aniline	D	C	B		A	B	B	D	B	C	A	D	D	B	A	A	A	A	A
Aniline Dyes	C	C	A		A	A		D	B	B	A	B	A			A	A	A	
Apple Juice	C	D	B		A	A		A	B	A		A	A			A	A	A	
Aqua Regia (Strong Acid)	D	D	B		B			D	D	D	A	D	D		A	D	A	C	C
Aromatic Solvents	A	C	A		A	B		D	D		A	D	A			A	A	A	
Arsenic Acid	D	D	B		B	D	B	A	A	A	A	A	D		A	A	A	A	A
Asphalt Emulsion	A	B	A		A	A	A	D	D	A		C	A	A		A	A	A	
Asphalt Liquid	A	B	A		A	A	A	C	D	A		C	A			A	A	A	
Barium Carbonate	B	B	B		B	B	A	B	A	A	A	A	A			A	A	A	A
Barium Chloride	B	C	B	B	C	B		A	A	A	A	A	A			A	A	A	A
Barium Cyanide	C		B		B	D		B	B	B	A	B	A			A	A	A	
Barium Hydrate	D		A		A	B							A			A	A	A	
Barium Hydroxide	C	C	B	A	A	B		A	A	A	A	A	A	A		A	A	A	A
Barium Nitrate			A		A						A	B	A			B	A	A	
Barium Sulfate	C	C	A		A	B		A	B	A	A	A	A			A	A	A	A
Barium Sulfide	D	C	B		B	C		A	A	A	A	A	A	B		A	A	A	A
Beer	B	D	A	A	A	A		A	A	A		A	A	A		A	A	A	A
Beet Sugar Liquors	A	B	A		A	A		A	A	A		B	A	A		A	A	A	
Benzaldehyde	A	A	A		A	B	B	D	A	D		D	A	A	A	A	A	A	D
Benzene (Benzol)	B	B	B	B	A	A	B	D	D	A	A	D	C	A	A	A	A	A	D
Benzoic Acid	B	D	B	A	B	B	A	D	D	A	A	D	A	D	A	A	A	A	A
Berryllium Sulfate	B		B		A	B		B	B	B	A	B	A			A	A	A	
Bleaching Powder wet	B		C		B	D	A	D	B	B		A	D	D	A	A	A	A	A
Blood (Meat Juices)	B		A	A	A	B		B	B	B		B	A			A	A	A	
Borax (Sodium Borate)	D	C	A			A	A	B	A	A		D	A			A	A	A	A
Bordeaux Mixture			A		A			B	A	A		B	A			A	A	A	
Borax Liquors	A	C	B		A	A	B		A	A		C	A			A	A	A	
Boric Acid	C	D	B		B	B	A	A	A	A	A	A	A	D		A	A	A	A
Brake Fluid	B		B	A		B		C	A	D		B	B			A	A	A	
Brines, saturated	B	D	B		B	B	A	A	A	A	A	B	A	C		A	A	A	A
Bromine, dry	B	D	D		B	A	A	D	D	A	A	D	D	D	A	B	A	C	D
Bunker Oils (Fuel)	B	B	A		A	A		A	D	A		D	A			A	A	A	D
Butadiene	C	B	A		A	C	B	D	D	A		D	A			A	D	A	D

Ratings: **A**-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Butane	A	B	A		A	B	A	A	D	A		A	A	A		A	A	A	A
Butter			A		A			A	A	A		B	A			A	A	A	A
Buttermilk	D	D	A		A	D		A	B	A		A	A			A	A	A	B
Butyl Acetate	B		B		A	B	B	D	B	D	A	D	B		B	A	A	A	D
Butylene	A	A	A		A	A		B	D	A		C	A	A		A	A	A	
Butyric Acid	C	D	B		B	B	A	D	B	B	C	D	A	D		A	A	A	D
Calcium Bisulfite	C	D	B		B	D	B	B	A	B	A	B	D			A	A	A	
Calcium Carbonate	C	D	B		B	B	B	A	A	A	A	A	A	A		A	A	A	A
Calcium Chlorate	D		B		B	B		B	B	B	A	B	D			B	A	A	A
Calcium Chloride	B	C	B	B	B	B	A	A	A	A	A	A	A	D	A	A	A	A	A
Calcium Hydroxide	C	C	B		B	A	A	A	A	A	A	A	A	A		A	A	A	A
Calcium Nitrate			B		B			A	A	A	A	A	C			B	A	A	A
Calcium Phosphate	C		B		B			A	A	A	A	B	B			A	A	A	A
Calcium Silicate	C		B		B			A	A	A		A	A			A	A	A	
Calcium Sulfate	C	C	B	B	B	B	B	A	B	A	A	A	A			A	A	A	A
Caliche Liquor		B	A		A			A	A	A		A	A			A	A	A	
Camphor	C		B		C	C		B	B	B	A	B	A			A	A	A	D
Cane Sugar Liquors	B		A		A	B		A	A	A		A	A			A	A	A	
Carbonated Beverages	B	D	B	B	B	C		B	B	B		B	A			A	A	A	
Carbonated Water	B	B	A	B	A	B		A	A	A		A	A			A	A	A	A
Carbon Bisulfide	C	B	B		B	B		D	D	A		D	A			A	A	A	D
Carbon Dioxide, Dry	A	A	A	A	A	A		A	A	A	A	B	A			A	A	A	A
Carbolic Acid Phenol	D	D	B	B	A	B		D	B	A	A	D	A			A	A	A	
Carbon Monoxide	A		A	A	A	A	A	A	A	A	A	B	A	A			A	A	A
Carbon Tetrachloride, dry	C	B	A	A	A	A	A	D	D	B	B	D	A	A	D	A	A	A	D
Carbon Tetrachloride, wet	D	D	B		B	B	B	D	D	B	B	D	B	A	D	A	A	A	D
Casein	C		B		B	C		B	B	B	A	B	A			A	A	A	
Castor Oil	A	B	A		A	A	A	A	B	A		A	A	A		A	A	A	A
Caustic Potash			A		A	B		B				B	D			A	A	A	
Caustic Soda		B	A		A	A		C	B	B	A		D			A	A	A	
