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# Diaphragm Valve Development – Challenging Traditional Thinking

by Per-Åke Ohlsson

This article presents the shortcomings of the traditional diaphragm and demonstrates how changes in the new generation diaphragm valve can reduce maintenance costs, minimize the risk of contamination, reduce pressure drop, and provide better flow regulation.

The traditional diaphragm valve has been a true workhorse for controlling flow of different kinds. Back in ancient Rome, a type of diaphragm valve was used to control the flow and temperature of hot baths. In 1928, a mining engineer from South Africa, P. K. Saunders, invented the type of diaphragm valve that is still used in the industry today.[1]

In the beginning, the diaphragm valve was mainly aimed at non-hygienic applications. However, the valve's simplicity, combined with its hygienic and aseptic design, turned it into a widely used valve for hygienic applications.

Since 1928, the diaphragm valve has seen a lot of improvements. These include new material suitable for hygienic applications, new valve configurations like T, tank-outlet and multi-port valves and a wide variety of automation and control units to operate and control the valve. However, the technology and performance are basically the same as the Romans used for their hot bath, for better or worse.

Even though the diaphragm valve that is widely used in the pharmaceutical industry today continues to work well, it has its shortcomings.

## Maintenance

The diaphragm may need frequent replacement depending on applications and duties. The BioPhorum Operations Group (BPOG) has estimated that "up to 40% of preventative maintenance tasks originate from diaphragm valve maintenance."[2]

## Contamination and Lost Batches

In the pharmaceutical industry, contaminated and lost batches are expensive. The diaphragm valve has high demands on the tightening of the diaphragm toward the valve body. If the four valve body bolts are not cross tightened with the right torque, the diaphragm sealing to the body will not be optimal. If this sealing is not optimal, the risk of crevices and a cracked diaphragm increases. The diaphragm itself also presents a risk for errors. In a diaphragm valve, the diaphragm elastomer is stretched and compressed. This puts very high demands on elastomer quality. BPOG members also have been seeing varying supply quality.[3] Variations in the quality of the diaphragm may increase the risk of cracking, which potentially leads to contamination of the batches.

Today, it is difficult to tell which supplier offers the longest diaphragm lifetime. The industry is looking for a standardized lifetime test;[2] therefore, some bigger end-users have even invested in their own test-skids to investigate diaphragm materials.

## Pressure Drop

The traditional diaphragm valve has a pressure drop that is approximately 20 times higher than a full bore valve, e.g., a ball valve., In a pharmaceutical water system distribution loop, water velocity is crucial in securing the correct temperature and to minimize biofilm in the system. With several diaphragm valves in the system, both the pump and installation work (like valves, tubes and fittings) has to be dimensioned accordingly in order to secure the minimum velocity. This significantly adds to the overall system cost and operating cost compared to a valve with a lower pressure drop.

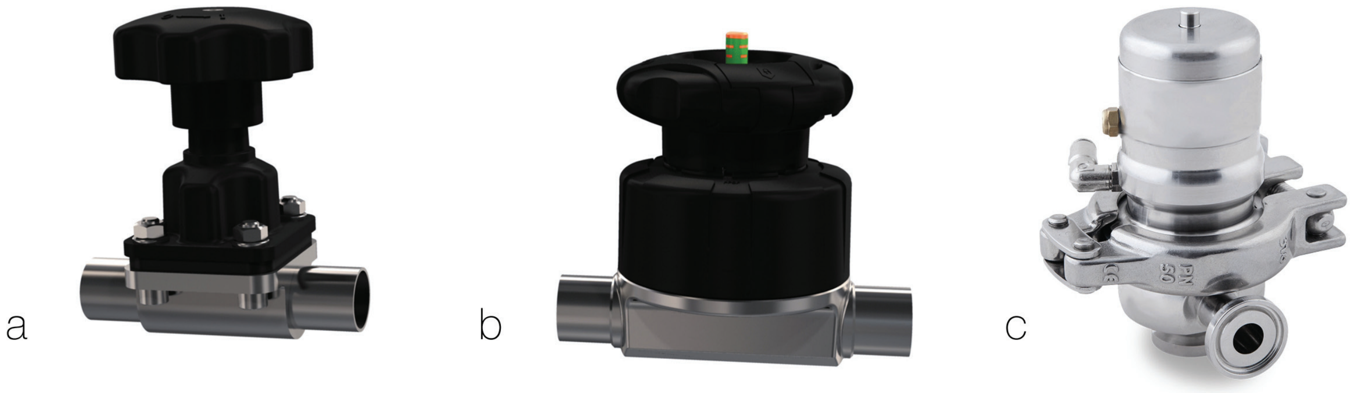


Figure 1. Comparing the four bolts of the traditional diaphragm value (a) to the centralized thread on the new generation diaphram (b) and the radial diaphragm with clamp assembly (c). The centralized thread provides quick, easy and safe installation as well as service of the valve.

