Four Tenets of Pressure Vessel Design

History of the Pressure Vessel Designs

There have been lessons learned in the field that have driven design improvements through the years.

Header - Lateral

Internal Cone

External Ring Header LowPro®

1980s | 1990s | 1990s | 2010s

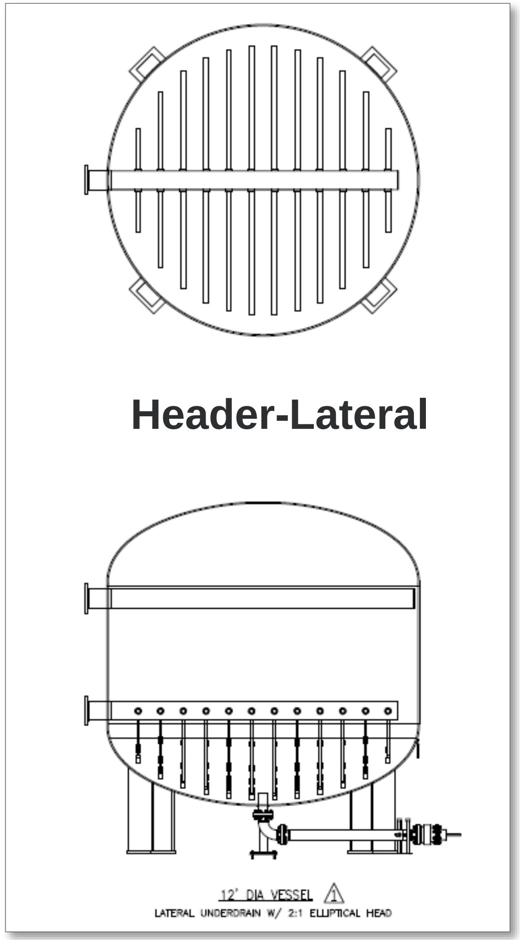
External Cone

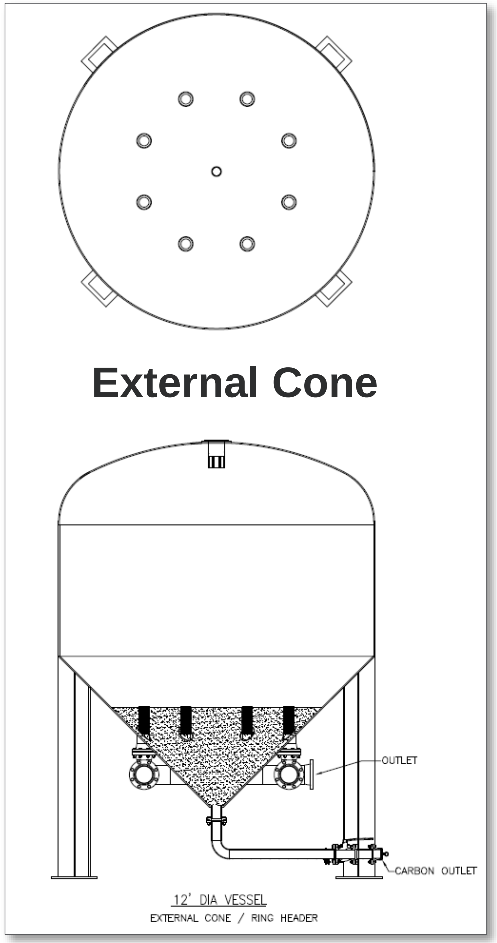
External Ring Header

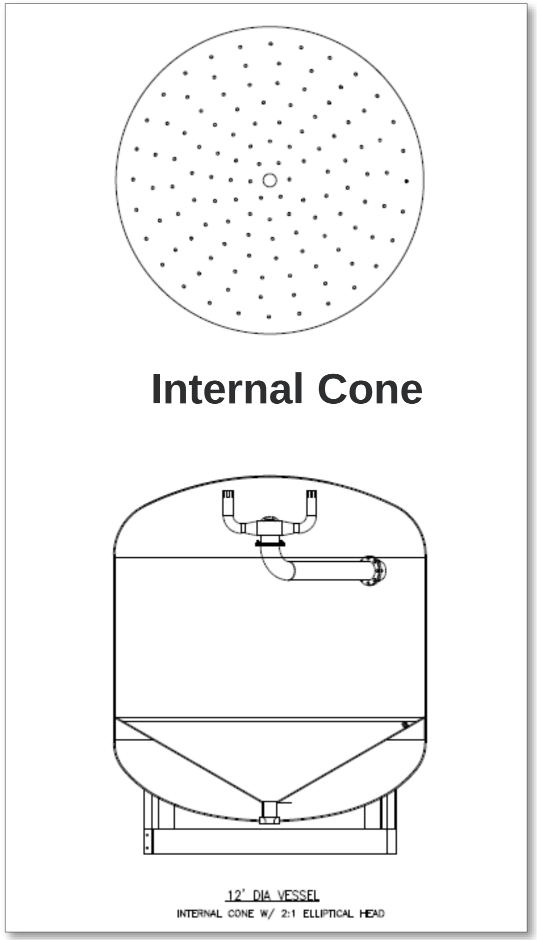
Evolution of the Mechanical Treatment Underdrain Designs

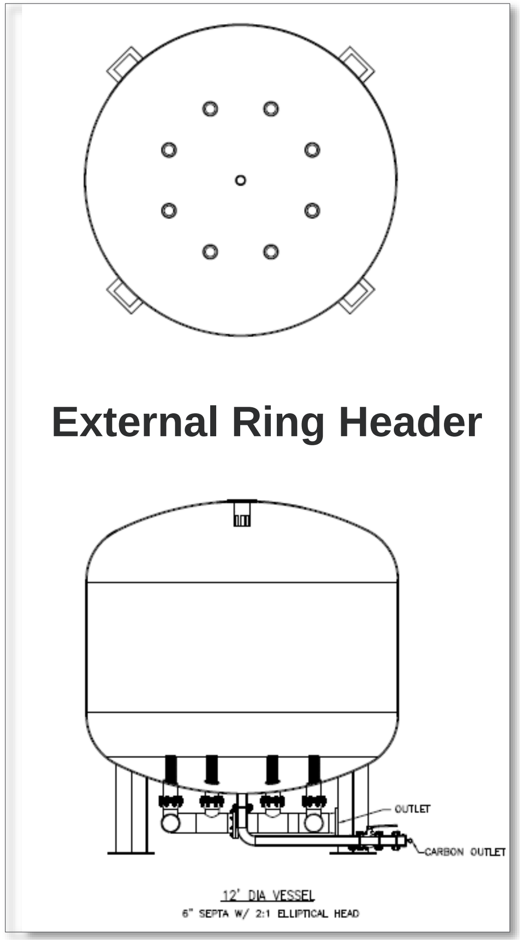
Understanding the underdrain design is as important as choosing the media.

All Four Designs Meet Your Water Treatment Goals.









The Tenets of Pressure Vessel Design

There are four engineering tenets to consider when designing treatment systems

Corrosion Management

- ✓ Per NACE Standard RP0178-2007 and Coating Manufacturer's Recommendations
- ✓ All immersed vessels have sharp edges ground to 1/8" min. radius.

Long-Term Operation & Maintenance

- ✓ One Homogenous lining to minimize lining repairs
- ✓ External Underdrain Removal for safety practices
- ✓ Media appurtenances can be removed and replaced exterior to the vessel

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Experienced. Proven. Reliable.