Cellulose Acetate	B		B			B	B	D	B	D	A	D	C			A	A	A	
China Wood Oil (Tung)	C	C	A		A	A	A	A	D	A		B	A	A		A	A	A	
Chlorinated Solvents	C	C	A		A	B		D	D	A		D	A			A	A	A	
Chlorinated Water			C	D	A	D	D	B		A		A	D	D		A	A	D	C
Chlorine Gas, dry	C	B	B	C	A	A	A	C	D	B	A	D	D	D	A	A	A	A	D
Chlorobenzene, dry	B	B	A		A	B	B	D	D	A	A	D	B	A	D	A	A	A	D
Chloroform, dry	B	B	A	B	A	A	B	D	D	A	A	D	A	B	D	A	A	A	
Chlorophyll, dry	B		B		A	B		B	B	B		B				A	A	A	
Chlorosulfonic Acid, dry	C	B	B		B	B	A	D	D	D	A	D	D	D	A		A	D	D
Chrome Alum	C	B	A		A	B		A	A	A	A	A	B	D		A	A	A	A
Chromic Acid < 50%	D	D	C	C	B	C	B	D	C	C	A	D	D	D	A	A	A	A	A
Chromic Acid > 50%	D	D	C	D	B	D	B	D	C	C	A	D	D	D	A	A	A	D	
Chromium Sulfate	C		B		C	B		B	B	B		B	C			A	A	A	
Cider			A		B	A							A			A	A	A	A
Citric Acid	C	D	B	C	A	B	A	A	A	A		A	A	B		A	A	A	A
Citrus Juices	B	D	B		A	A		A		A		A	A			A	A	A	
Coca-Cola Syrup			A		A			B		B		B	A			A	A	A	A
Coconut Oil	B	C	B		A	B		A	C	A		C	A			A	A	A	A

Ratings: A-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Coffee	A		A		A	B		A	A	A		A	A			A	B	A	A
Coffee Extracts, hot	B	C	A		A	A							A	D		A	A	A	
Coke Oven Gas	C	B	A		A	B		D	D	A		D	D	C		A	A	A	
Cooking Oil	B	B	A		A	A		A	D	A		B	A			A	A	A	
Copper Acetate	D	D	A		A	C	B	B	A	D	A	B	D			A	A	A	
Copper Carbonate			A		A						A		A			A	A	A	
Copper Cyanide	D		A		A	C		A	A	A	A	A	A			A	A	A	A
Copper Nitrate	D	D	B		B	D		A	B	A	A	A	A			B	A	A	A
Copper Sulfate	D	D	B	B	B	C	A	A	A	A	A	A	A	A		A	A	A	A
Corn Oil	B	C	B		B	B		A	C	A		C	A			A	A	A	A
Cottonseed Oil	B	C	B		B	B		A	C	A		C	A			A	A	A	A
Cresol			B		B			D	D	B	A	D	D		A	A	A	A	D
Creosote Oil	B	B	B	B	A	B	B	C	D	A	A	D	D			A	A	A	D
Cresylic Acid	C	C	B		B	B		D	D	A	A	D	D			A	A	A	A
Crude Oil, sour	C	B	A		A	B		A	D	A		B	A			A	A	A	
Crude Oil, sweet	B	B	A		A	A		A		A		B	A			A	A	A	
Cupric Nitrate			A		A	D							D			B	A	A	
Cutting Oils, Water Emulsions	A	B	A		A			A	D	A		B	A			A	A	A	
Cyanide	D		B		B	D		B	B	B	A	B	D				A	A	
Cyclohexane	A	A	A		A	B	B	A	D	A	A	C	A	A		A	A	A	C
Cyclohexanone	B		A		A	B	B	D	B	D	A	D	A	A	A	A	A	A	D
Detergents, synthetic	B		B		A	B		A	A	A		B	A			A	A	A	A
Dextrin	B		B		B	B		B	B	B		B	A			A	A	A	A
Dichloroethane			C		B	B		D	D		A	D	D		A	A	A	A	
Dichloroethyl Ether	B		B		B			D	D	D		D	D				A	A	
Diesel Oil Fuels	A	A	A		A	A		A	D	A	A	C	A			A	A	A	
Diethylamine	B	A	A		A	B		B	B	D		B	A	B	C	A	A	A	
Diethyl Benzene			B		B			D	D		A	D	C			A	A	A	
Diethylene Glycol	B		A		A	B		A	A	A	A	A	A			A	A	A	A
Diethyl Sulfate	B		B		B	B		C	C	B		C	A			A	A	A	
Dimethyl Formamide	B		A		A	B		B	A	D	A	C	A		A	A	A	A	
Dimethyl Phthalate			D					D	B	B	A	D	C			A	A	A	
Dioxane	B		B		B	B		D	B	D	A	D	C		A	A	A	A	
Dipentane (Pinene)	A		A		A			B	D	B	A	D	A			A	A	A	
Disodium Phosphate			B		B	C		B		B		B	A			A	A	A	A
Dowtherm	A	B	A		A	A		D	D	A	A	D	A	C		A	A	A	
Drilling Mud	B	B	A		A	B		A	A	A		C	A			A	A	A	
Dry Cleaning Fluids	C	B	A		A	B		C	D	A		D	A			A	A	A	
Drying Oil	C	C	B		B	B		A				B	A			A	A	A	
Enamel	A		A					B	D			B	A			A	A	A	
Epsom Salts ($MgSo_4$)	B	C	B		B	B		A		A		A	A	B		A	A	A	
Ethane	B	C	B		B	B		A	D	A		B	A			A	A	A	
Ethers	B	A	A	B	A	B		D	C	C		D	C			A	A	A	D
Ethyl Acetate	C	B	B	A	B	B	B	D	B	D	A	D	C	A	C	A	A	A	C
Ethyl Acrylate	B	C	A		A	B	A	D	B	D	A	D	B	A		A	A	A	
Ethyl Benzene			B		A		A	D	D	A	A	D	A	B		A	A	A	
