How Safe are Fire-Safe Valves?

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In recent years, specification of fire-safe valves has been increasing. Ideally, a "fire-safe" valve will be leak-free at normal service temperatures and during and after a fire. Yet, these valves permit a small amount of internal and external leakage, and stem and packing leakage, when subjected to fire. The term "fire-safe" is ambiguous. Thus, the valve specification engineer must know fire-test standards, real expectations, advantages and disadvantages, and the future liability associated with fire-safe valves. He must be familiar with the pitfalls of using them in an application where a standard, non-fire-safe valve would do better. The engineer should know what steps assure fire safety when a system really does require fire protection.

Typical designs

Fire-safe, meaning that the valve will control leakage to an acceptable level after damage, applies only to conditions encountered after the fire. Until that event—which could be several years after the valve installation, or most likely never—the valve must perform as well as a standard non-fire-safe valve under everyday operation.

A fire-safe valve uses *dual-seat* sealing to contain through-seat leakage before, during, and after the valve is subjected to fire (see Figures 1 and 2). The first seat (also known as the primary seat) is made of "soft" plastic materials, such as polytetrafluoroethylene (PTFE) or other elastomers. The second seat (also known as the secondary metal seat) is usually made of stainless steel or Inconel® (Ni-Cr-Fe alloy). These seats make contact with a metal closure member, also called a disc, ball or plug.

The primary seat assures a tight (zero leak) seal during normal service. The secondary metal seat allows minimal through-seat leakage at the high temperatures encountered during a fire. During normal service, the secondary metal seat may or may not keep contact with the closure member. However, after disintegration of the primary seat during a fire, the secondary seat must contact the closure member to provide the necessary sealing.

The stem packing usually consists of rings made from asbestos or graphitic materials to provide stem sealing. These materials can keep a tight seal at temperatures up to 1400°F. Body joints (such as bonnet-to-body) use gaskets made from asbestos or graphitic materials such as Grafoil®.

The closure member is usually chrome or electroless nickel plated (ENP) to provide a galling-free surface against the secondary metal seat. Sliding surfaces may also be coated with a dry film lubricant, such as moly-disulfide or other high temperature resistant materials, to reduce friction.

Test standards

To be labeled "fire-safe" (and also to seek name recognition), a valve is typically subjected to tests based on one of the fire-test standards as shown in Table 1. The standards make no attempt to describe fires, but they do attempt a prediction of fire-safe valve operation at extremely high temperatures.

Fire-safe standards vary significantly in testing procedures and acceptance

Summary of test specifications.**				
Test Specification	**OCMA FSV.1**	**Exxon BP3-14-1**	**API 607 Third Edition**	**FM 6033**
Stem position	Vertical	Vertical	Horizontal	Not specified
Bore position	Horizontal	Horizontal	Horizontal	Not specified
Valve open or shut	Open	Open	Shut	Shut
Test pressure during burn	30 psi	25 psi	Depends upon valve pressure rating	125 psi
Test media	Kerosene or diesel fuel	Liquid hydrocarbon	Water	Not specified
Valve body temperature	Sufficient to destroy soft seat	1200°F minimum	130°F minimum	Not specified
Burn duration when seat leakage measured	15 min. after test	15 min. after test	30 min. during test and after test	15 min. during test
Maximum external leakage	No appreciable leakage	Leakage shall be negligible	200 ml/min in. diameter	0.1 qt/min (94.6 cc/min)
Maximum seat leakage	10 ml/min/in. diameter*	10 ml/min/in. diameter*	400 ml/min/in diameter	Individual drops
Operability	3 cycles open to shut	3 cycles open to shut	1 cycle open to shut	Must be operable

*In no case shall leakage rate exceed 100 ml/min.
**Based on the table from Lyon's Valve Designers Handbook, Jerry L. Lyons, Van Nostrand Reinhold Co., 1982.
***OCMA, API and FM designate Oil Companies Mutual Association, American Petroleum Institute and Factory Mutual, respectively.

requirements. There is no uniformity in specifying stem position, pressures, media, duration of burn, or permissible leak rates. It is conceivable that a valve which passes the test from one standard may fail the fire test from another.

Not all of the standards mandate an independent third-party certification, random sampling, or a sample size which must pass the fire tests for qualification. A valve manufacturer could conduct a valve test with no outside witness and fail all valves until one passes (which would be an anomaly), thus allowing the manufacturer to label his product fire-safe.

