VESSEL DESIGN HAS SIGNIFICANT EFFECT ON MEDIA UTILIZATION

Modern Design Can Reduce Operational Costs and Improve Operational Performance

By Chris Phillips, President, Yardney Filtration Systems

Demand for filtration media, especially media capable of removing PFAS from drinking water, like granular activated carbon (GAC) and ion exchange (IX) resin, has begun an atmospheric ascent. As municipalities prepare for PFAS regulatory compliance deadlines, the impact on the global supply of filtration media will be profound.

In this environment, dead zones inside legacy pressure vessels cannot continue sailing under the radar. The constraints have changed, and what used to be acceptable is now expensive, risky and intolerable.

A Short History of Dead Zones

Pressure vessels have been used in water treatment since the early 1900s, and for most of their existence they have been plagued by dead zones – areas where fluid movement is minimal to nonexistent. This causes fouling and solids accumulation, premature contaminant breakthrough and media underutilization, all of which creates additional expense in the form of premature media rebed, greater operational maintenance and increased pressure differential for utilities. Until recently, this "problem" wasn't too much of a problem, because regulatory compliance was easier to achieve, carbon was abundant and relatively cheap, and disposal was manageable. The main reason dead zones went unaddressed for so long, however, was that technological limitations prevented operators from seeing or quantifying dead zone dynamics. Utilities typically reacted to symptoms (like unexpected breakthrough or unplanned downtime) without visibility into the root cause. The industry responded with innovations in media chemistry, but vessel hydraulics and design were largely overlooked.

Advances over the last 40 years in computational fluid dynamics (CFD) modeling and internal flow diagnostics exposed this shadow villain. Operators now know that poor flow distribution is directly linked to corrosion and fouling, elevated energy demand, wasted media due to premature breakthrough and increased maintenance requirements. Many municipal systems, however, have continued to operate with legacy vessels under the assumption that upgrading vessels is more costly than tolerating the dead zones.

More recently, a new factor has entered the equation: Drinking water regulations have tightened, with more contaminants restricted at lower allowable limits. These regulatory pressures, combined with a deeper understanding of contaminant health impacts, are driving demand for and price of filtration media. In response, innovations in pressure vessel design have caught up with the problem. The industry now has both motivation and opportunity to stop tolerating dead zones.

How Advanced Vessel Design Maximizes Media Life

Pressure Vessel design can have a major impact on effluent water quality and cost. A pressure vessel is essentially a device in which contaminated water enters, interacts with treatment media and exits less contaminated. But what happens while the water is in the vessel is critically important to media performance and other process objectives. Flow distribution is the key.

Achieving uniform flow through the media bed depends on how the vessel's internal hydraulics are engineered. Inlet diffusers and header systems must dissipate influent

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water and spread the flow laminarly across the vessel cross-section, avoiding high-velocity jets that can cause channeling or coning of the media. Vessel geometry (diameter, bed depth and aspect ratio) directly influences contact time and the shape of breakthrough curves. Poorly proportioned vessels or uneven distribution shorten effective empty bed contact time (EBCT), leading to earlier breakthrough and reduced media bed life. Underdrain architecture, such as underdrain lateral or septa spacing, orifice sizing or screening elements, controls how effluent water is distributed and ensures consistent velocity gradients through the media bed.

When these systems are not well designed, flow follows the path of least resistance, creating localized high-velocity zones and stagnant regions that leave portions of the media underutilized. The result is inefficiency and degraded performance across all media types, whether GAC, IX, catalytic media or specialty medias. Maintaining an appropriate (and uniform) velocity profile is essential: too high, and you risk media disturbance, attrition and excessive pressure loss; too low, and near-stagnant conditions can allow fouling, scaling or incomplete mass transfer.

The goal is to balance energy input and hydraulic distribution to engage more of the media bed. Well-designed distribution systems minimize pressure drop while maximizing contact efficiency, producing more predictable breakthrough behavior and extending filtration media life.

A Word on ASME Code

The ASME Boiler & Pressure Vessel Code – first issued in 1914 in response to catastrophic boiler explosions in the early industrial era and last updated in 2025 – creates legally enforceable, non-negotiable requirements that ensure all pressure vessels meet the same baseline for structural integrity. It dictates materials, wall thickness, weld quality and pressure ratings to make designs broadly equivalent regardless of manufacturer.

What the code does not do, however, is optimize process performance or internal flow behavior. The code's purpose is to keep vessels from failing, not to ensure that what happens inside them is efficient or well distributed. As a result, two vessels can both be "ASME code-compliant" but perform very differently according to flow behavior and treatment efficiency.

Why Eliminating Dead Zones Is Worth the Time and Money

Installing pressure vessels that eliminate dead zones is one of the most effective ways to reduce operating costs and improve reliability in water treatment systems. When flow is uneven, a significant portion of the media bed does little useful work, forcing operators to replace or regenerate media sooner than necessary. Uniform flow distribution ensures that more of the bed is actively engaged, extending effective bed life, improving contact efficiency and producing more predictable breakthrough behavior.

This has a direct financial impact. Treatment media represents a major and increasingly volatile operating expense. With less frequent media replacement, utilities can lower ongoing costs and buffer against supply chain constraints and price fluctuations. Fewer changeouts also result in reduced labor, less downtime and smaller disposal costs.

Eliminating dead zones also improves overall system performance. Uniform hydraulics reduce fouling and scaling by preventing solids from settling in low-flow

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regions, minimize localized corrosion and help control unnecessary pressure loss that drives up energy consumption. The result is a more efficient system that operates closer to its design intent, with more stable effluent quality and lower lifecycle cost.

PFAS Regulations Have Upped the Ante

In light of the latest PFAS drinking water regulations, the importance of eliminating dead zones is even more pronounced. PFAS treatment (most commonly using GAC or IX media) depends heavily on consistent contact time and full media utilization. These contaminants exhibit relatively sharp breakthrough curves, meaning that once media begins to exhaust, performance can decline quickly. Dead zones accelerate this process by reducing effective EBCT and leaving portions of the media underutilized. Demand for PFAS treatment media is spiking, driving supply down and price up; getting the most life of a media bed has never been more important.

On the disposal side, options are narrowing for what utilities can do with spent PFAS-laden media. The effort may require specialized handling, regeneration or disposal pathways that add further cost and logistical complexity. Extending media life by even a modest margin can translate into substantial savings and reduced operational risk.

Equally important is compliance risk. As PFAS compliance deadlines approach, utilities have less margin for performance variability. Poor flow distribution introduces unpredictability into breakthrough behavior, making it harder to maintain consistent effluent quality. By minimizing dead zones, utilities can stabilize system performance and achieve greater confidence in meeting regulatory requirements.

Vessel Design Comes of Age

The industry has spent years optimizing media performance while generally accepting legacy vessel designs that hide inefficiencies. But as treatment demands increase, costs rise and solutions emerge, this scenario is no longer acceptable. Flow distribution determined by vessel design can directly improve media utilization, breakthrough behavior, pressure drop and overall system operability, resulting in reduced media replacement frequency, lower operating costs and less maintenance. Vessel design is now a primary strategy to control lifecycle costs and achieve systems that are effective and practical to operate and maintain.

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