Ethyl Bromide	A		B		C	B		B	D	A	A	D	A			A	A	A	
Ethyl Chloride, dry	B	B	A	A	A	B	B	C	C	B	A	C	A	A		A	B	A	D

Ratings: A-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Ethyl Chloride, wet	C	D	B		B	B	B	C	B	B	A	C	A	A		A	A	A	D
Ethylene Chloride			A		A	B	B	D	D	B	A	D	A		A	A	A	A	
Ethylene Dichloride			B		A	B		D	C	A	A	D	C	A		A	A	A	D
Ethylene Glycol	B	B	B	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A
Ethylene Oxide	C	B	B		B	B	A	D	C	D	A	D	A	D	D	A	A	A	C
Ethyl Ether	B		A		A	A	B	C	C	D		D	A		C	A	A	A	
Ethyl Silicate	B		B		B	B		A	A	A		A	A			A	A	A	
Ethyl Sulfate			B		B			B	C	A		B	A			A	A	A	
Fatty Acids	C	D	A		A	B	A	B	C	A	A	B	A	A		A	A	A	A
Ferric Hydroxide			A		A	A		B			A		A			A	A	A	
Ferric Nitrate	D	D	C	B	A	D	B	A	A	A	A	A	A			B	A	A	A
Ferric Sulfate	D	D	B	B	A	D		A	A	A	A	A	A	C		A	A	A	A
Ferrous Ammonium Citrate			B		B						A		A			A	A	A	A
Ferrous Chloride	B	D	D		D	D	D	A	A	A	A	A	A	C	A	A	A	A	A
Ferrous Sulfate	B	D	B		B	B	B	A	A	A	A	A	A		A	A	A	A	A
Ferrous Sulfate, Saturated	C	C	A		A	B	B	C	B	B		C	A		A	A	A	A	
Fertilizer Solutions	C	B	B		B	B		B				B				A	A	A	
Fish Oils	B	B	A		A	A		A	D	A		B	A			A	A	A	
Fluorine Gas, dry			B		A	A	A								A		A	A	
Flue Gases	B		A		A	B		C	D	C		C	C			A	A	A	
Fluoboric Acid			B		A			A			A	B	D				A	D	A
Fluorosilicic Acid	B	D	B		B	A	B	C	C	C	A	C	C				A	D	A
Formaldehyde, cold	A	A	A	A	A	A	B	B	B	D	A	C	A	A		A	A	A	A
Formaldehyde, hot	B	D	C		B	B	B	B			A	B	A		B	A	A	A	A
Formic Acid, cold	B	D	B	B	A	B	A	D		B	B	B	D	A	A	A	A	A	A
Formic Acid, hot	B	D	B	D	B	B	B	D		A	B	A	D	D	B	A	A	A	A
Freon Gas, dry	B	B	A	A	A	A	B	C	C	C		C	A	A		A	A	A	
Freon 11, MF, 112, BF	B		A		A	B	B	C	C	D	D	C	A	A	C	A	A*	A	
Freon 12, 13, 32, 114, 115	A		A		A	B	B	B	A	D	D	A	A	A	C	A	A*	A	
Freon 21, 31	B		A		A	B	B	D	D	D	A	D	A	A	C	A	A*	A	
Freon 22	A		A		A		B	D	D	D	C	B	A	A	C	A	A*	A	
Freon 113, TF	B		A		A	B	B	B	C	C	D	C	A	A	C	A	A*	A	
Freon, wet	D		C	B	B	B	B	B	B	D		B	A	D		A	A	A	
Fruit Juices	B	D	A		A	B		A	A	A		A	A				A	A	A
Fuel Oil	B	B	A		A	B		A	D	A		B	A			A	A	A	D
Fumaric Acid					A			A	B	A	A	B	A				A	A	
Furfural	A	A	A	B	A	B	B	D	C	D		C	A			A	A	A	D
Gallic Acid 5%	C	D	B		B	B	B	B	B	A	A	B	A	A	A		A	A	A
Gas, Manufactured	B	B	B		B	A		A		A		A	A	A	A	A	A	A	
Gas, Natural	B	B	A		B	A		A	D	A		A	A	A		A	A	A	
Gas, Odorizers	A	B	B		A	B		B		A		B	A	A		A	A	A	
Gasoline, Aviation	A	A	A		A	A	A	C		A	A	D	A	A		A	A	A	D
Gasoline, Leaded	A	A	A		A	B	A	C		A	A	D	A	A		A	A	A	D
Gasoline, Motor	A	A	A	A	A	A	A	C	D	A	A	D	A	A		A	A	A	D
Gasoline, Refined	B	B	A		A	B	A	C	D	A	A	C	A	A		A	A	A	D
Gasoline, Sour	B	B	A		A	C	A	C	D	A		D	A	B		A	A	A	D
Gasoline, Unleaded	A	A	A		A	A	A	C		A	A	D	A	A		A	A	A	D
Gelatin	A	D	A		A	B		A	A	A		A	A	A		A	A	A	A

Ratings: A-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Glucose	A	B	A		A	A	A	A	A	A	A	A	A	A		A	A	A	A
Glue	B	A	B		A	B	A	A	B	A	A	A	A	A		A	A	A	A
Glycerin (Glycerol)	B	C	A	A	A	A	A	A	A	A	A	A	A	A		A	A	A	A
Glycol Amine	D		B	A			D	A	D	D			C			A		A	
Glycol	B	C	B		A	B		A	A	A		A	C			A	A	A	A
Graphite	B		B		A	B		B	B	B		B	A			A	A	A	
Grease	C	A	A		A	B		A	D	A	A	C	A			A	A	A	
Helium Gas	B		A		A	B	A	A	A	A		A	A			A	A	A	A
Heptane	A	B	A		A	B	A	A	D	A	A	B	A			A	A	A	C
Hexane	B	B	A		A	B	A	A	D	A		B	A	A	C	A	A	A	D
Hexanol, Tertiary	A	A	A		A	A	A	A	D	B	A	C	A	A		A	A	A	A