Design deficiencies: high torque

A fire-safe valve has an inherent operating torque from 1½ to 2 times the operating torque required by a similar non-fire-safe (soft-seated) valve. Additional operating torque is required to "break loose" the metal closure member from the secondary metal seat. The coefficient of friction between this metal-to-metal seating can be up to ten times the coefficient of friction between the primary soft seat and the closure member. Higher operating torques force the fire-safe valve manufacturer to mount oversize actuators or larger handles (levers), making the valve-actuator assembly bulky and expensive.

Directional sealing

When specifying fire-safe valves, address the issue of bi-directional sealing. Is it really a necessary sealing requirement? If yes, then ask if the specified valve is *truly* bi-directional. Almost all soft-seated high performance butterfly valves (HPBV) seal fluids bi-directionally (in either direction of flow) at ambient temperatures (the soft PTFE seat seals nicely below 350°F). The user may assume that if the standard soft-seated HPBV is bi-directional, so is the fire-safe HPBV. This assumption may be far from the truth. These valves work fine in both directions under normal non-fire situations. Yet most fire-safe HPBVs perform poorly in *one* direction during or after a fire. Generally, these valves leak when the valve seat retainer faces the high pressure side of the line medium.

Fluid pressure in the pipeline acts behind the closed disc and pushes the

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Unlike non-fire-safe valves, fire-safe valve construction mandates that parts be machined and assembled with extreme precision.

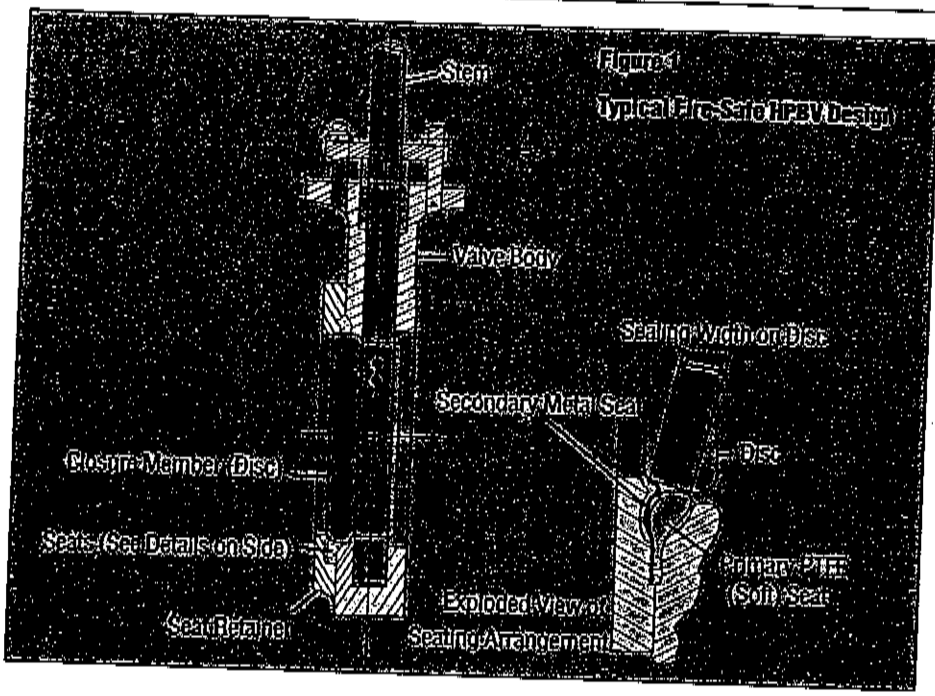

Figure 1
Typical Fire-Safe HPBV Design

disc away from the secondary metal seat. The disc moves due to stem deflection, bearing clearances, etc. The metal seat, which is contained in a narrow seat retainer/body cavity, has limited flexibility and cannot "follow" the disc to maintain an effective contact with the disc.

Few fire-test standards address the issue of bi-directional testing. Some manufacturers fire-test their valves in only one direction and fail to put the "directional arrow" on the valve body. The valve installer is never made aware of such limitations and may install the valve in the wrong direction. Such a valve works fine in both directions of flow during normal service, but may fail in the non-fire-tested direction under fire situations.

