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The Connection Bulletin for The Flexial Reactive Seal™

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THE FLEXIAL REACTIVE SEAL™

Guy A Jolly, P.E.
Chief Engineer
Vogt Valve Division
Vogt Valves
and
Richard A. Larsen, P.E.
President
Flexial Corporation
Cookeville, Tennessee

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A NEW CONCEPT IN ZERO FUGITIVE EMISSIONS

THE AUTHORS

Guy Jolly is Chief Engineer of the Valve Division of Vogt Valves. He is a registered professional engineer in the State of Kentucky. He holds a BS degree in Mechanical Engineering from the University of Kentucky and a MA degree in Mathematics from the University of Louisville.

He is active in the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), and the Manufacturing Standardization Society of the Valve and Fitting Industry (MSS). He currently serves as Vice President of MSS.

Rick Larsen is President and founder of Flexial Corporation, and developer of the Flexial Reactive Seal.' He holds a Bachelor of Science in Engineering from Florida Technological University (now University of Central Florida), is a registered professional engineer in the State of Florida. He has been awarded seven U.S. and foreign patents related to welded metal bellows with several more in application for the Flexial Reactive Seal™.

Prior to starting Flexial Corporation, he began Robertshaw Tennessee's welded bellows operation, and managed it for five years. Before that he held positions as manager of development engineering, engineering manager, and manager of special products, all related to welded bellows. He is a member of the External Advisory Board, Center for Manufacturing Research, Tennessee Technological University.

INTRODUCTION

Federal regulations for reduced equipment leaks from valves and other apparatus have prompted the development of a radically new type of zero emission seal for rising stem valves. When Flexial Corporation presented its seal to Henry Vogt Machine Company in 1993, Vogt recognized the seal's potential and began to offer direction to Flexial toward compliance with industry standards. In 1994, when Flexial was awarded two Federal grants to develop the seal, Vogt agreed to participate, furnishing 3-inch, Class 600, API-602 gate valves and custom parts to Flexial to help put the seal under test.

The Flexial Reactive Seal™ offers a unique new way of blocking emissions while allowing the freest possible stem motion through the bonnet. Key to the seal's performance is a method for passively pressure balancing a relatively small, light welded bellows hermetic seal, while the pressure load is transferred to a secondary pressure seal capable of handling extremely high pressure. Tests conducted to demonstrate compliance with API, MSS and EPA Method 21 standards have given highly predictable and stable results with extremely long life and no leakage whatever.

BEGINNINGS

The Flexial Reactive Seal™ was conceived in 1993 by Rick Larsen who presented the concept to a number of valve companies with minimal response until the technology was reviewed by representatives of the Henry Vogt Machine Company. Recognizing the potential for presenting its customers with a new method of compliance with upcoming regulations under the Clean Air Act Amendments of 1990- the HON and Title V-Vogt engineers began offering guidance to Flexial to develop the seal in compliance with industry standards. Proprietary drawings were shared so that the seal could be designed into a real valve application for review and a look at pricing.

FEDERAL GRANTS

In July, 1994, Flexial Corporation was awarded a Small Business Innovation Research (SBIR) grant from the Department of Defense Advanced Research Projects Agency (ARPA) under President Clinton's new Technology Reinvestment Project. Flexial sought Vogt as a partner and Vogt agreed to participate along with Phillips Laboratory and Tennessee Technological University's Center for Manufacturing Research. The results of this proof-of-concept effort met or exceeded all projections, proving that a bellows could be passively pressure balanced and made to react to changing pressure and temperature conditions without itself being a pressure barrier.

In September, 1994, Flexial received a

THE FLEXIAL REACTIVE SEAL™

grant from the EPA to do refinements of critical components within the seal. Flexial designed the test apparatus around the seals used in the valves supplied by Vogt for the ARPA tests, and gained a six-fold improvement in performance over the earlier tests, making the seal even more reliable for a zero-emission seal in a rising stem valve. Since these grants were finished in early 1995, the EPA's National Risk Management Research Laboratory in Research Triangle Park, N.C., has applied to EPA Washington for an Environmental Technology Initiative grant for additional development of the seal. In their study, they projected that the seal "...could significantly impact air toxic emissions of 523,000 tons per year from equipment leaks."