Hydraulic Oil, Petroleum Base	B	A	A		A	A		A	D	A		B	A			A	A	A	
Hydrazine	D		B		B	D		B	A	D	A	B	D				A	A	
Hydrocyanic Acid	D	D	A		A	C	B	B	A	A	A	B	D				A	A	A
Hydrofluosilicic Acid	A	D	C		B	B		B	A	A	A	B	A			A	A	D	
Hydrogen Gas, cold	B	B	A		A	A		A	A	A		A	A	A		A	A	A	A
Hydrogen Gas, hot		B	B		A		A	A	A	A		A	A			A	A	A	A
Hydrogen Peroxide >25%	D	D	B		B	D	D	D	B	B	A	D	D	D	A	D	A	A	C
Hydrogen Peroxide <25%	C	D	B		B	D	D	A	B	A	A	B	D	D	A	C	A	A	A
Hydrogen Sulfide, dry	C	B	A	B	B	B	B	C	A	A	A	A	C	D	A	A	A	A	A
Hydrogen Sulfide, wet	D	C	B		B	C	D	C	B	A	A	B	C	D	A	A	A	A	A
Hypo (Sodium Thiosulfate)	C	D	B		B	B		A	A	A		A	A			A	A	A	
Illuminating Gas	A	A	A		A	A		C	D	A		C	A			A	A	A	
Ink-Newsprint	C	D	A		A	B		A	B	A	A	B	A	A		A	A	A	A
Iodoform	C	B	A		A	C				A	C		A				A	A	
Iso-Butane			B		B			B	D		A	D	A			A	A	A	
Iso-Octane	A	A	A		A	A		A	D	A	A	B	A			A	A	A	
Isopropyl Acetate			B		A			D	B	D	A	D	A			A	A	A	
Isopropyl Ether	A	A	A		A	B	A	B	D	D	A	C	A	A	A	A	A	A	
J P-4 Fuel	A	A	A		A	A	A	A	D	A	A	D	A	A		A	A	A	
J P-5 Fuel	A	A	A		A	A	A	A	D	A	A	D	A	A		A	A	A	
J P-6 Fuel	A	A	A		A	A	A	A	D	A		D	A	A		A	A	A	
Kerosene	A	B	A		A	A	A	A	D	A	A	B	A	A		A	A	A	C
Ketchup	D	D	A		A	B		A		A		A	A			A	A	A	
Ketones	A	A	A		A	A		D	D	D		D	A			A	A	A	
Laquer (and Solvent)	A	C	A		A	A		D	D	D	A	D	A			A	A	A	
Lactic Acid Concentrated Cold	D	D	A	D	A	D	A	B	B	A	A	A	D	A		A	A	A	A
Lactic Acid Concentrated Hot	D	D	B	D	A	D	B	C	B	B	A	C	D			A	A	A	A
Lactic Acid Dilute Cold	D	D	A	B	A	C	A	B	B	A	A	A	D			A	A	A	A
Lactic Acid Dilute Hot	D	D	A	D	A	D	B	C		D	A	D	D			A	A	A	A
Lactose	B		B		B	B		B	B	B		C	A			A	A	A	
Lard	B		A		A			A	B	A		B	A			A	A	A	A
Lard Oil	B	C	B		A	B		A	B	A		B	A			A	A	A	A
Lead Acetate	C	D	B		B	B		B	A	D	A	B	A			A	A	A	A
Lead Sulfate	C		B		B	B		B	B	B		B	A			A	A	A	
Lecithin	C		B		B	B		D	D	B		D	A				A	A	
Linoleic Acid	B	B	A		A	B		B	D	B		B	A			A	A	A	
Linseed Oil	B	A	A		A	B		A	C	A		C	A			A	A	A	A

Ratings: **A**-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Lithium Chloride	B		B		A	B		B	B	B	A	B	A			A	A	A	
LPG	A	B	B		B	B		A	D	A		B	A			A	A	A	
Lubicating Oil Petroleum Base	B	A	A		A	B		A	D	A		B	A			A	A	A	C
Ludox	D		B		B	B		B	B	B		B	B				A	A	
Magnesium Bisulfate	B	B	A		A	B		B	B	B		B	A			A	A	A	
Magnesium Bisulfide	D		B		B	B		B	B	B		B	A			A	A	A	
Magnesium Carbonate	B		A		A	B		B	B	B		B	A			A	A	A	A
Magnesium Chloride	B	C	B	C	B	B	A	A	A	A		A	A	C		A	A	A	A
Magnesium Hydroxide	B	B	A	A	A	B	B	B	A	A	A	B	A	D		A	A	A	A
Magnesium Hydroxide Hot	D	B	A	A	A	A	B	B		A	A	B	A	D		A	A	A	A
Magnesium Nitrate			A		A	B		B		B		A	A			B	A	A	A
Magnesium Sulfate	B	B	A	A	A	B	A	A	A	A		A	A	A		A	A	A	A
Maleic Acid	B	B	B		B	B	A	B	D	A	A	B	A			A	A	A	A
Maleic Anhydride	B		B		B	B	B	D	D	A	A	D	C			A	A	A	
Malic Acid	B	D	B		B	B		A	B	A	A	B	A			A	A	A	
Malt Beverages			A		B	A		A	B	A		A	A			A	A	A	
Manganese Carbonate			B		A			B			A		A			A	A	A	
Manganese Sulfate	B		A		A	B		B	B	B	A	B	A			A	A	A	
Mayonnaise	D	D	A		D	B		A		A		A	A			A	A	A	
Meat Juices	D		A		A			B				B	A			A	A	A	A
Melamine Resins			C		C			B				B	A			A	A	A	
Mercuric Chloride	D	D	B		B	D	B	A	A	A	A	A	A	C	A	A	A	A	A
Mercuric Cyanide	D	D	A		A	C	B	A	A	A	A	B	A			A	A	A	A
Mercurous Nitrate	D		A		A	D				B	A		A			B	A	A	A
Mercury	D	A	A		A	B	B	A	A	A	A	A	A			A	A	A	A
Methane	A	B	A		A	B	A	A	D	A		B	A			A	A	A	