Reduced service life

Fire-safe valves need a hard sealing surface on the closure member to mate effectively against the relatively softer secondary metal seat. Differential of hardness between the mating parts is needed to reduce the possibility of galling wear. Typically, the hard sealing surface is achieved by plating—the most common is "hard chrome" or "ENP." The contact seating loads between the closure member and the secondary metal seat are so high (especially when the valve is operated at higher pressures), that sometimes the plating gets stripped off the base metal during opening and closing of the valve. The result is deep scratches in both the metal seat and the closure member. When the plating peels off, the base metal is exposed to corrosion by the line medium, because the base metal is often a less noble metal. Furthermore, when the primary soft seat rubs against this scratched and often corroded closure member, the soft seat also gets scratched severely. Deep nicks are often formed. A hairline scratch in the soft elastomeric seat may be enough to cause an unacceptable through-seat leak under normal operating service. The leak worsens with further cycling of the valve, thus shortening the life of the valve.

Unlike the simple replacement of the soft seat in a conventional soft-seated valve, it is tedious and sometimes impossible to replace the metal seat or the closure member. Many metal seats need custom lapping, and the closure member is often attached to the valve stem by pins which are tack welded. The tack welding has to be removed to replace the closure member. At times, it is cheaper to replace the entire valve.

Precise tolerances

Unlike non-fire-safe valves, fire-safe valve construction mandates that parts be machined and assembled with extreme precision. The secondary metal seat has limited resiliency compared to the soft seat. The resiliency is required for the sealing members to seal every time the valve is cycled open-shut-open, or pressurized-depressurized. To seal, sufficient contact loads must be maintained between the sealing members at all times. The inside diameter of the metal seat, the outside diameter of the closure member, and the relative locations of the metal seat and the closure member in the valve body need precise tolerances. The metal seat or the closure member may require lapping and assembly as a matched set to insure a full 360° contact. Consequently, a slight mismachining of parts may result in gross leakage under fire situations. Thus, a fire-safe design is inherently sensitive to part tolerances. Unfortunately, a mismachined part can go undetected during valve assembly and testing, because a typical production valve is only tested for through-seat leakage at room temperature. Such a test would only test the sealing capability of the primary soft seat. One would never know if the secondary metal seat would provide the necessary seal when needed—until the valve undergoes a fire.

A true test of the secondary metal seat would require an additional test by first assembling the valve with the secondary metal seat only (omitting the primary soft seat), and then conducting the through-seat leakage test by subjecting the valve to an appropriate test pressure at ambient temperature. Such a test would be time consuming, and it is doubtful that many fire-safe valves would pass. Many secondary metal seats are designed to contact with the closure member only after the disintegration of the primary soft seat. It is impossible to know at assembly time whether this seat would contact the closure member during a fire.

Valve-actuator connection

Certain fire-safe valves require extremely precise alignment of the closure

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The fire-safe valves which maintain an all-out contact between the secondary seat and the closure member during all times suffer a drawback.

member with the secondary metal seat. If the valve stem is slightly out of rotation, the closure member will not contact the secondary metal seat.

For instance, the closure member (disc) of a HPBV is designed to a minimum sealing width necessary to minimize the obstruction to the flowing medium (see Figure 1). Usually the width is adequate for seating the soft seat in a non-fire-safe HPBV. However, on fire-safe HPBVs, this width on the closure member is extremely narrow when *both* the primary and secondary seats are seated. A slight rotation of the valve stem can dislodge the seats from the closure member and cause a leak.

The manual handle (lever) or the actuator must be mounted with extreme position accuracy to assure precise alignment of the seating surfaces. Since proper alignment depends upon precise positioning of the stem-disc connection, actuator-valve coupling, actuator mounting bracket, and the actuator internal travel stop, a slight deviation of machine-tolerancing of parts can result in a buildup of tolerances—enough to dislodge the secondary metal seat from the disc. Deviations can go undetected in production, until it is too late to find and fix the problem.

Partial destruction of primary seat

Sealing success during fire in some valve designs relies on *complete* destruction of the primary soft seat. Standard fire tests prescribe sufficient time to ensure the complete destruction of the primary seat. During a real fire, the complete destruction of the primary soft seat may never happen, especially if the fire lasts only a few minutes. If the line medium in the valve is flowing, it may carry enough heat so that only a partial circumference of the primary seat is destroyed. Under such situations, the secondary metal will not fully seat around the closure member, and the valve will leak.

The fire-safe valves which maintain an all-out contact between the secondary metal seat and the closure member during all times suffer a drawback. Such a design normally requires maintaining extremely high seating loads at all times (the metal seat may be spring-loaded), which may result in high operating torque, excessive wear between seating elements, or shortening of the service life as described earlier.