## Flow Regulation

The flow curve of the traditional diaphragm valve is only linear up to around 40% stroke opening and thereafter the flow curve drops. This makes it more difficult to control the flow with a diaphragm valve over the entire flow curve of the valve.

## Generation Diaphragm Valves

Now some of the largest valve suppliers are developing new diaphragm valve concepts.

These concepts are built around solving many of the shortcomings of the traditional diaphragm valve. They meet the demands in the industry for new innovative solutions providing, e.g., longer lifetime of diaphragms and reducing the carbon footprint with higher efficiency. Innovations vary from small to more radical improvements on the traditional diaphragm valve concept to developments of other valve types like, e.g., radial diaphragm valves.

In these next generation, diaphragm valves there are typically three main changes compared to the traditional diaphragm valve design.

1. New innovative tightening mechanisms for safer and simple assembly - *Figure 1*
2. New diaphragm materials and/or new diaphragm designs such as radial and circular designs - *Figure 2*
3. Design changes improving valve interior - *Figure 3*

## Maintenance

Most of the new innovative valve concepts have maintenance improvements. In some cases, diaphragm replacement has been reduced by up to 50%. Typically, there are between 1,000 to 5,000 diaphragm valves in a single pharmaceutical manufacturing site. It takes more than two minutes to service a traditional diaphragm valve. This gives a time savings of 17 to 85 hours every time the diaphragms need replacing.

Another advantage of new diaphragm valve developments are that they do not need retightening after steaming. The traditional diaphragm valve has a larger amount of rubber between the valve body and handle/actuator compared to the new designs. The elasticity of this rubber is affected when the rubber is steam sterilized or exposed to high temperatures; therefore, the valve needs retightening in order to compensate for the reduced elasticity in the rubber material. Most of the new designs also allow for a minimized amount of rubber material between the body and the handle/actuator. The reduced amount of rubber between the body and handle/actuator in the new design minimizes the affect of the elasticity, which means that there is no need to retighten.


Figure 2. Comparing new diaphragm designs (b) and (c) to traditional square diaphragm design (a).

These improvements mean savings both in working and downtime hours.

Advanced Finite Element Method (FEM) analysis has been used to optimize designs, e.g., the new circular diaphragm, will distribute forces and stress more evenly in the diaphragm, compared to the traditional squared diaphragm.

Steam tests[4] have shown that circular diaphragms have approximately twice the lifespan compared to squared diaphragms. This should reduce both the cost for diaphragm spare parts and further reduce maintenance and downtime hours for the industry.

With these new improvements, it should be possible to reduce the high maintenance cost the industry experiences with the traditional diaphragm valve. The future will tell us how great this reduction will be in practice.

## Contamination and Lost Batches

Incorrect assembly and tightening of the bonnet over the diaphragm and valve body is one of the main reasons for failure and leakage of the diaphragm valve. If one or more bolts are tightened harder than the other bolts, the forces will be unevenly distributed over the diaphragm. This can lead to leakages between the atmosphere and the product. The uneven forces on the diaphragm also will lead to premature and unforeseen cracking of the diaphragm.

Some of the new designs have a centralized thread or clamp connections that make it very safe and easy to assemble and tighten the bonnet as seen in Figure 1. This secures that tightening is evenly distributed every time. This will minimize the risk of leakage to the atmosphere as well as minimizing the risk for cracking of the diaphragm due to uneven tightening.

The traditional diaphragm valve has often been seen as very easy to clean. However, the sharp corners in the weir and especially in the connection between the body and the diaphragm are areas where flow velocity is very low and which makes these areas rather hard to clean. For really high demands on cleanability, these areas could require extensive cleaning in order to become totally free from residues.