Methanol	B		A		A	B		A	A	D	A	A	C		A	A	A	A	
Methyl Acetate	A	B	A		A	B	A	D	B	D	A	B	B	A	A	A	A	A	
Methyl Acetone	A	A	A		A	A		D	A	D		D	B	A		A	A	A	
Methylamine	D	B	A		A	C	B	D	B	D	A	D	A	A		A	A	A	
Methyl Bromide 100%	C		B		A	B		B	D	A	A	D	A			A	A	A	D
Methyl Cellosolve	A	B	A		A	B	B	C	B	D		C	A	B		A	A	A	
Methyl Cellulose			A		A		B	B	B	D		B	A			A	A	A	
Methyl Chloride	B	B	A		A	B		D	C	A	A	D	A	A	C	A	A	A	D
Methyl Ethyl Ketone	A	A	A		A	A	B	D	A	D	A	D	A	A	A	A	A	A	D
Methylene Chloride	A	B	A		A	B	B	D	D	B	A	D	A	A		A	A	A	D
Methyl Formate	A	C	B		A	B	B	D	B	D		B	A		A	A	A	A	
Methyl Isobutyle Ketone			A		A			D	C	D		D	A			A	A	A	
Milk & Milk Products	B	D	A		A	B		A	A	A		A	A	A		A	A	A	B
Mineral Oils	B	B	A		A	A		A	C	A		B	A		A	A	A	A	D
Mineral Spirits	B	B	B		B	B		A		A		C	A			A	A	A	D
Mixed Acids (cold)	D	C	B		B	C		D	D	B		D	D	C			A	A	
Molasses, crude	A	A	A		A	A		A		A		A	A	A		A	A	A	B
Molasses, edible	A	C	A		A	A		A		A		A	A	A		A	A	A	B
Molybdic Acid			A		A								A			A	A	A	
Monochloro Benzene Dry			B		B	B		D	D	A		D	C			A	A	A	
Morpholine	B		A		A	B		D	B	D		D	A			A	A	A	
Mustard	A	B	A		A	A		A		A		A	A			A	A	A	

Ratings: **A**-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Naptha	B	B	B		B	B	A	B	D	A	A	D	A	A		A	A	A	D
Napthalene	B	B	B		B	B	B	D	D	A	A	D	A	A		A	A	A	D
Natural Gas, Sour	B	B	A		A	D	A	A	D	A	A	A	A	A		A	A	A	A
Nickel Ammonium Sulfate	D	D	A		A	C		A	B	D	A	B	C	A	A	A	A	A	
Nickel Chloride	D	D	B		A	B	A	A	A	A	A	B	D	C		A	A	A	A
Nickel Nitrate	D	D	B		A	B		A	A	A	A	A	C			B	A	A	A
Nickel Sulfate	D	D	B		A	B	B	A	A	A	A	A	C	A		A	A	A	A
Nicotinic Acid	A	B	A		A	A		D	D	B		D	C			A	A	A	A
Nitric Acid 10%	D	D	A	A	A	D		C		A	A	B	D	D	A	A	A	A	A
Nitric Acid 30%	D	D	A	D	A	D		C	B	A	A	C	D	D	A	B	A	A	A
Nitric Acid 80%	D	D	A	D	A	D		D	D	B	A	D	D	D	A	C	A	D	D
Nitric Acid 100%	D	D	A	D	A	D		D	D	B	A	D	D	D	A	D	A	D	D
Nitric Acid Anhydrous	D	D	A	D	A	D		D	D	A		D	D	D		D	A	D	
Nitrobenzene	D	B	A		A	B	B	D	A	B	A	D	B	A	A	A	A	A	D
Nitrogen	A	A	A		A	A		A	A	A	A	A	A			A	A	A	A
Nitrous Acid 10%	D	D	B		B	D		C		A	A	A	B			A	A	A	
Nitrous Gases	D	B	A		A	D							B			A	A	A	
Nitrous Oxide	B	B	B		B	D	B	A	A	A		B	A	A		A	A	A	
Oils & Fats			A		A			B	D				A	A		A	A	A	
Oils, Animal	A	A	A		A	B	A	A	B	B		B	A	A		A	A	A	
Oils, Petroleum Refined	B	A	A		A	A	A	A	D	A	A	B	A	A		A	A	A	
Oils, Petroleum Sour	C	B	A		A	A	A	B	D	A	A	B	A	A		A	A	A	
Oils, Water Mixture	A	B	A		A		A	A		A	A	B	A	A		A	A	A	
Olaic Acid			B		B	A		D		C		D	C	A		A	A	A	
Oleic Acid	B	C	B		A	B	B	C	D	B	A	D	C	A		A	A	A	C
Oleum	C	B	B		B	C	B	D	D	A	A	D	D	D			A*	D	D
Oleum Spirits	D		B		B	D		B	D	A		C	D	D			A	D	
Olive Oil	C	B	A		A	A		A	B	A		B	A	A		A	A	A	A
Oxalic Acid	B	D	B	D	B	B		B	A	A		B	C	D	A	A	A	A	A
Oxygen	A	B	A	A	A	A	A	B	A	A	A	A	D	D		D	A	A	A
Ozone, dry	A	A	A		A	A	A	D	A	A		C	C	D	A		A	A	C
Ozone, wet	B	C	A		A	A	A	D	A	A		C	C	D	A		A	A	C
Paints & Solvents	A	A	A		A	A		D	D	B		D	A			A	A	A	
Palmitic Acid	B	C	B		B	B		A	B	A	A	B	A	D		A	A	A	
Palm Oil	B	C	B		A	A		B	D	A		B	A	A		A	A	A	A
Paper Pulp	B		A		A	B		B	B	B		B	A	A		A	A	A	
Paraffin	A	B	A		A	A	A	A	D	A	A	C	A	A		A	A	A	C
Paraformaldehyde	B	B	B		B	B		B	D		C	B	A			A	A	A	
Paraldehyde			B		B			B	D			B	A			A	A	A	
Pentane	A	B	A		A	B		A	D	A	A	B	A			A	A	A	
Perchlorethylene, dry	C	B	A		A	B	B	B	D	A	C	D	B	A		A	A	A	
Petrolatum (Vaseline Pet. Jelly)	B	C	B		A	A		A	D	A		B	A			A	A	A	A