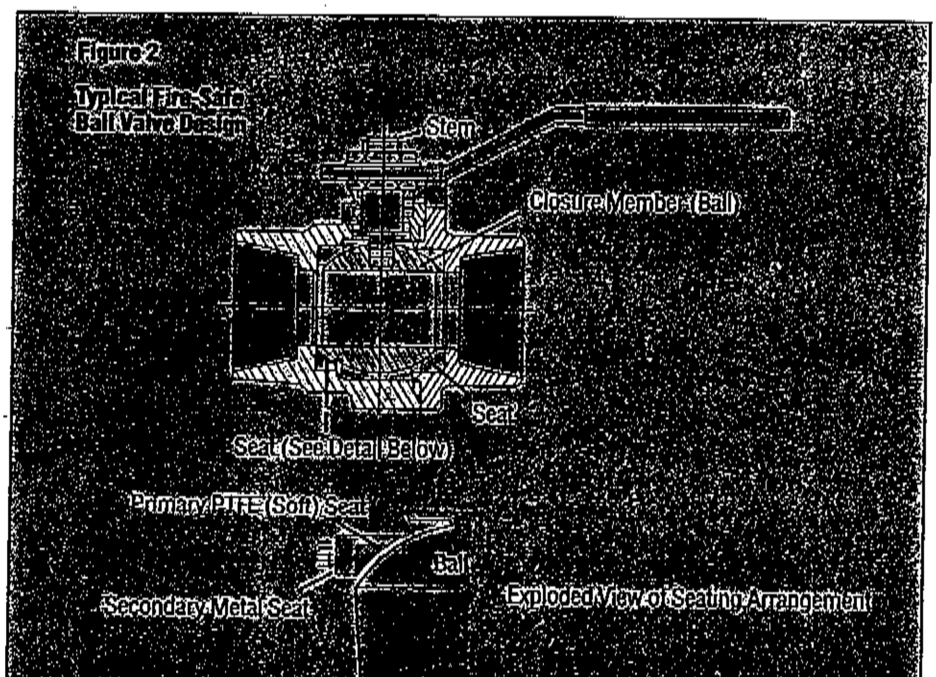

Figure 2
Typical Fire-Safe Ball Valve Design

Solids entrapment

In some fire-safe valves, a narrow cavity is designed into the valve body/seat retainer, behind the secondary seat, to give room for flexing of the metal seat. This cavity is highly prone to entrapment of suspended solids flowing in the line medium. With time, solids completely fill the cavity, and the metal seat cannot flex. The result is extremely high torque, or possibly an inoperable valve. Entrapped solids are impossible to flush out and may lead to contamination of the line medium. No simple solutions exist to broaden this cavity because of a lack of room in the seating area of the valve body. This may call for increasing the valve end-to-end dimensions beyond the standard end-to-end dimensions.

Stem corrosion

Most fire-safe valves use a graphitic-based stem packing to contain stem leakage at high temperatures. The most common packing arrangement is three or four rings of die-formed graphite ribbon, sandwiched between top and bottom rings of braided carbon fibers. The graphite rings are susceptible to extrusion from the stuffing box. Therefore, the braided carbon rings are needed to prevent extrusion.

Although graphite is fairly inert to most line media, stem problems due to galvanic corrosion in the packing gland area have been reported. Some success in reducing this corrosion has been achieved by using nobler stem materials, plating the stem with chrome or ENP or coating the graphite rings with zinc (commonly known as zinc dusting). The zinc in the graphite acts as a sacrificial material and corrodes first, leaving the stem surface undamaged.

However, the length of time the zinc lasts in the packing is unknown. It may be consumed by the line medium. Before the popularity of graphite packing, environmentally hazardous asbestos was the material of choice at high temperatures. Valve manufacturers have been left with no other choice but to use Grafoil®.

Materials

Most of the fire test standards, such as API 607, let a valve manufacturer "qual-

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No test standards exist for the safe operation of valve actuators mounted on fire-safe valves.

ify" valves of a given metallurgy, even though the materials have never been subjected to a fire test. API 607 states, ". . . in lieu of testing each size and class of a given valve design, other valves of the same basic design as the test valve and of the same *non-metallic* materials with respect to the seat-to-closure member seal, seat-to-body seal, stem seal, and body joint and seal may be qualified . . ."

The standard overlooks the possibility of leakage between the secondary metal seat and the closure member resulting from the differing high temperature behaviors of different *metallic* materials of construction. For instance, a valve made of stainless steel may pass the fire test. However, it may distort and fail the fire test if made from a material like bronze, which has a lower melting temperature.

