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# The Critical Role of Dished Ends in Plastic-Lined GRP Pressure Vessels for Reactor and Scrubbing Applications


## Abstract

This paper examines the structural and operational advantages of dished ends in glass-reinforced plastic (GRP) pressure vessels used in pharmaceutical reactor and fume scrubbing systems. Traditional coned vessel geometries, whilst widely used, introduce fabrication complexity and localised stress concentrations that can affect long-term vessel integrity. Vessels incorporating dished ends with controlled radial transitions offer improved stress distribution, greater fabrication consistency, and enhanced performance under corrosive, high-pressure operating conditions.

This paper presents the technical rationale for preferring dished end designs in critical pharmaceutical applications where process containment, regulatory compliance, and operational reliability are paramount.


## 1. Introduction

### 1.1 Context and Scope

Pressure vessels form the primary containment boundary in both chemical reactor systems and downstream emissions abatement equipment. In pharmaceutical manufacturing environments, these vessels must withstand aggressive chemical species, elevated pressures, thermal cycling, and prolonged service intervals whilst maintaining structural integrity. Design decisions at the vessel junction level, specifically the method of joining cylindrical shell sections to domed or conical end closures - directly influence structural performance, fatigue life, and maintenance requirements.

This paper examines the comparative performance of radial transitions versus traditional coned transitions in plastic-lined GRP pressure vessels, with particular reference to pharmaceutical reactor and scrubbing vessels designed and constructed to the requirements of BS EN 13121 and associated pressure equipment directives.

## 1.2 Functional Commonality Between Reactors and Scrubbers

Although reactor vessels and fume scrubbing vessels perform distinct process functions, they share fundamental engineering requirements. Reactor vessels provide containment for chemical transformations under controlled temperature and pressure,often involving corrosiveor reactive media. Scrubber vessels neutralise hazardous off-gases generated by upstream processes, frequently handling acidic or alkaline species at elevated temperatures.

In integrated pharmaceutical installations, the scrubber functions as an extension of the reactor system. Any structural deficiency in either vessel, whether process-side or emissions-side, introduces systemic risk. Consequently, best practice demands equivalent rigour in the design and fabrication of both vessel types.

# 2.0 Limitations of Traditional Coned Vessel Geometries

## 2.1 Design Background

Conical end closures have historically been employed in GRP vessel construction and are permitted under BS EN 13121 where appropriate radiused knuckle transitions are incorporated. However, conical sections without a knuckle are classified as non-preferred constructions and are generally restricted to static storage applications rather than pressure or cyclic service. The cone-to-cylinder transition provides a method of transitioning from the vessel's cylindrical body to a smaller-diameter outlet or closure. Whilst structurally feasible, this geometry introduces inherent challenges. This junction represents geometric discontinuity, resulting in localised stress intensification relative to the surrounding shell.

## 2.2 Stress Concentration at Cone-to-Cylinder Junctions

The transition zone between conical and cylindrical sections represents discontinuity in shell curvature. Under internal pressure, this discontinuity generates concentration of localised stress. Whilst these can be managed through appropriate laminate design and fillets, the junction remains a region of elevated stress relative to the uniform cylindrical shell.

In fatigue-sensitive applications, particularly those involving pressure or thermal cycling, stress concentrations accelerate crack initiation and propagation. Over extended service life, this can lead to cracks in liner or laminate delamination.

## 2.3 Thermoplastic Liner Integrity

For corrosion-resistant applications, GRP pressure vessels are typically lined with thermoplastic materials such as polypropylene (PP), polyvinyl chloride (PVC), chlorinated polyvinyl chloride (cPVC), polyvinylidene fluoride (PVDF), or fluorinated ethylene propylene (FEP), or ethylene-chlorotrifluoroethylene (ECTFE). The liner must maintain continuity and bond integrity across all vessel surfaces.

The geometric complexity at the cone-to-shell transition increases the likelihood of fabrication defects in the liner, including incomplete weld fusion and surface irregularities such as wrinkles or folds. These imperfections act as stress concentration sites within the liner material. Under thermal cycling or chemical attack, crack initiation at these sites can lead to liner disbondment or perforation, exposing the structural GRP laminate to process media - a failure mode particularly associated with the circumferential weld joint at the transition zone.

# 3. Dished Ends Technology

## 3.1 Design Principle

The use of dished ends eliminates abrupt geometric transitions by employing smooth,continuous radius sections between the cylindrical shell and end closures. This approach replaces the cone-to-cylinder discontinuity with a controlled radial profile, typically matched to a domed or torispherical head geometry.

The radial transition distributes loads more uniformly across the junction, reducing peak stresses and improving fatigue resistance.