In April, 1995, ARPA invited Flexial to apply for a coveted Phase II SBIR grant to do field testing of the seal in a variety of environments and valve types. Vogt and Flexial will continue its partnership in extended testing of the seal. Only the most critical of valve designs receive such a broad program of testing, but Flexial and Vogt agree that only through such responsible activity can they assure the customer a truly reliable product.

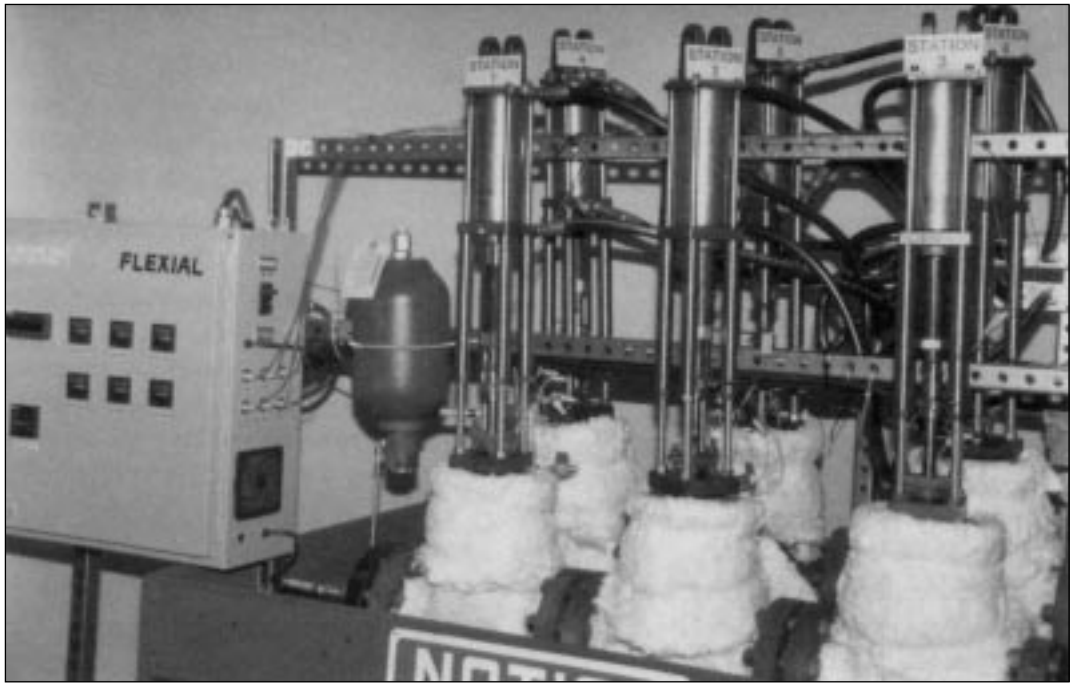
TECHNICAL DISCUSSION

The Flexial Reactive Seal™' is a unique synergy of two technologies:

- The metallic bellows
- The spring-energized seal

either of which might raise reactions ranging from skepticism to outright rejection. But since its development, even some of the industry's most recognized and outspoken critics against bellows have spoken favorably about the concept. Each of these technologies has serious and well-documented problems that have prevented their widespread acceptance, even in a time when Federal regulations are mandating vastly improved sealing methods.

The metallic bellows has historically been associated with high cost, but without a proportional improvement in reliability. While it is a zero leakage seal, its sensitivity to pressure and the unpredictability of the pressure variable from application to application, has attached a stigma to the metallic bellows as evidenced by various papers presented at a number of the Valve



Six Flexial Reactive Seals™ under life test in Vogt 3-inch, API-602 forged steel gate valves at 1250 psi and 425°F. Test sponsored by Advanced Research Projects Agency.