Hydraulic Performance

- ✓ Water Distribution & Collection
- ✓ Minimizing Head Loss
- ✓ CFD Modeling for design verification

Media Optimization

- ✓ Analyzing inlet distributor designs
- ✓ Analyzing underdrain / collection designs
- ✓ CFD Modeling for design verification

Least complex & lowest cost of ownership

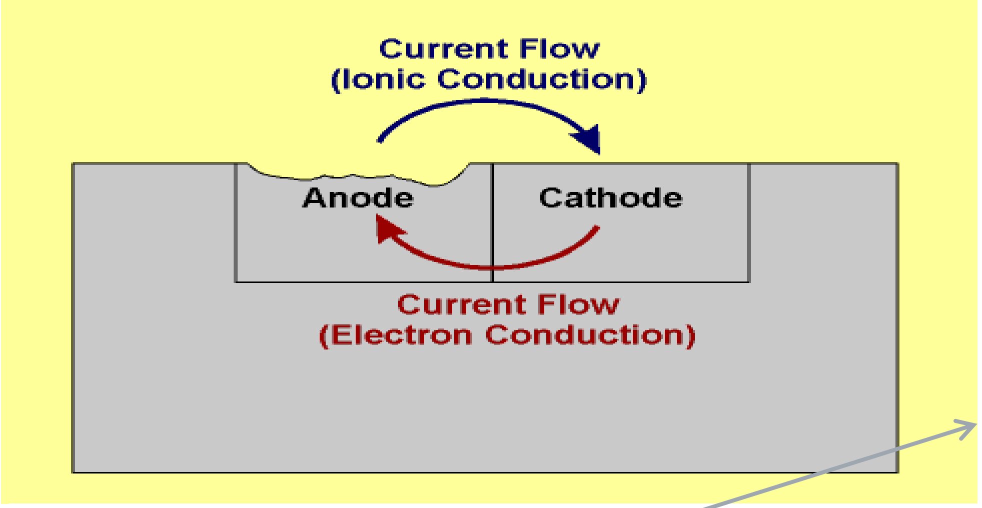
Section 1

Corrosion Management

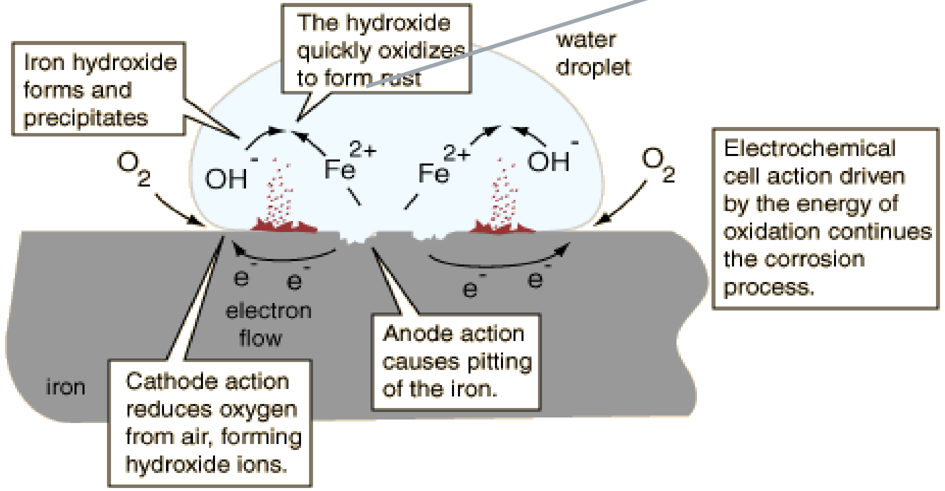
Corrosion 101: All four elements must be present in order for corrosion to take place – unimpeded flow of electrons and ions

Four Critical Elements:

- **Cathode:** The cathode is the more “noble” region on the electrode (metal surface, or in a battery analogy -the carbon rod) where the electrons are consumed.
- **Anode:** The anode is that part of the metal that corrodes (i.e., dissolves in the electrolyte).
- **Electrolyte:** An electrolyte is a medium that conducts ionic (rather than electrical) current. The majority of electrolytes in the field are based on water.
- **Return Path** (metallic pathway): The return path connects the anode and cathode and allows passage of electrons, generated at the anode, to the cathode.



The electrolyte is the medium for the ion exchange



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Dissimilar Metal Corrosion: Electrons flow in metals from areas with more negative charges to areas with more positive charges

Materials Selection - Galvanic Series

[Seawater at 25°C]

Most Active ➡

- Magnesium
- Zinc
- Aluminum
- Carbon Steel
- Cast Iron
- Copper
- Stainless Steel
- Silver
- Gold
- Platinum

Least Active ➡

NACE® International, 2000

- **Design**
  - Unfavorable area ratios should be avoided.
  - Avoid dissimilar metal crevices such as those that occur at threaded connections
  - Provide appropriate corrosion allowance of the more active member.
- **Material Selection**
  - Combination of metals or alloys widely separated in the galvanic series should be avoided.
- **Electrical Isolation**
  - The joint between dissimilar metals can be insulated to break the electrical continuity
- **Barrier Coatings**
  - According to NACE, it is “potentially dangerous to coat only the anodic member of a couple. This reduces its area and severely accelerated attack on holidays can occur.”

Corrosion Control: Industry best practices with bonded coatings

70% of Coating failures are due to inadequate surface preparation – NACE® 2000.

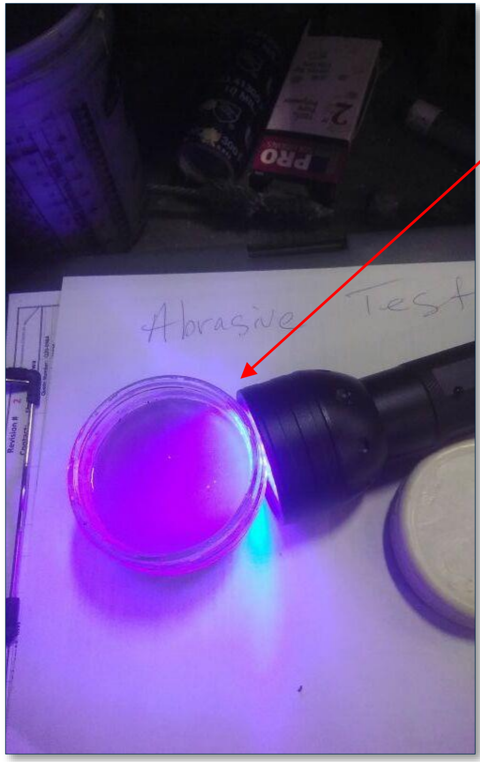
Surface Preparation is broken into three distinct phases:

1 – Removal of what you can see:
- Residues of oil, grease, and soil that can prevent adhesion
- Rust on the surface interferes with adhesion
- Loose or broken mill scale: can cause early coating failure
- Tight mill scale: can cause later coating failure

2 – Removal of what you can't see:
- Residues of (non-visible) soluble salts that can induce coating failure after coating has been applied via osmotic blistering

3 – Blast or Surface Prep:
- Cleans the surface to an appropriate level, while creating an anchor profile for adhesion (Example: SSPC SP-5 / NACE No.1 with a 3-5 mil anchor profile

- Factors that effect surface preparation:
  - Blast Media
  - Environmental factors such as Temperature, Humidity and Wind
  - Air pressure and angle of blast nozzle