Phenol	B	D	A	B	A	A	A	D	D	A	A	D	C	D	A	A	A	A	D
Phosphate Ester	D	A	A		A	A		D	A				A	A		A	A	A	
Phosphoric Acid 10%	D	D	D	B	B	D		A	A	A	A	B	D	D	A	A	A	A	A
Phosphoric Acid 50% Cold	D	D	B	B	B	C		B	B	A	A	B	D	D	A	A	A	A	A
Phosphoric Acid 50% Hot	D	D	D	D	B	C		B	B	A	A	B	D	D	A	A	A	A	A
Phosphoric Acid 85% Cold	D	B	A	C	B	A		C		B	A	C	D	D	A	A	A	B	A

Ratings: **A**-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Phosphoric Acid 85% Hot	D	C	B	D	B			C			A	C	D	D	A	A	A	B	A
Phosphoric Anhydride			A		A			D		B		D	B	D		A	A	A	
Phosphorous Trichloride		B	A		A			D	A	A		D	D	D		A	A	A	A
Phthalic Acid	B	C	B		B	A	B	C		A		C	B	A		A	A	A	
Phthalic Anhydride	B	C	B		B	A	A	C		A		C	A	A		A	A	A	A
Picric Acid	C	D	B	C	B	D	B	C	B	B		A	D	B			A	A	A
Pineapple Juice	C	C	A		A	A		A		A		A	A			A	A	A	
Pine Oil	B	B	A		A	B		A	D	A		D	A			A	A	A	D
Pitch (Bitumen)			A		A			C	D			C	A			A	A	A	
Polysulfide Liquor	D		B		A	B		B	B	B		B	D			A	A	A	
Polyvinyl Acetate	B		B		B	B			A		A	B	A			A	A	A	
Polyvinyl Chloride	B		B		B	B			B		A	C	A			A	A	A	
Potassium Bicarbonate			A		A	B		B			A		A			A	A	A	A
Potassium Bichromate			A		A	A		B		B	A	B	B			A	A	A	
Potassium Bisulfate			A		A	B		B		A	A	B	A			A	A	A	
Potassium Bisulfite	C	D	B		B	D		A	B	A	A	A	A			A	A	A	
Potassium Bromide	C	D	A	C	B	B		A	B	A	A	A	A			A	A	A	A
Potassium Carbonate	B	B	B	A	B	B		A	B	A	A	A	A			A	A	A	A
Potassium Chlorate	B	B	B	B	B	C		A	B	A	A	A	A			C	A	A	A
Potassium Chloride	C	C	B	B	A	B	B	A	A	A	A	A	A	A		A	A	A	A
Potassium Chromate	B		B		B	B		B	B	B	A	A	A				A	A	A
Potassium Cyanide	D	B	B		B	B	B	A	A	A	A	A	A			A	A	A	A
Potassium Dichromate	D	C	B		A	B		A	B	A	A	A	A		A		A	A	A
Potassium Ferricyanide	D	C	A	B	B	B		A	B	A	A	A	A			A	A	A	A
Potassium Ferrocyanide	B	C	B		B	A		A		A	A	A	A			A	A	A	A
Potassium Hydroxide Dilute Cold	D	A	B	B	B	A		A		D	A	B	D	B	A	A	A*	A	A
Potassium Hydroxide 70% Cold	D	B	B	C	B	A		B	B	D	A	B	D	B	A	A	A*	A	A
Potassium Hydroxide Dilute Hot	D	B	B	C	B	A		B			A	B	D		A	A	A*	A	A
Potassium Hydroxide 70% Hot	D	A	B	D	B	A		C	A		A	B	D		A	A	A*	A	A
Potassium Iodide	D	C	B	B	B	C		A	B	A	A	A	A			A	A	A	
Potassium Nitrate	B	B	B	B	B	B	B	A	A	A	A	A	A			B	A	A	A
Potassium Oxalate			A		A						A		A			A	A	A	
Potassium Permanganate	B	B	B	B	B	B	B	A	B	A	A	A	A		A		A	A	A
Potassium Phosphate	C		B		B	B	B	A	A	A	A	A	A	A		A	A	A	
Potassium Phosphate Di-basic	B	A	A		A	B	B	A	B	A	A	A	A	A		A	A	A	
Potassium Phosphate Tri-basic		A	B		B	B		B	B		A	B		A		A	A	A	
Potassium Sulfate	B	B	A	A	A	B		A	A	A	A	A	A	A		A	A	A	A
Potassium Sulfide	B	B	A		A	C	A	A	B	B	A	B	A	A		A	A	A	A
Potassium Sulfite	B	B	A		A	C	B	A	A	A	A	A	A	A		A	A	A	A
Producer Gas	B	B	B	A	B	A		A	D	A		B	A			A	A	A	
Propane Gas	A	B	B	A	A	B	A	A	D	A	A	B	A	A		A	A	A	A
Propyl Bromide	B		B		A	B		B	B	B		B	A			A	A	A	
Propylene Glycol	B	B	B		B	B		A	B	A	A	A	C			A	A	A	A
Pyridine			B		A			D	B	D	A	D	D		A	A	A	A	
Pyrolgallic Acid	B	B	B	B	A	B		A		A	A	A	A		A		A	A	
Quench Oil	B	B	A		A			A		A		B	A			A	A	A	
Quinine, Sulfate, dry			A	B	A	B					A		A			A	A	A	
Resins & Rosins	A	C	A	B	A	A		C		A		C	A	A		A	A	A	

Ratings: **A**-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Resorcinol			B		B											A	A	A	A
Road Tar	A	A	A		A	A		B	D	A		C	A			A	A	A	
Roof Pitch	A	A	A		A	A		B		A		C	A			A	A	A	