THE FLEXIAL REACTIVE SEAL™

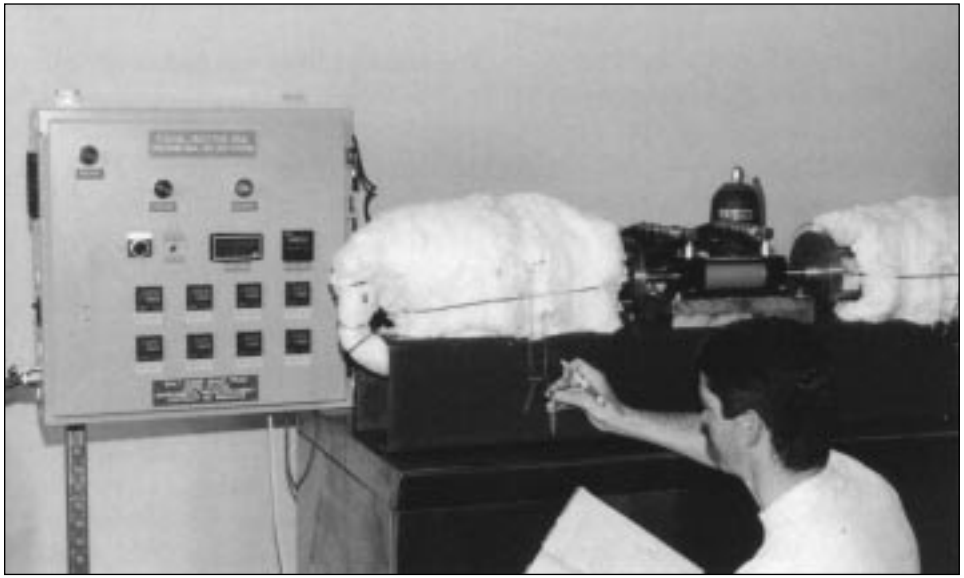
Manufacturers Association's Fugitive Emissions Conferences.

The spring energized seal has decades of excellent performance in clean hydraulic applications where it can give hundreds of thousands of practically leak-free cycles. But for petrochemical valve seal applications, the spring-energized seal is virtually unused. Even the smallest pitting or corrosion of the mating metallic surface, when passed through the seal, results in permanent scoring and leakage.

But these two unlikely technologies combine to offer a seal with an array of timely advantages, not the least being a completely leak free seal with extremely long and predictable life. We will examine the principle behind the seal, then look at its construction, and finally its performance.

Water balloon analogy

If the reader will bear with us, we would like to resort to a bit of simple hydraulics that will get us through the technical concept rather quickly. Let us fill a balloon with water so it is just full, but not distended. The pressure of the water in the balloon is now one atmosphere. It's a small balloon, so we will disregard the difference in head pressure. Now let us submerge the balloon in a deep lake to about 1000 feet. The depth has raised the pressure outside the balloon to around 430 psi. A gage inside th balloon shows the pressure of the water inside to be exactly the same as the pressure outside. And the balloon itself is essential unchanged in size or shape, and is just as flexible as if it were near the surface. (Technically, it is 0.1% smaller because water is not completely incompressible.) The reason the balloon is unchanged is because the flexibility of its wall allows pressure t transfer passively to the water inside, offering an equal and opposing force. The Flexial Reactive Seal™ maintains this same state of passive pressure balance across the bellows wall by much the same method. Given this analogy, we will now look at the construction of the seal.



Eight spring energized lip seals undergo life testing at 425°F and 1250 psi, 2 inch travel each direction. Program sponsored by an SBIR grant from the EPA.

CONSTRUCTION

One of the principal differences between the Flexial Reactive Seal™ and the balloon is that while the balloon is flexible in all directions, the metallic bellows is flexible only along its central axis. The bellows can accept axial load, but attempting to apply pressure radially only accelerates failure, and is the reason bellows do not perform well under heavy differential pressure.