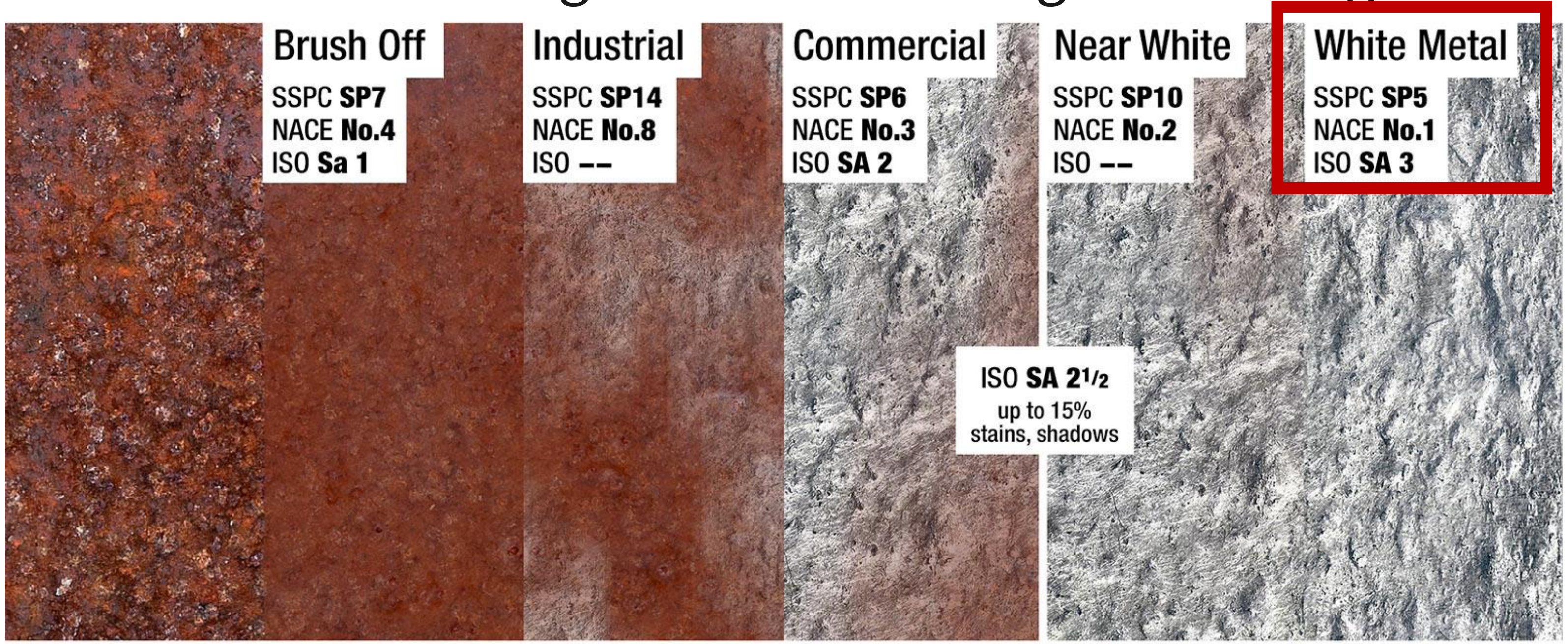


Verification that media is free of oils and grease

Verification that surface profile meets mfg's recommendations

Surface Preparation: Inspection includes cleanliness, anchor profile, and removal of chemicals and other material that may affect coating adhesion

SSPC: Society for Protective coatings has been serving the coatings industry since 1950

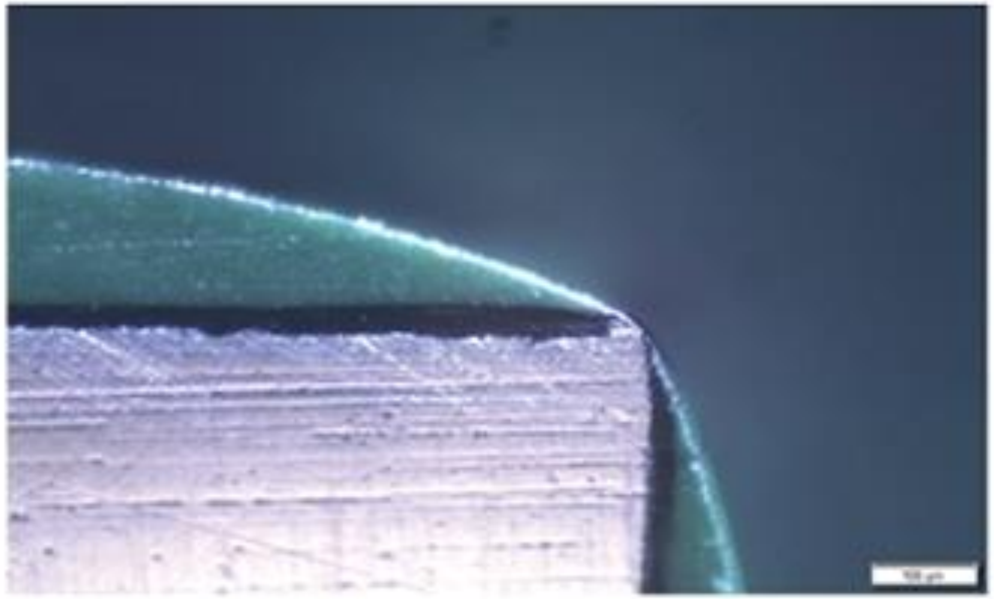


	Brush Off	Industrial	Commercial	Near White	White Metal
Loose Material	None	None	None	None	None
Tight Material	100%	up to 10%	None	None	None
Stains, Shadows	100%	100%	up to 33%	up to 5%	None

SSPC SP-5 NACE No. 1 - When viewed without magnification, surface shall be free of all visible oil, grease. Dust, dirt, mill scale, rust, coating, oxides, corrosion products and other foreign matter.

Coating considerations: Care should be taken in design to extend the life of the coating that protects the vessel.

- Industry best practice of the NACE Standard #RP0178-2007 & Coating Mfg. recommendations for proper lining
  - Design, Fabrication, and Surface Finish Practices for Tanks and Vessels to Be Lined for Immersion Service
  - **NACE specifies that All Immersed Vessels Have Sharp Edges Ground to 1/8” Minimum Radius. NACE Standard #RP0178-2007**
- A lining suitable for the abrasive change out services such as industry standard Carboline Plasite® 4110, 35-45 mils to meet NSF 61 standards.
- Optimal Conditions Result in System Longevity
  - Homogenous lining from flange to flange
  - No thinner lining, outside of manufacturers recommendations, below underdrain at risk of corrosion
  - Limit vessel entry when possible, to minimize lining damage during installation
- Third Party testing is always recommended to ensure proper testing
  - Holiday testing ASTM D-5162 and NACE RPO188-88



As coatings polymerize, they shrink and pull from sharp edges leaving critical welds or sharp edges in the vessel exposed.

Coating performance requirements

Implementing a performance specification based on industry standards and manufacturers recommendations

- **Manufacturers Recommendations**
  - NSF 61 Material
  - 35-45 mils
  - Cleanliness, SSPC-SP10 Minimum
  - 4 mil anchor as measured by ASTM D4417
  - Defects Exposed by blasting must be repaired

- **Performance Requirements**
  - All Welds and Sharp Edges ground to 1.8” minimum **per NACE RP0178**
  - SSPC SP6 White metal ensures no staining, loos material or shadowing on the surface **per NACE RP0178**
  - Full holiday testing to NACE RPO188 for verification of integrity

carboline®
Coatings - Linings - Fireproofing

Plasite® 4110
PRODUCT DATA SHEET

SELECTION & SPECIFICATION DATA

Generic Type	Vinyl ester
Description	Vinyl ester resin combined with special curing system and inert flake pigment to provide outstanding chemical and physical properties. Specially formulated for excellent abrasion resistance. PLASITE 4110 meets the FDA requirements for 21 CFR, 175.300 and 177.2420 and is suitable for potable water service per NSF Std. 61. Uses: As a high chemical abrasion-resistant thick film for tank lining service and as a maintenance coating for severe exposure.
Features	Meets the criteria of NSF/ANSI/CAN 600
Color	Grey (0700)
Primer	Primer (optional, as needed): Self-priming to steel To control outgassing on concrete: Dudick Primer 27 Pit/void filler and surfacer: Dudick Scratch-Coat 800 Control Moisture Vapor Transmission (MVT): Dudick Vapor Stop
Dry Film Thickness	35 - 45 mils (889 - 1143 microns) total thickness achieved in 2-3 multi-pass spray coats recommended for immersion service. Consult Carboline Technical Service Department for any deviation to this film thickness. Refer to APPLICATION section.
Coverage Rate	Plasite 4110 will cover approximately 960 mil ft.^{2}/gal. or 86.4 sq. m. per 25 microns/gal. This is a coverage obtained from field use on small jobs and includes loss in can, spray loss, small amount of shrinkage, etc. Application by conventional spray equipment may affect coverage.
VOC Values	**As Supplied** : 0.50 lbs/gal (60 g/L) Plasite Thinner #20 : Thinned 5% by volume 0.78 lbs/gal (93 g/L)
Dry Temp. Resistance	Continuous: 380°F (193°C) Non-Continuous: 460°F (238°C) **Limited short excursions to 460 °F (238 °C) acceptable**. Wet temperature resistance depends upon concentration and reagent exposure.
Topcoats	Not Applicable
Density	79.1 lbs/ft^3 (0.26384 lbs/ft^2 at 40 mils)