The new developments/constructions of the interior provides a smoother and more corner free design (Figure 3). This ensures that even the highest demands on cleanability will be fulfilled with a quick and simple cleaning procedure.

## Pressure Drop and Flow Regulation

An improved interior design with less

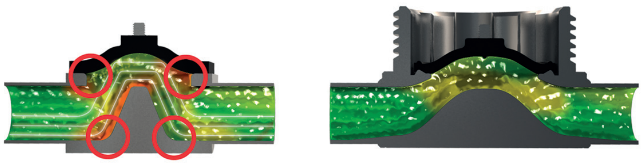

Figure 3. The new generation diaphragm valve (right) has minimized sharp corners compared to the traditional valve (left) which has sharper corners (circled). The smoother corners reduce turbulence and thereby pressure drop.

sharp corners has two main benefits:

1. It provides a more linear flow curve over a wider area of the valves opening stroke, shown in Figure 4. This now makes it possible to use a diaphragm valve for more exact flow regulation.
2. It improves the flow rate across a range of sizes. The improved flow rate helps to empty tanks faster, reducing system cost and operating cost since the whole installation can be made in smaller dimensions (piping, pumps, etc.)

The small and innovative changes made in the next generation diaphragm valves has really improved the shortcomings of the traditional diaphragm valve and lifted the diaphragm valves to a much higher level in terms of lifetime cost, reliability and performance.

## Conclusion

The design of the diaphragm valve has survived the test of time, and has changed little over the last 90 years. Not surprisingly, it has its shortcomings.

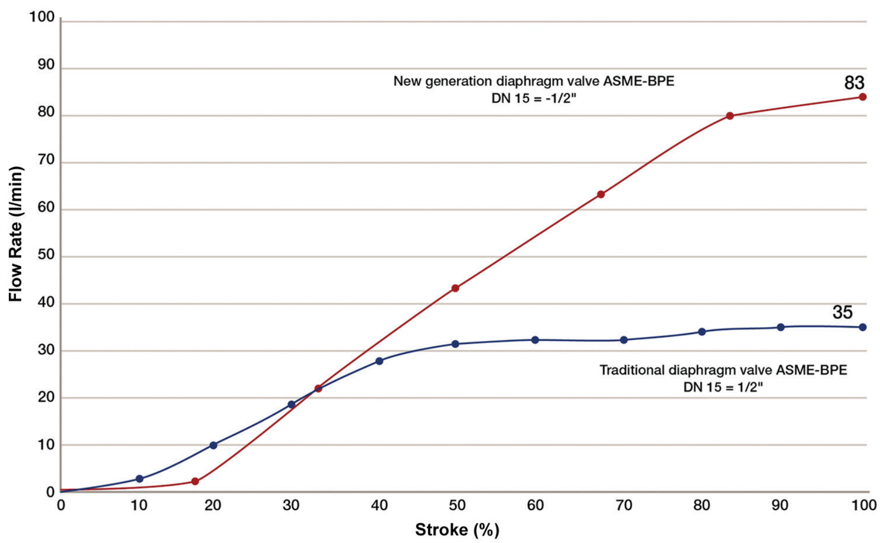


Figure 4. Flow curve of the new generation diaphragm valve compared to the traditional diaphragm valve. The next generation diaphragm valve has a more linear flow characteristic creating a more stable process and better regulating.

By implementing design changes, namely improving valve interior, new innovative tightening mechanisms for safer and simpler assembly, new diaphragm materials and/or new diaphragm designs, radial and circular type instead of a squared type diaphragms, the traditional diaphragm valve performance can be improved.

By challenging traditional thinking the next generation diaphragm valves produce greatly improved efficiencies. It reduces maintenance costs, minimizes the risk of contamination, reduces pressure drop and provides better flow regulation.

## References

1. www.centuryinstrument.com/history.html.

2. BioPhorum Operations Group, presentation by Steve Jones, 2012 during BPOG meeting.

3. www.biopharminternational.com/The Future of Valves and Diaphragms Supply.

4. All tests and simulations have been performed in Alfa Laval's test facility and laboratory. The steam test has been performed according to The American Society of Mechanical Engineers Bioprocessing Equipment revision 2009 (ASME BPE-2009) appendix J sub-section J-2 Simulated Steam-in-place (SIP).

## About the Author

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