Working within the physical properties of the bellows requires a design that is somewhat different from the normal bellows seal. To explain the configuration, we will refer to the drawing in the center of this document.

As shown on the left side of the drawing, the seal is a complete module with no serviceable parts, with the possible exception of the graphite packing used for firesafing. In this view, the bonnet extension has been removed for clarity, but it can be seen in the assembly drawing. We will now look

THE FLEXIAL REACTIVE SEAL™

at the various components, highlighting the nonstandard ones for clarity.

Seal Bellows
Same as for a conventional valve. It is welded to the stem at one end, and compresses and expands with motion of the stem. But this is as far as the familiarity goes. At the other end, the seal bellows is welded to the midplate rather than the bonnet.

Midplate
This is new. The midplate is a washer-shaped disk that is welded to the seal bellows at its I.D., and to the counterbellows at its O.D. This is the surface through which we transfer pressure from the process fluid on the outside to the pressure equalizing fluid on the inside. The midplate moves axially in countermotion to the seal bellows and stem: When the stem rises and the seal bellows compresses, the midplate moves in the opposite direction as governed by the counterbellows.

Counterbellows
Also new, the counterbellows completes the hermetic seal path between the stem and the bonnet. But the counterbellows is more than a seal, it is an acute addition to this new invention, serving also as a reservoir, a volume compensator and a temperature compensator. We will look at the counterbellows in more depth in the section on performance.

Equilant[1]
This fluid is contained permanently within the seal to pressure balance the walls of the seal bellows, the midplate and the counterbellows. It can be any liquid compatible with th stem sealing surface and the spring energized lip seal and which can handle the overall operating environment such as temperature. In Vogt valves the equilant is typically a mineral oil heat transfer fluid such as Paratherm NF.

Spring energized seal
Referred to as the 'lip seal' on the drawing, this is the pressure barrier for the Flexial Reactive Seal™. It is a critical component, and as such, it has undergone extensive development. It and its mating stem surface were the objects of test under the EPA grant mentioned at the beginning of this paper, and have undergone continued refinement since the conclusion of the formal EPA tests, using the test apparatus. The seal is rated at 22,500 psi at 400°F with a maximum operating pressure of 30,000 psi. As this is at least a decade more than the operating pressure experienced in petroleum refining and chemical processing, it becomes apparent why there is little concern for damage of the Flexial Reactive Seal™ by unusual pressure operating conditions as there would be if the bellows were the pressure barrier.

We mentioned earlier that this type of seal performs well in non-corrosive environments. One of the unique characteristics of the Flexial Reactive Seal™ is that the spring energized seal is always immersed in the equilant which is contained by the bellows. The bellows protects this seal, and the seal surface of the stem that runs through it, from the corrodants of the process fluid. When the valve is open, and the stem is outside of the seal, it is still fully contained within the bonnet and shielded from atmospheric corrosion by the packing.

The spring energized seal is a major contributor to the high performance of the Flexial Reactive Seal,TM. but it does have a weakness. Because it is a PTFE compound, it cannot withstand very high temperatures that would be experienced in a fire. For this reason, we have a tertiary backup seal at the top in the form of standard graphite packing.

Graphite packing
This is conventional, high temperature, flexible graphite packing used in API-602 valves and tested per API-589 for fire testing of valve seals. As with conventional bellows valve seals, the packing serves no real function unless we experience failure of the zero emission seal. In the case of the Flexial Reactive Seal™, this is not likely to come from fatigue failure as with conventional bellows, but only from fire temperatures that could cause the spring energized seal to fail.

Welded bellows
Flexial Corporation uses welded bellows exclusively in its seats because of their unique properties. As we have discussed, the bellows in this new seal do not have differential pressure imposed across their walls. Because of this, we can design bellows with very wide spans (distance from

[1] The fluid is a 'pressure equalizing' or 'equipoisal' fluid from which the term 'equilant' was coined by adding the suffix'-ant' (as in coolant) to the verb to produce the noun.