SUBSTRATES & SURFACE PREPARATION

General	Surfaces must be clean and dry. Employ adequate methods to remove dirt, dust, oil and all other contaminants that could interfere with adhesion of the coating.
Steel	Cleanliness: Abrasive blast to SSPC-SP10 (minimum) Profile: Minimum 4 mil (100 micron) dense, sharp anchor profile free of peening, as measured by ASTM D 4417. Defects exposed by blasting must be repaired.

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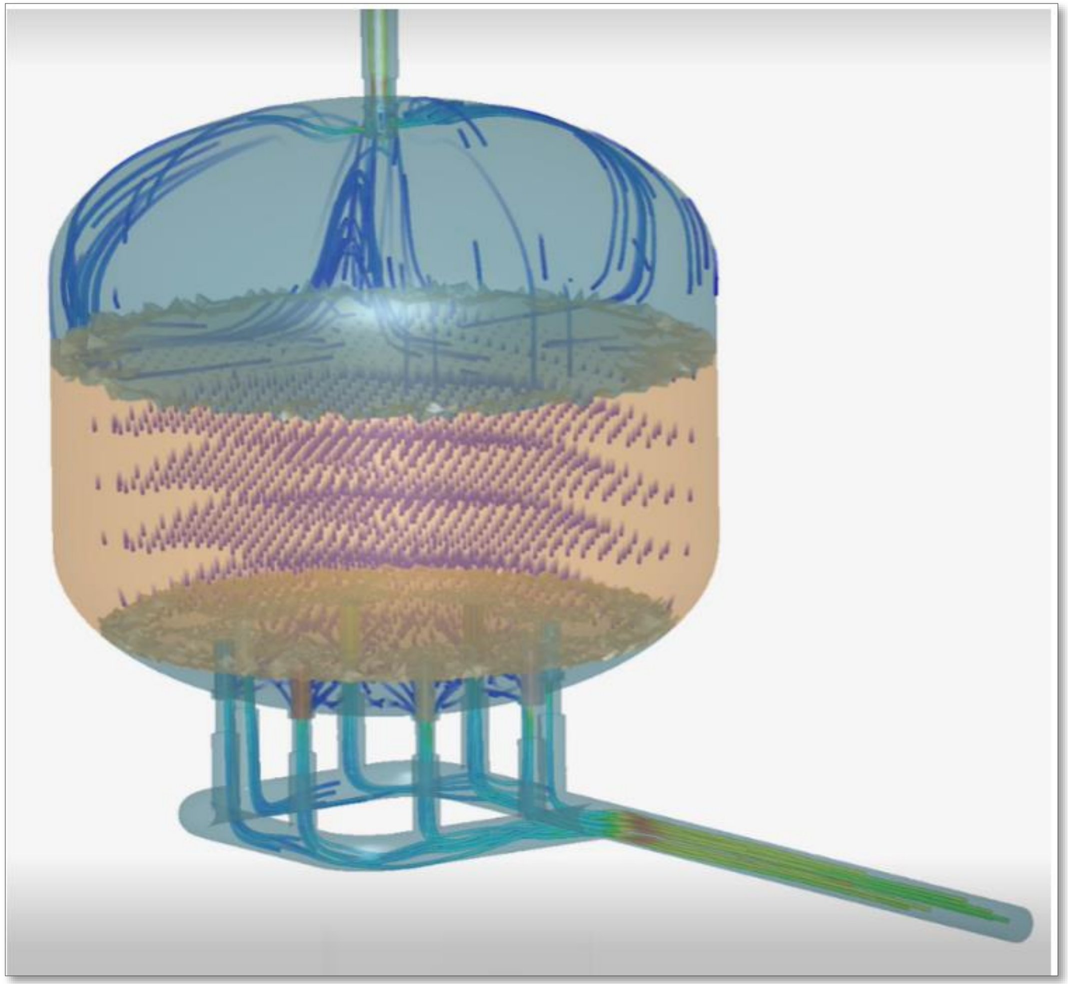
Section 2

Hydraulic Performance

Engineered Hydraulic Modeling of Pressure Vessel Designs

Head loss is one of the most expensive aspects of the operational costs.

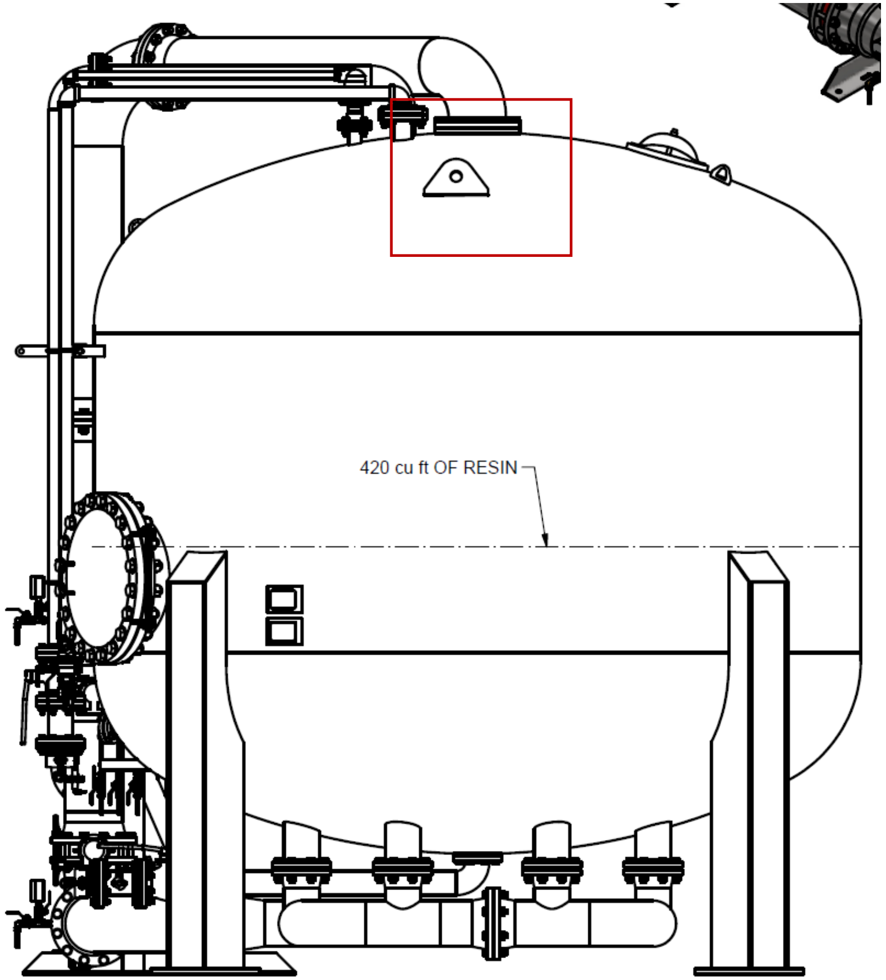
- Computation Fluid Dynamic (CFD) Modeling
  - Software for modelling fluid flows. CFD is especially useful for internal flows that cannot be viewed visually
  - Provides a model of internal velocity and pressure distributions in a fully developed flow
  - Results can inform and validate design choices
- **Optimize pressure drop in all 3 regions of the pressure filter**
  - **Overdrain –** study water velocities and water distribution
  - **Stratified Media Bed –** Creates a torturous path that develops plug flow, given proper distribution
  - **Underdrain –** Design selection that minimizes head loss through nozzles and any necessary piping.
- Plug Flow is an idealized flow in which all streamlines are parallel, and normal to a given vessel cross-section
- Plug Flow creates a linear mass transfer zone through the media bed



Mechanical Design Differences Effecting Head Loss

It is critical to design a system with efficient water distribution and collection systems.