All components in a piping series must perform:

Actuators

No test standards exist for the safe operation of valve actuators mounted on fire-safe valves. Many actuators fail at fire temperatures, because of their design materials. Power-operated actuators will lose piston O-rings. The internal gearing mechanisms which are typically made of bronze will either melt or deform grossly. Internal lubricants evaporate or disintegrate, and the actuator handwheel may melt. Only recently have some manufacturers started making fire-resistant actuators. The problem is that many users buy the actuators separately from the valves, and fail to specify high temperature requirements for the actuator. The test standards for fire-safe valves do not require measurement or acceptance criteria for the maximum operating torque requirement of the valve under fire conditions. The torque after a fire invariably goes up as the mating surfaces, such as the metal seat/closure member and stem/bearings, soften, and the lubricants disintegrate. Some parts may be severely deformed to the point that they cease to function. The actuator must provide a sufficient margin of safety for added torque.

Pipe flanges, gaskets

Pipe flanges and gaskets can be one of the most neglected, yet most important, aspects in the overall piping design. Fire-safe equipment needs fire-safe pipe flange gaskets. Often, non-fire-safe sheet gaskets (PTFE, rubber, felt) are inadvertently specified in fire situations. Like soft seats in fire safe valves, these gaskets disintegrate at fire temperatures. The result is a gross leak in the pipe-valve joint. Spiral wound, graphite-filled gaskets have been successful under fire conditions. However, these gaskets require the right surface finishes on both the valve and pipe flanges. Most spiral-wound gasket manufacturers recommend mating surface finishes between 125 and 250 rms. Extremely smooth (below 100 rms) or coarse (above 500 rms) surface finishes do not provide effective seals.

Bolting

Most bolts made of carbon steel or low alloy steel lose their bolting loads at fire temperatures due to stress relaxation (elongation), resulting in flange gasket leakage. Bolts made of high temperature materials, such as SS 17-4 PH, have been successful. To insure adequate residual flange gasket loads during and after a fire, bolts must be tightened up to 50% more than needed for non-fire-safe-applications.

The bolt stress relaxation can also be reduced by either providing a jacket of insulation to the exposed bolt lengths, or embedding the bolt in the valve body. Many HPBV manufacturers recommend that lug style valves be used instead of wafer styles.

Recommendations

- If the equipment does not absolutely require fire protection, then do not specify a fire-safe valve. A soft-seated, non-fire-safe valve gives trouble-free service for a much longer life at a much lower cost.
- If a fire-safe valve is specified, expect that it may leak about 500 or more cc/min/in of valve size during or after a fire. The unusually low acceptable leak rates in fire test standards are based upon testing a brand new valve. The secondary metal seat takes a permanent set during valve cycling, and results in greater leak rates after a period of time, although the leak is undetected as long as the primary soft seat continues to provide an effective seal.
- Under most situations, 500 cc/min/in of through-seat leakage will not cause a larger fire which might lead to additional damage to the surroundings. For example, locations with valves containing explosive fuel need to be assured that the valves will not leak *externally* to feed the fire, and a small amount of internal leakage may be tolerated.
- Do not rely on the successful operation of the valve handle (lever) or the actuator during or after a fire. The power supply to the actuator may be unreliable under such circumstances.
- To prolong sealing member life, limit use of fire-safe valves to applications where frequent cycling is not required.
- Consider installing a semi-fire-safe valve in series with a regular fire-safe valve. A semi-fire-safe valve is essentially an all soft-seated valve which is constructed similarly to a regular fire-safe valve, with the exception that there is no secondary metal-to-metal seat. Although such a valve will not provide through-seat leakage protection at fire temperatures, it will maintain a tight through-seal at its normal service temperatures and will prevent the line medium from spilling out of the valve body. The regular ~~fire-safe backup valve~~ will provide the service during fire.
- Consider witnessing the fire tests and setting your own acceptance criteria on the sample size of valves for fire-testing. The test samples should be random, preferably picked from the manufacturer's stock of production valves.
- All-metallic gate and globe valves may ordinarily be considered "fire-safe" because of their metal-to-metal sealing design. They are rugged and reliable. Since the previously listed fire test standards allow a small amount of leakage, gate and globe valves may satisfy fire-safe requirements but may not provide the *positive* shutoff required in normal operation. These valves may be considered for applications not requiring positive shutoff during normal operations. ■

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