THE FLEXIAL REACTIVE SEAL™

I.D. to O.D.) without fear of distortion induced by differential pressure, and we gain a significant reduction in the length of the assembly. We also achieve a reduction in length because a wide-span bellows requires far fewer convolutions. Such wide-span dimensions simply cannot be achieved with formed bellows which are limited in span by the elongation of the material during forming. And formed bellows are inherently longer due to the large radii at the inner and outer bends of the I.D. and O.D.

Because of the ability to use welded bellows in our seals, we have been able to achieve an exceptional size advantage that we will discuss in the next section. We will now look at how all these components function together to offer a valve seal of unusual efficacy.

PERFORMANCE

Appearance
From the user's viewpoint, there is little apparent difference in a Vogt gate valve with the Flexial Reactive Seal™ or with conventional packing. For the 3-inch valve, the length difference is about five inches, a modest amount compared with a 14 inch increase for the industry average.[2] An advantage in handling is that there is no bellows exposed. The bellows are completely contained within the bonnet extension, out of harm's way. There is no knowledge of bellows required. The seal bolts to the valve body the same as the standard bonnet, and accepts the topworks in the same way.

Pressure balancing
We have explained the principle behind the seal's ability to balance pressure. It is worth restating that this occurs passively within the seal at any temperature or pressure within the specifications. No external devices or connections are required. We will look at several significant performance improvements gained by pressure balancing the bellows.

Predictability
One of the most significant performance characteristics from pressure balancing the bellows is the seal's insensitivity to pressure "anomalies." We put this in quotes because the pressure behavior of a system is only an anomaly if the performance is not expected or wanted. To the designer of a conventional bellows seal, sudden surges of pressure, fluid hammer, pressure spikes, inadvertent overpressure, pump pulsations, or continuous pressure cycling are a cause for concern and might be considered anomalies. All these forms of system behavior which the user may consider normal can cause a bellows to fail prematurely and unpredictably if the bellows is a pressure barrier subject to the full differential pressure of the service fluid. The bellows designer has little choice but to overdesign the bellows by an amount that might cover at least part of the anticipated problems. This means heavier bellows walls which translate to additional convolutions and result in greater bellows and valve bonnet length. Hence, the unusually long bonnets in conventional bellows seals. In the Flexial Reactive Seal™, the pressure is carried by a spring-energized seal that is more than capable of handling these system pressure conditions, so they are no longer regarded as anomalies. Flexial's engineers do not have to cope with variable, pressure-induced stresses. Bending stress is the only consideration, and this is based solely on the length of travel of the valve, making cycle life highly predictable.

Pressure and temperature derating curves
In conventional bellows seals, bellows stresses run high. To give the user some degree of life predictability under various conditions, the bellows engineer may provide curves that derate life as pressure across the bellows wall increases. Also as temperature increases and bellows strength diminishes, cycle life may be derated unless the bellows strength tracks or exceeds the pressure/temperature rating scheme of the valve pressure boundary.

The Flexial Reactive Seal™ has no derating curves. The bellows wall is under very low bending stress only. Pressure is not a factor. And as we have seen, the spring-energized seal is used so conservatively that it needs no derating. Temperature derating is also not needed for the same reasons. This greatly simplifies engineering specifications for new seals or replacements. A temperature limit of 425°F is imposed on the seal because of the PTFE lip seal design.

[2] Esteban, Steve M., ARCO Use of Bellows Sealed Valves (BSVS) and Fugitive Emission Monitoring, VMA Fugitive Emissions Seminar, "Coping with California," Sept. 15-16, 1993, Long Beach, California. Data for 3-inch, Class 600 gate valve.