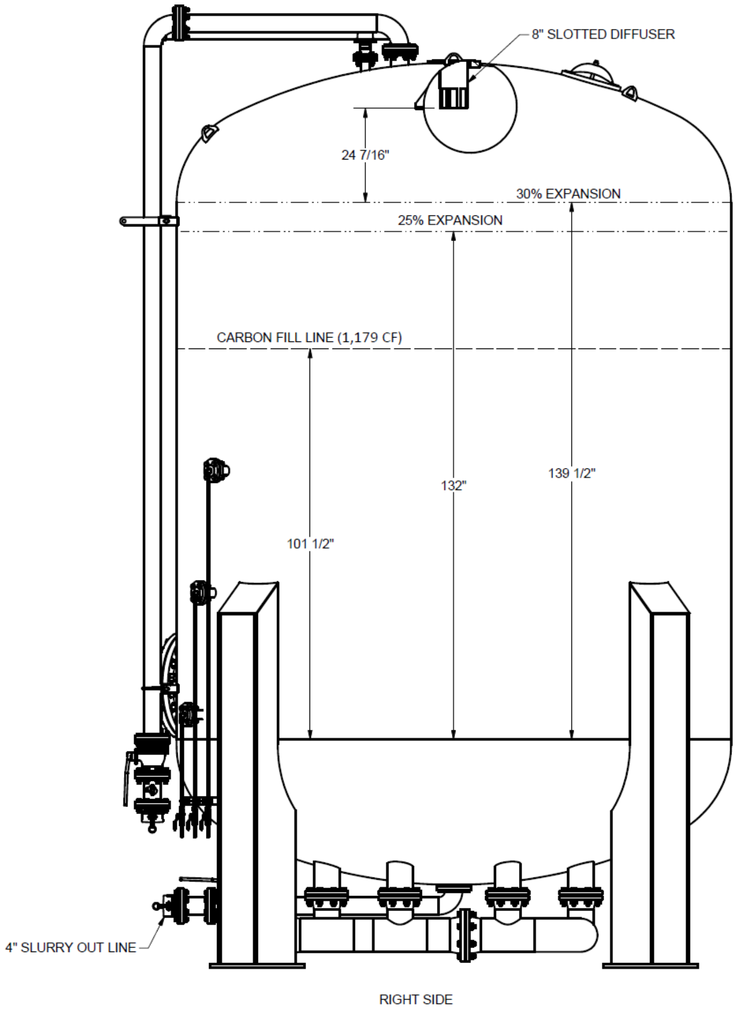
- Optimize distribution and collection of water
  - Inlet Distributor
  - Underdrain
- Inlet Distributor Design Differences create different pressure drops
  - Inlet Diffuser
  - Four-point header lateral
  - Four-point screened nozzles for water distribution
- Optimized Pressure Drop
  - Example: 12-ft diameter GAC system w/ 700 ft^3 @1,000 GPM is approx.
    - 6 psi with external ring header design
    - 15 psi with older underdrain designs
- Pressure Rating
  - Vessel and underdrain rated to 125 psi – ASME
  - Internal Cone Underdrain is rated for a differential pressure of:
    - Downflow – 50 psi
    - Upflow – 20 psi



Media Bed Expansion from Backwashing

Vessel sizing considerations are based on project parameters.

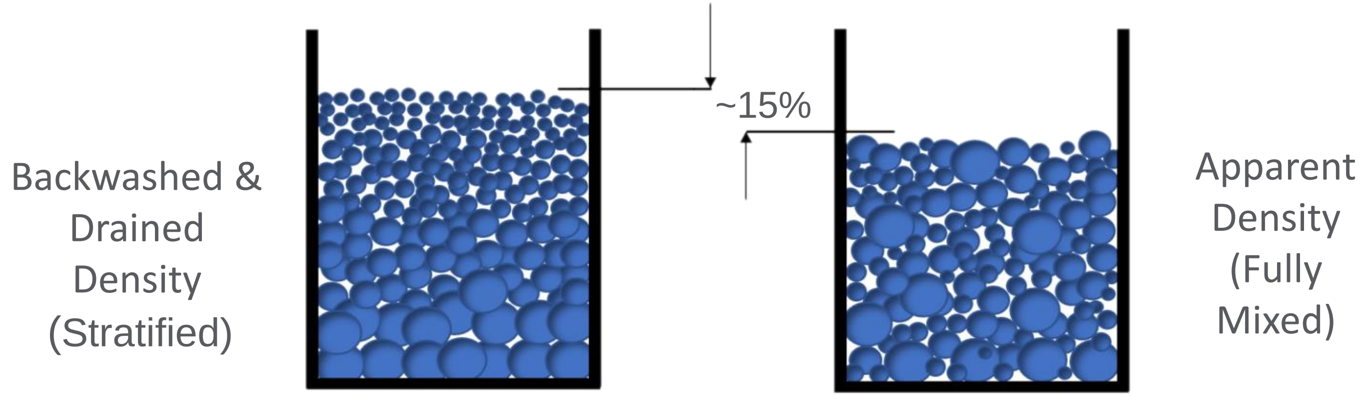
- Significant cost savings when optimizing the design.
- When granular activated carbon (GAC) media is installed a backwashing procedure is required.
  - It removes fines to reduce head loss and prevent clogging
  - Stratifies the carbon bed to configure larger particles on bottom, which also reduces head loss
- Bed Expansion expressed as a % increase in bed depth
- Bed expansion is used to properly stratify the media bed
- Can be defined through vessel volume or within the side shell
- Typically, 25-30% expansion in overall volume of vessel to achieve stratification

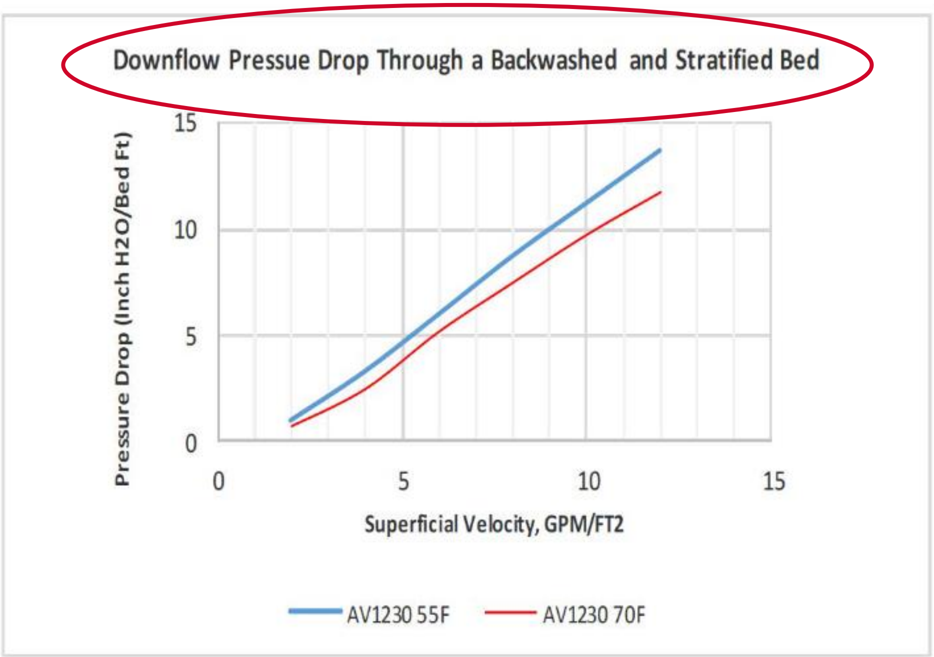


Carbon Backwashing: Based on a backwashed and segregated bed

Media start up is important to understand because of it's impact to the operations of the treatment systems.