Rosin Emulsion	B	C	A		A	A		D		B		C	A			A	A	A	
R P-1 Fuel	A	A	A		A	A		A	D	A		B	A			A	A	A	
Rubber Latex Emulsions	A	B	A		A					A			A			A	A	A	
Rubber Solvents	A	A	A		A	A		D		D		C	C			A	A	A	
Salad Oil	B	C	B		A	B		A	B	A		A	A			A	A	A	
Salicylic Acid	C	D	A		B	B		B	A	A	A	A	A			A	A	A	A
Salt (NaCl)	B	C	B		A	A		A		A		A	A			A	A	A	A
Salt Brine	B		B		B	B		A	B	B		D	A	C		A	A	A	A
Sauerkraut Arine			B		B								C			A	A	A	
Sea Water	C	D	B		B	A		A	A	A	A	B	A	C		A	A	A	A
Sewage	C	C	B	A	B	B		A	A	A	A	B	B			A	A	A	A
Shellac	A	A	A		A	A		A			A	A	A			A	A	A	
Silicone Fluids	B		B		B			B		B	A	B	A		A	A	A	A	C
Silver Bromide			A	C	A	B					A		D			A	A	A	
Silver Cyanide	D		A		A	B		B		B	A	B	D			A	A	A	
Silver Nitrate 10%	D	D	A		A	D		B	A	A	A	A	A			B	A	A	A
Silver Plating Sol.			A		A							B	D				A	A	
Soap Solutions (Stearates)	A	A	A		A	A		A	A	A	A	B	A			A	A	A	
Sodium Acetate	B	C	B		B	B	B	B	A	D	A	B	A	A		A	A	A	A
Sodium Aluminate	B	C	A		B	B	B	A	B	A	A	A	A	A		A	A	A	
Sodium Benzoate			B		B	B					A		B			A	A	A	A
Sodium Bicarbonate	B	C	B		A	B		A	A	A	A	A	B			A	A	A	A
Sodium Bichromate			B		B			D			A		A				A	A	
Sodium Bisulfate 10%	B	D	A		A	B		A	A	A	A	A	D	A	A	A	A	A	A
Sodium Bisulfite 10%	B	D	A		B	B	B	A	A	A	A	A	D	A	A	A	A	A	A
Sodium Borate	B	C	B		B	B		A	B	A	A	A	A		A	A	A	A	A
Sodium Bromide 10%	B	C	B		B	B		A	B	A	A	A	A			A	A	A	A
Sodium Carbonate (Soda Ash)	B	B	A		A	B	B	A	B	A	A	A	A	A	A	A	A	A	A
Sodium Chlorate	B	C	B		B	C	B	A	B	A	A	A	A			B	A	A	A
Sodium Chloride	B	C	B		A	A	B	A	A	A	A	A	A	A	A	A	A	A	A
Sodium Chromate	C	B	A		B	B		A	B	A	A	A	A				A	A	
Sodium Citrate			B		B						A		A			A	A	A	
Sodium Cyanide	D	B	A	B	A	B		A	A	A	A	A	A			A	A	A	
Sodium Ferricyanide			A		A	B					A		A			A	A	A	A
Sodium Fluoride	C	D	B	B	A	B		A	B	A	A	A	A	C		A	A	A	A
Sodium Hydroxide 20% Cold	A	A	A	A	B	A		A	B	B	A	A	D	C	A	A	A*	A	A
Sodium Hydroxide 20% Hot	A	B	A	C	A	A		B	B	C	A	B	D	C	A	A	A*	A	A
Sodium Hydroxide 50% Cold	A	A	A	B	A	A		A	B	C	A	A	D	C	A	A	A*	A	A
Sodium Hydroxide 50% Hot	A	B	A	C	A	B		B		C	A	B	D	C	A	A	A*	A	A
Sodium Hydroxide 70% Cold	A	A	A	B	B	A		B	B	C		C	D	C	A	A	A*	A	A
Sodium Hydroxide 70% Hot	B	B	A	C	B	B		D	B	C		D	D	C	A	A	A*	A	A
Sodium Hypochlorite (Bleach)	D	D	D	D	C	D	A	B	A	A	A	B	D	B		A	A	A	A
Sodium Hyposulfite			B		B	B					A		A			A	A	A	
Sodium Lactate			A		A	B					A		A			A	A	A	
Sodium Metaphosphate	C	B	B	B	B		A	A	A	A	A	B	B			A	A	A	

Ratings: A-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Sodium Metasilicate Cold	B	C	A		A	A		B		B	A	A	A	A		A	A	A	
Sodium Metasilicate Hot	B	D	A		A	A	A						A			A	A	A	
Sodium Nitrate	B	B	A	B	A	B	B	B	A	A	A	B	A	A			A	A	A
Sodium Nitrite			B		B	C	B	C	A	B	A	D	B	A		B	A	A	A
Sodium Perborate	B	B	B	B	B	B	B	B	A	A	A	B	A			A	A	A	
Sodium Peroxide	D	C	B	B	B	B	B	B	A	A	A	B	A			A	A	A	
Sodium Phosphate	C	C	B	B	B	B	B	A	A	A	A	B	B	A	A	A	A	A	A
Sodium Phosphate Di-basic	C	C	B		B	B	B	A	A	A	A	A	A	A		A	A	A	
Sodium Phosphate Tri-basic	C	C	B		B	B	B	A	A	A	A	B	A	A		A	A	A	
Sodium Polyphosphate			B		B	B	B	B	A		A	B				A	A	A	
Sodium Salicylate			A		A						A		A			A	A	A	
Sodium Silicate	B	B	B		B	B		A	A	A	A	A	A	D		A	A	A	A
Sodium Silicate, hot	C	C	B		B	B			B				A	D		A	A	A	A
Sodium Sulfate	B	B	A	B	A	A		A	A	A	A	A	A			A	A	A	A
Sodium Sulfide	D	B	B	A	B	B		A	A	A	A	A	A	A		A	A	A	A