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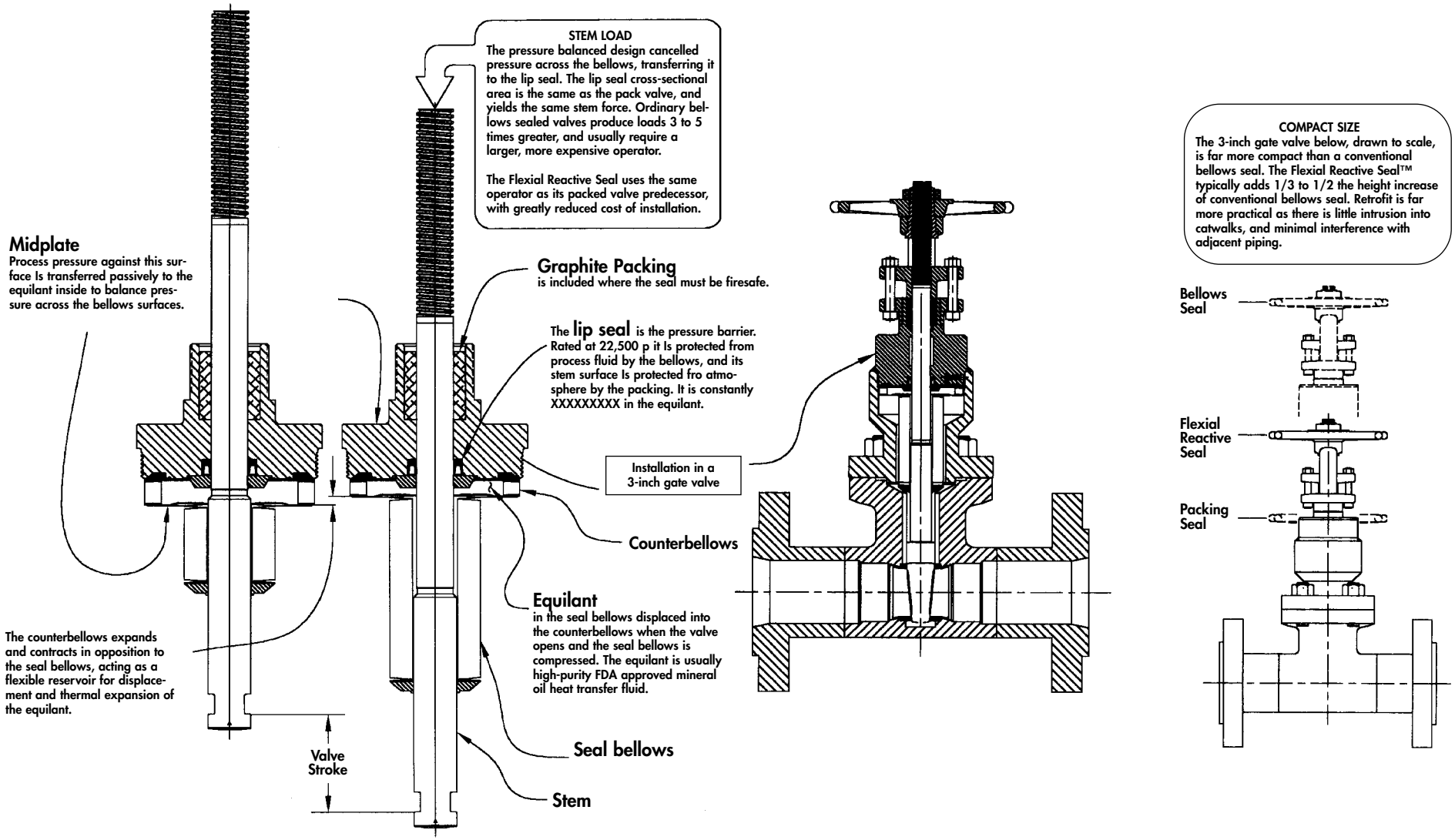
A LOOK AT THE TECHNOLOGY



THE FLEXIAL REACTIVE SEAL™

Proof pressure
Prior to shipment, all Vogt valves with Flexial Reactive Seals™ are shell pressure tested to 150% of room temperature rating per MSS and API standards. The seal experiences the full test pressure differential; no other pressure is applied to relieve the load.