- When the GAC media bed is backwashed, and proper stratification occurs the carbon bed volume increases
- Per AWWA B604-18 Page 36 Section C.1.3 Paragraph 3
  - GAC should be added to ~ 85% of the final volume.
  - A permanent expansion of ~15% occurs during stratification after the GAC is backwashed.





Example of How Head Loss Results in increase O&M Costs

Small design differences can affect head loss and can change over all costs.

Illustrative energy savings from AV design

	AV 12' Septa System	12' Cone System
System Pressure Drop (PSI)	12.8	22.5
System Head Loss (ft. of H_2O)	30	52
Power Required (HP)	8	14
System Energy Use (KWH/yr.)	67,732	119,060
Annual Energy Cost ($/yr.)	$5,439	$9,560
Energy Cost Delta ($/yr.)	-	$4,121

Energy saving provides long term value to customers:

The City of Tulare has ~15 systems

~4K dollars per system per year

~25 years lifetime = ~$1.5 million of savings

Assumptions Made:

1. Pump Motor Efficiency of 75%

2. Energy Cost of $0.13/KWH

3. Demand cost of $453/KW per month

4. Pump Operating time of 24 hours per day

5. The annual energy costs shown are based on head loss only, and do not reflect actual pumping costs.

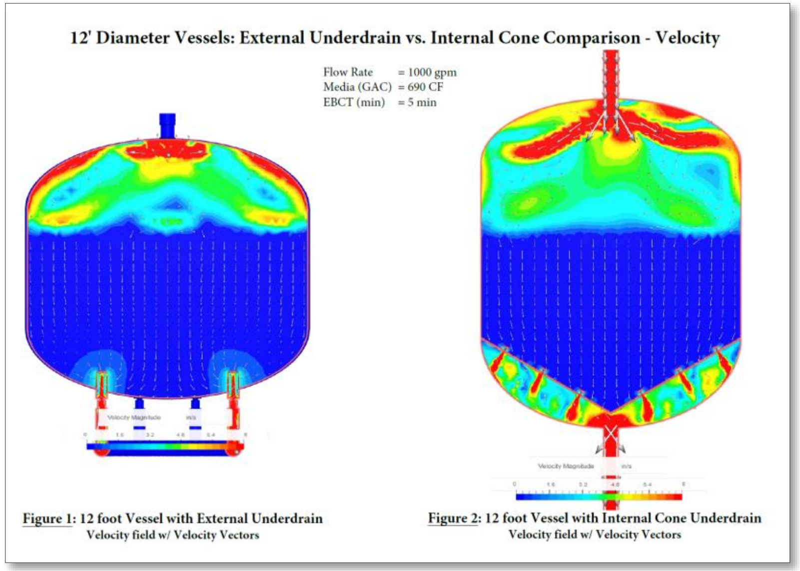
Section 3

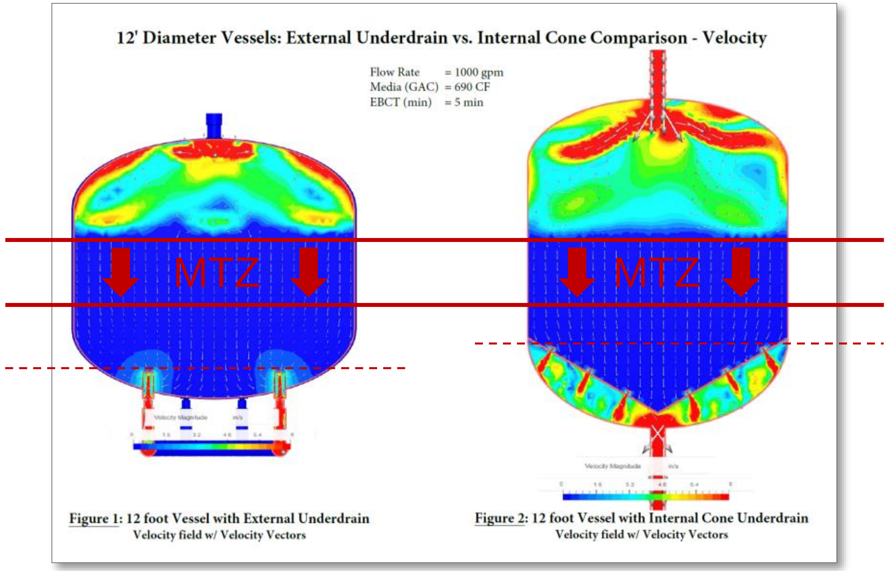
Media Optimization

Importance of Water Distribution

Each vendor has their own versions of each mechanical design, AV has analyzed industry designs to ensure proper water distribution and media optimization.

- Velocity Maps are a valuable tool for visualizing CFD results
  - Overdrain Design
    - The overdrain design dictates distribution above the bed
    - Can also affect the shape of the bed
    - Different media’s call for different overdrains (GAC/IX Resin)
  - Mass Transfer Zone (MTZ) Tracking
    - A well-defined MTZ is a function of hydraulic design
    - Breakthrough occurs when MTZ reaches the top of the nozzles (dotted line)
    - Media volume beneath the top of the highest nozzle is not generally used to full capacity
- Each vendor can have different underdrain geometry
  - Not all underdrains are created equal (changes in dimensions change hydraulic flow patterns)





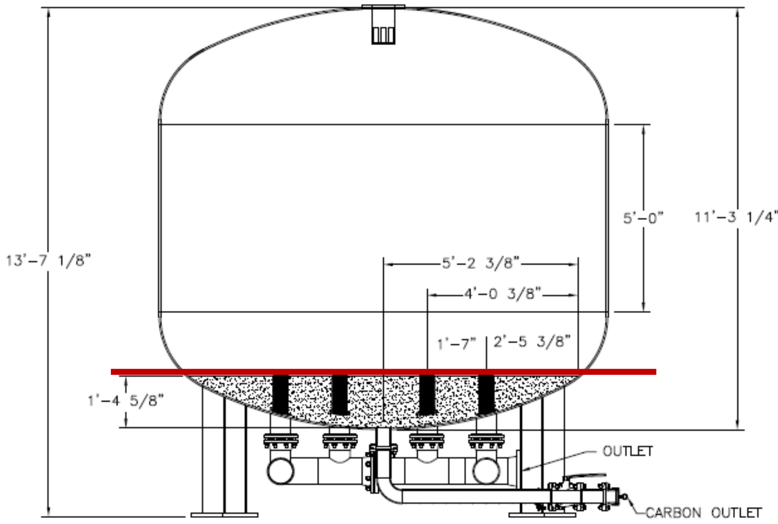
Understanding Initial Breakthrough in Relation to the Underdrain

Contaminated water breakthrough occurs when the leading edge of the MTZ reaches the uppermost nozzle within the underdrain