Sodium Sulfite	C		A	A	A	B	B	A	A	A	A	A	A	D		A	A	A	A
Sodium Tetraborate			A		A			A	B		A	A	A			A	A	A	
Sodium Thiosulfate	C	B	B	A	B	B		B	A	A	A	A	A	A		A	A	A	
Soybean Oil	B	C	A		A	A		A	C	A		C	B			A	A	A	A
Starch	B	C	B		A	A		A	C	A	A	A	A			A	A	A	A
Steam (212°F)	A	A	A	A	A	B		D	B	D	A	D	D			A	A	A	A
Stearic Acid	C	C	B		B	B	A	B	B	A	A	B	A	A		A	A	A	A
Styrene	A	A	A		A	B	A	D	D	B	A	D	A	A		A	A	A	
Sugar Liquids	A	B	A		A	A		A	B	A		A	A	A		A	A	A	A
Sugar, Syrups & Jam	B		A	A	A							B	A			A	A	A	A
Sulfate, Black Liquor	C	C	B	A	B	B		C	B	C	A	B	C			A	A	A	
Sulfate, Green Liquor	C	C	B	A	B	B		C		C	A	B	A			A	A	A	
Sulfate, White Liquor	C	C	B	B	D	C		C		C	A	B	D			A	A	A	
Sulfur	D	C	B		A	B		D	A	A	A	A	A	C		A	A	A	A
Sulfur Chlorides	B	D	D		A	B		D	D	A	A	D	A			A	A	A	
Sulfur Dioxide, dry	B	B	A	A	B	B	A	D	A	D	A	D	A	A		A	A	A	A
Sulfur Dioxide, wet	D		A	C	B	A	B	D	A	D	A	B	D			A	A	A	A
Sulfur Hexafluoride	B		A		A						C	B	A			A	A	A	
Sulfur, Molten	D	C	B		A	D	B	D	C	A		C	D			D	A	A	
Sulfur Trioxide	B	B	B	B	B		B	D		B	A	D	D			D	A	A	
Sulfur Trioxide, dry	B	B	B	B	B	B	B	D	B	A	A	D	A	A		D	A	A	
Sulfuric Acid 0 to 77%	C	D	C		B	B		B		A	A	B	D	D	A	A	A	A	B
Sulfuric Acid 100%	C	C	A	B	A	D		D	C	B	A	D	D	D	A	D	A	D	D
Sulfurous Acid	D	D	B		B	D	B	B	B	A	A	B	C	D		A	A	A	A
Tall Oil	B	B	B		B	B	A	B	D	A		B	A	D		A	A	A	
Tannic Acid (Tannin)	B	C	B	B	B	B	B	A	A	A	A	B	A	A		A	A	A	A
Tanning Liquors			B		B			B				D	D				A	A	
Tar & Tar Oils	A	A	A	A	A	A		B	D	A	A	C	A			A	A	A	
Tartaric Acid	B	D	A	A	A	B	B	A	B	A	A	B	A			A	A	A	A
Tetraethyl Lead	B	C	B		B	A		B	D	A		B	A			A	A	A	
Toluol (Toluene)	A	A	A		A	A	A	D	D	A	A	D	C	A	A	A	A	A	D
Tomato Juice	C	C	A		A	B		A		A		A	A			A	A	A	
Transformer Oil	B	A	A		A	A		A	D	A		B	A			A	A	A	C

Ratings: **A**-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®

Fluid Compatibility Table

	Brass	Carbon Steel	316 Stainless Steel	17-4PH®	Carpenter 20®	Monel®	Hastelloy C®	Buna N (Nitrile)	EPDM/EPR	Viton®	Kalrez®	Neoprene	Delrin®	Nylon	Kel-F®	Grafoil®	Teflon®	Peek®	UHMWPE
Tributyl Phosphate	A	A	A		A	A		D	A	D	A	D	A	A		A	A	A	
Trichlorethylene	B	B	B	A	B	B	A	C	D	A	B	D	A	A	C	A	A	A	D
Trichloroactetic Acid	B		D		B	B	A	B	B	C	C	D	D		A		A	A	C
Triethanolamine			B		B	B	A	C	B		A	B	A			A	A	A	C
Triethylamine	B		B		B		A	B			A	B	C				A	A	
Trisodium Phosphate			B		B		A	A	B	B		A	A			A	A	A	A
Tung Oil	B	B	A		A	C	A	A	D	A		B	A			A	A	A	
Turpentine	B	B	B	A	B	B	A	A	D	A	A	D	A	A		A	A	A	D
Urea	B	C	B		B	B	A	C	B	D	A	B	A			A	A	A	A
Uric Acid			A		A		A				A		B			A	A	A	
Varnish	A	C	A		A	A	A	B	D	A	A	D	A			A	A	A	
Vegetable Oils	B	B	A		A	B	A	A	C	A		C	A			A	A	A	
Vinegar	B	D	A		A	B	A	B	B	C		B	B			A	A	A	A
Vinyl Acetate	B		B		B	B	A		A		A	B	D	A		A	A	A	
Water, Distilled	A	D	A	A	A	A	A	A	A	B	A	B	A			A	A	A	A
Water, Fresh	A	C	A	A	A	A	A	A	A	B	A	B	A	C		A	A	A	A
Water, Acid Mine	D	D	B	B		D	C	B	A	D	A	A	A			A	A	A	A
Waxes	A	A	A		A	A	A	A	C	A		B	A			A	A	A	
Whiskey & Wines	B	D	A		A	A	A	A	A	A		A	A	A		A	A	A	A
Xylene (Xylol), dry	A	B	A		A	A	A	D	D	A	A	D	A	A	A	A	A	A	D
Zinc Bromide	B		B		B	B	A	B	B	B		B	A			A	A	A	
Zinc Hydrosulfite	C	A	A		A	B	A	A	A	A	A	A	A				A	A	
Zinc Sulfate	B	D	B		A	B	A	A	A	A	A	A	A			A	A	A	A

Ratings: A-Satisfactory **B**-Fair **C**-Poor **D**-Unsatisfactory **Blank**-No Information *Unsatisfactory with Reinforced Teflon®