Counterbellows
The counterbellows is one of the unique components of the seal, and performs a variety of functions. Its name comes from its motion, which is always counter to the seal bellows. When the valve is opened and the seal bellows compresses, the counterbellows expands. This is because the fluid inside the seal bellows is displaced as the bellows compresses, and it moves out into the counterbellows causing it to become longer.

Another critical function of the counterbellows is that of a fluid expansion chamber. When the seal is subjected to hot operating conditions, the equilant in the seal bellows and counterbellows expands volumetrically, causing the counterbellows to grow in length. In cold temperatures, the counterbellows contracts to follow the volume reduction of the equilant.

Earlier, we mentioned that while fluids are almost incompressible, they are not totally so. When the seal encounters high pressure, the force against the equilant causes it to compress slightly, and the counterbellows shortens a few thousandths of an inch to accommodate. This is critical, because the alternative without the counterbellows would be to have the bellows diaphragms distort. Even slight pressure distortion would induce severe stresses, but the counterbellows prevents the occurrence.

Finally, the counterbellows acts as a reservoir, holding extra equilant that will pass the spring energized lip seal in microscopic amounts as the valve is cycled. This loss is extremely small and quite predictable. The extra fluid is held in reserve by the counterbellows.

Stem load
We have held this for last, because it is one of the most important advantages of the Flexial Reactive Seal™. When process pressure exerts on a valve stem with conventional packing, the stem delivers an outward load against the handwheel or operator in an amount equal to the cross-sectional area of the stem multiplied by the pressure. When a conventional bellows seal replaces the packing, the area acted upon by the pressure is now the bellows effective area instead of the stem area, and this greater area is typically 3 to 5 times the stem area. The result is a stem load against the topworks 3 to 5 times greater. If an automatic operator is being used on a conventional bellows valve, a new, larger, and far more expensive operator will be required to handle the increased load. This adds greatly to the cost of switching to a zero emission seal. This is not the case with the Flexial Reactive Seal™. Because the pressure is balanced across the bellows and its effective area, this greater force is canceled, leaving only the load across the stem as with the original packed valve. To give an example, consider the load on a 3/4 inch stem in a class 600 valve with 1200 psi process pressure:

	LOAD/LB
Conventional packing	530
Flexial Reactive Seal	530
Conventional bellows seal	1844

When an operator is involved the cost saving can equal the cost of the original valve whether a new valve or retrofit seal is being offered. And for handwheels, the reliability and safety of having the same handwheel load as the original condition is a very important consideration.

SUMMARY

The Flexial Reactive Seal™ is a very recent development in zero leakage seals for rising stem valves. Its developers have extensive welded bellows engineering and manufacturing background, and are leaders in innovation in this technology with numerous U.S. and foreign patents to their credit. The seal was recognized by Vogt Engineering very early in its development as an important new technology for Vogt's valve products in light of regulatory mandates. It can now be offered in Vogt's forged steel valves and/or retrofit packages as a service to our customers. The spirit of cooperation between Vogt and Flexial has produced a product that will serve the most demanding needs of Vogt's customers for years to come.

Vogt Valves
1511 Jefferson Street
Sulphur Springs, TX 75482

US Sales Offices
Phone: 903-885-3151
Fax: 903-439-3386

Toll-Free Telephone Service
1-800-225-6989

Visit Our Website
www.flowserve.com

After Hours Customer Service
1-800-543-3927

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FLOWSERVE CORPORATION
FLOW CONTROL DIVISION
Vogt Valves
1511 Jefferson Street
Sulphur Springs, TX 75482
Phone: 903-885-3151
Facsimile: 903-439-3386

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