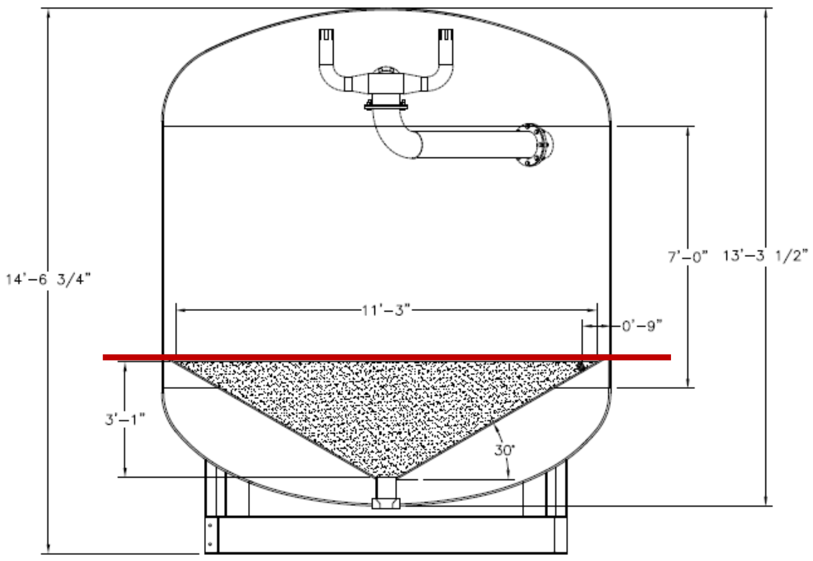
External Ring Header
Volume Beneath Nozzle:
62 ft^3

Internal Cone
Volume Beneath Nozzle:
108 ft^3

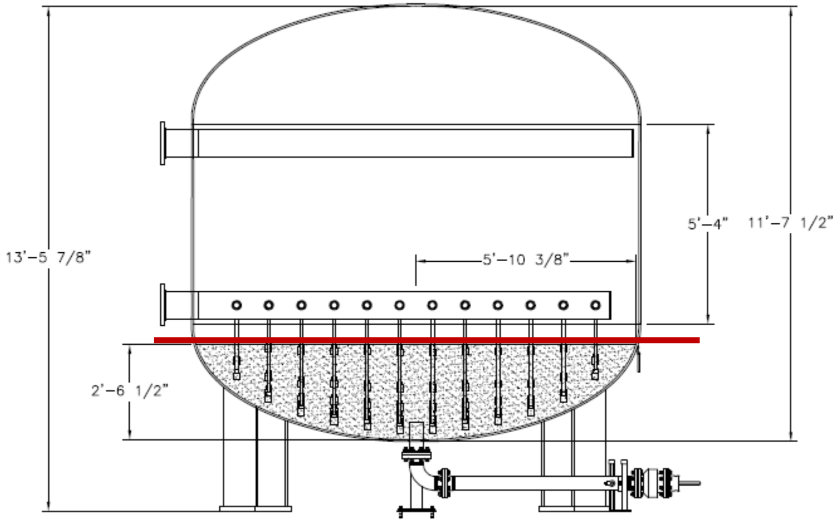
Header Lateral
Volume Beneath Nozzle:
169 ft^3



12' DIA VESSEL
6" SEPTA W/ 2:1 ELLIPTICAL HEAD



12' DIA VESSEL
INTERNAL CONE W/ 2:1 ELLIPTICAL HEAD



12' DIA VESSEL 1
LATERAL UNDERDRAIN W/ 2:1 ELLIPTICAL HEAD

Design Selections Drive Long Term Operational Costs

The most effective utilization of media is determined by hydraulic engineering

External Ring Header
Carbon $144,894
IX Resin $603,723

Internal Cone
Carbon $252,395
IX Resin $1,051,646

Carbon + $107,502
IX Resin +$447,923

Header -Lateral
Carbon $394,952
IX Resin $1,645,631

Carbon +$250,058
IX Resin +$1,041,909

25 Year Life Cycle Comparison of Under Utilized Media

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Section 4

Long Term Operations and Maintenance

Design & Selection of Equipment That Meets Your Long Term O&M Goals

Operators field experience input on design selection is key to understanding future maintenance.

- Making maintenance easy – Select a system that:
  - **Doesn't** require carbon removal for underdrain maintenance or repair
  - **Doesn't** require confined space entry
  - **Does** allow internal maintenance from the exterior of the vessel
  - **Does** have an underdrain that meets the pressure rating of the vessel
- Simpler designs mean easier inspections at service events
  - Robust septa designs reduces change for malfunction
- Underdrain Maintenance
  - External nozzle removal doesn't require confined space entry
- Media Change Outs
  - 4-inch media lines at the top and bottom of the vessel
  - 2:1 elliptical heads allow for easy removal
- GAC versus Ion Exchange
  - GAC more abrasive media on linings
  - GAC requires backwashing, IX resin does not

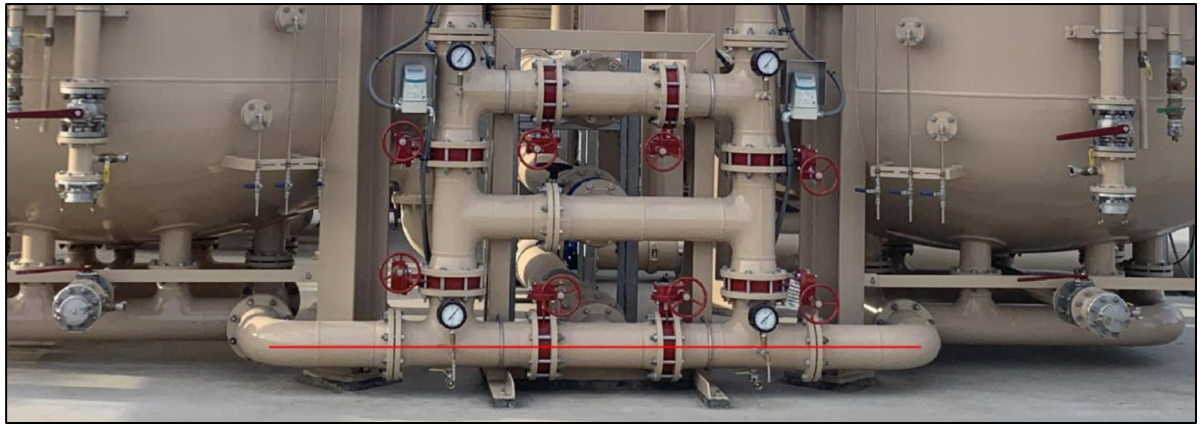
Turnkey Media Change Out Service Events

Changing out the media is a turnkey service provided by most vendors

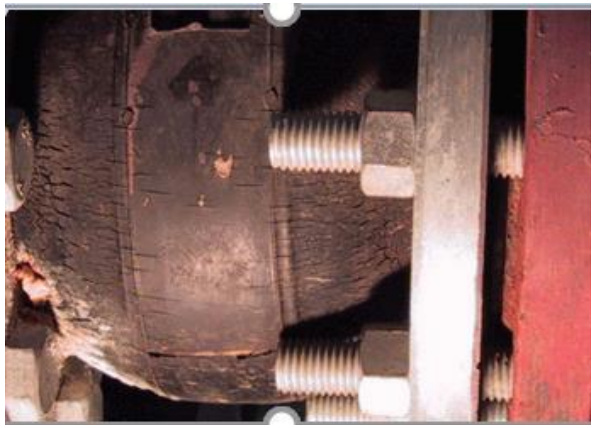
- Vessels features that help facilitate media movement
  - 2:1 elliptical heads allow for easy removal
  - Cone underdrain creates a path down towards the center
- Slurry Method
  - 8 ft. diameter vessel and larger
  - 4-inch media lines at the top and bottom of the vessel
  - Virgin media comes and spent media leaves in the slurry truck
  - A slurry is taking an air compressor to push the media filled with water to and from vessel and slurry truck
- Bag Load and Vacuum
  - For small vessels 6 ft. diameter vessel and smaller
  - The spent media is vacuumed out of the top manway
  - The virgin media is bag loaded over and into the top manway
- Vessel Inspection
  - Between media changes outs a visual inspection should be completed.

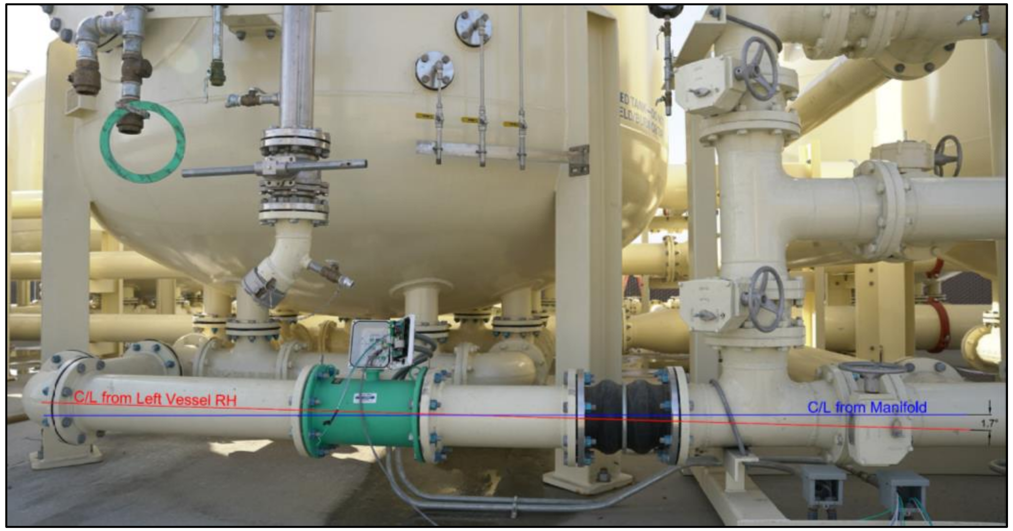
Installation Is Key to Ensure Longevity

Materials have stress limitations, these need to be considered when installing expansion joints



- Pro’s - Expansion joints allow piping to be assembled on site that was not previously fit-up
- Con’s - Expansion joints are an inherently weaker material and cannot be relied on to mitigate all fit-up issues
- Susceptible to the elements
  - EPDM and other polymers photodegrade in UV light – all outdoor applications be wary
  - Expansion joints may need to be replaced early if rubber degrades
- Proper installation is required
- Use of restraining rods increase tensile capacity and horizontal alignment
- Do not use expansion joints to adjust for elevation differences
  - That should be done by leveling the system components
    - Vessels and manifold
- Maintaining elevations between components will ensure vertical alignment





Pressure Vessel Design Comparison

Use of best-in-class designs ensures equipment longevity and ease of maintenance

Description	External Ring Header	Internal Cone	Header Lateral
NACE Standard #RP0178-2007 Compliant	✓	X	✓
Design Mitigates Risk of Corrosion	✓	X	✓
One Homogenous Lining	✓	X	✓
Underdrain Fully Pressure Rated to the Vessel	✓	X	✓
Media Optimized Design Volume Beneath Top Nozzle	✓ 62 ft^3	X 108 ft^3	X 192 ft^3
Optimizes Pressure Drop & Pumping Costs Pressure Drop at 1,000 gpm; 700 ft^3 of carbon (12' vessel lead-lag) Total of Each Nozzles Open Screen Area	✓ ~7 psi 27.6 in^2	X ~15 psi 1.52 in^2	X ~15 psi 1.48 in^2
Prevents Confined Space entry	✓	X	X

Don’t trade your long-term goals for the short-term goals of others

Decisions made in the project design phase will dictate life cycle costs

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- ✓ Per NACE Standard RP0178-2007 and Coating Manufacturer’s Recommendations
- ✓ All immersed vessels have sharp edges ground to 1/8” min. radius.

Long-Term Operation & Maintenance

- ✓ One Homogenous lining to minimize lining repairs
- ✓ External Underdrain Removal for safety practices
- ✓ Media appurtenances can be removed and replaced exterior to the vessel

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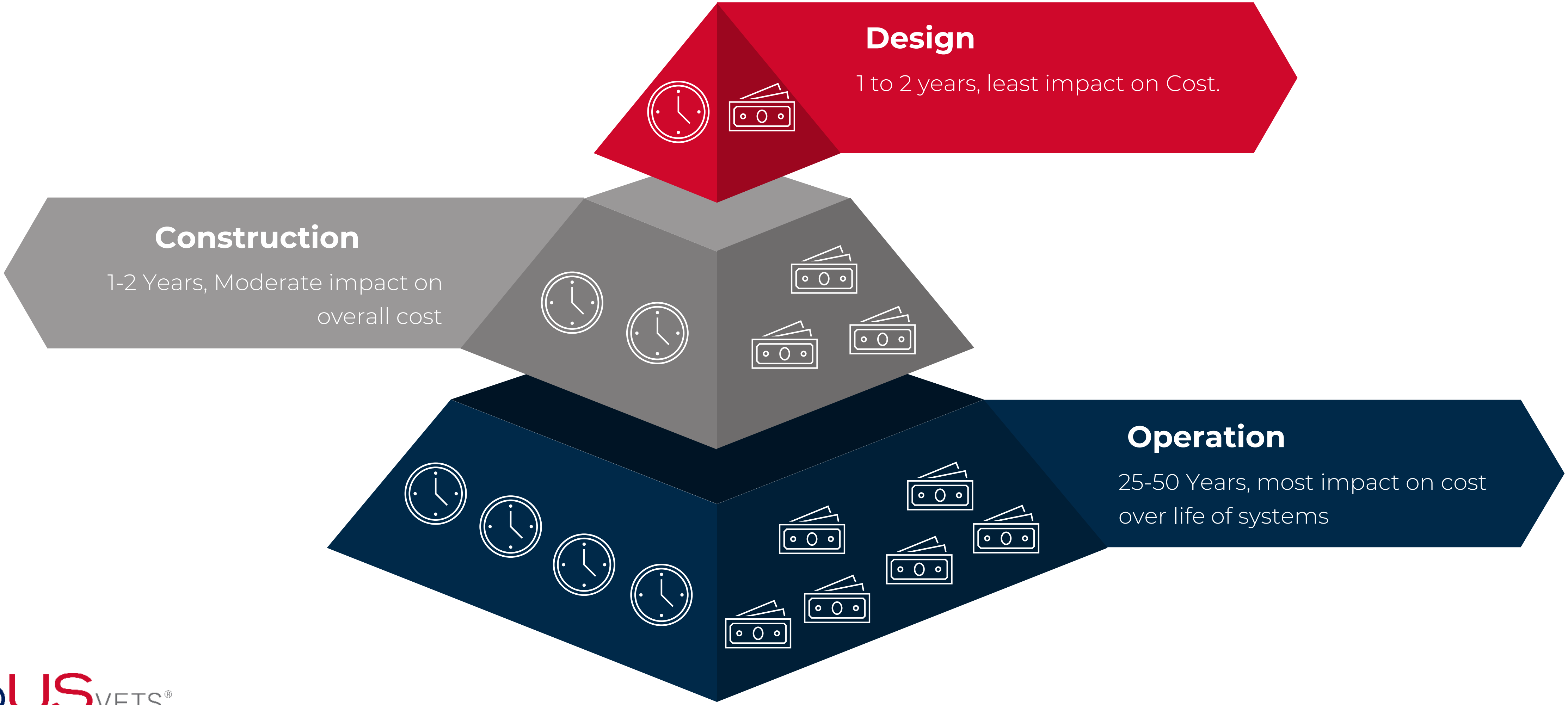
Lowest Cost of Ownership

Design Decisions Drive the Total Cost of Ownership

Don’t trade long term operational goals for short term design decisions



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Questions?

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