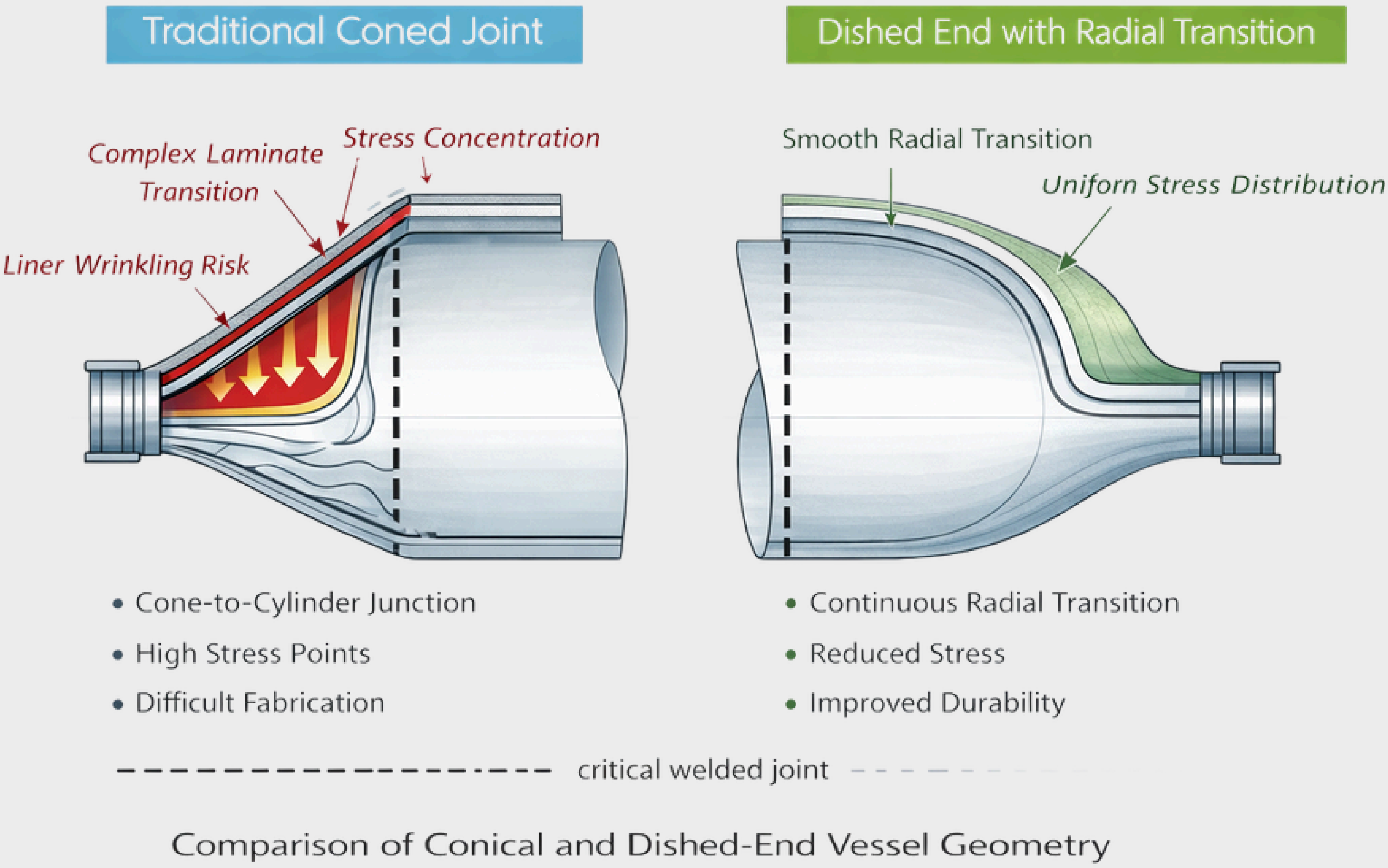



Figure 1: Comparison of coned transition and dished end with radial transition geometry in GRP pressure vessels

## 3.2 Structural Advantages

| Parameter | Advantage of Dished Ends with Radial Transitions |
|---|---|
| Stress distribution | Eliminates cone-to-cylinder stress concentrations; promotes uniform load paths |
| Fatigue resistance | Reduced stress cycling amplitude extends service life under pressure and thermal cycles |
| Laminate quality | Simplified geometry enables more consistent hand lay-up or filament winding |
| Liner integrity | Smooth transitions facilitate thermoplastic liner installation with minimal risk of defects |
| Pressure capacity | Improved load distribution permits higher design pressures for given wall thickness |

Table 1: Comparative structural performance of radial end joins

## 3.3 Fabrication and Quality Assurance

Dished end design is a more robust fabrication in several respects. The smoother geometry allows for:

- More consistent laminate deposition
- Reduced dependence on individual operator skill
- Easier inspection and non-destructive testing access
- Improved reproducibility across multiple vessels
- Enhanced integration with automated or semi-automated fabrication processes

From a quality assurance perspective, radial joins reduce the number of critical control points requiring intensive inspection, thereby improving overall manufacturing consistency.

## 3.4 Thermoplastic Liner Performance

The continuous radial transition geometry provides significant advantages for plastic liner systems. The absence of sharp transitions or conical sections reduces mechanical stress on the liner during installation, thermal expansion, and pressurisation. Liner bond integrity is more readily achieved and maintained, reducing the risk of delamination or chemical ingress to the structural laminate.

## 3.5 Limitations of Dished End Construction

Whilst dished ends offer clear structural advantages, their adoption introduces fabrication considerations. Thermoplastic-lined dished ends require a greater number of welds and longer construction time compared to conical designs, increasing labour costs. The upfront investment in forming tooling represents an additional capital consideration, particularly for non-standard vessel diameters. Material efficiency is also a factor: the thermoplastic liner sheet must be oversized to account for thermal shrinkage during the forming process, and subsequent trimming by the fabricator generates offcut waste. These costs should be weighed against the long-term performance and reliability benefits that dished end designs provide.

# 4. Domed vs Coned End Closures

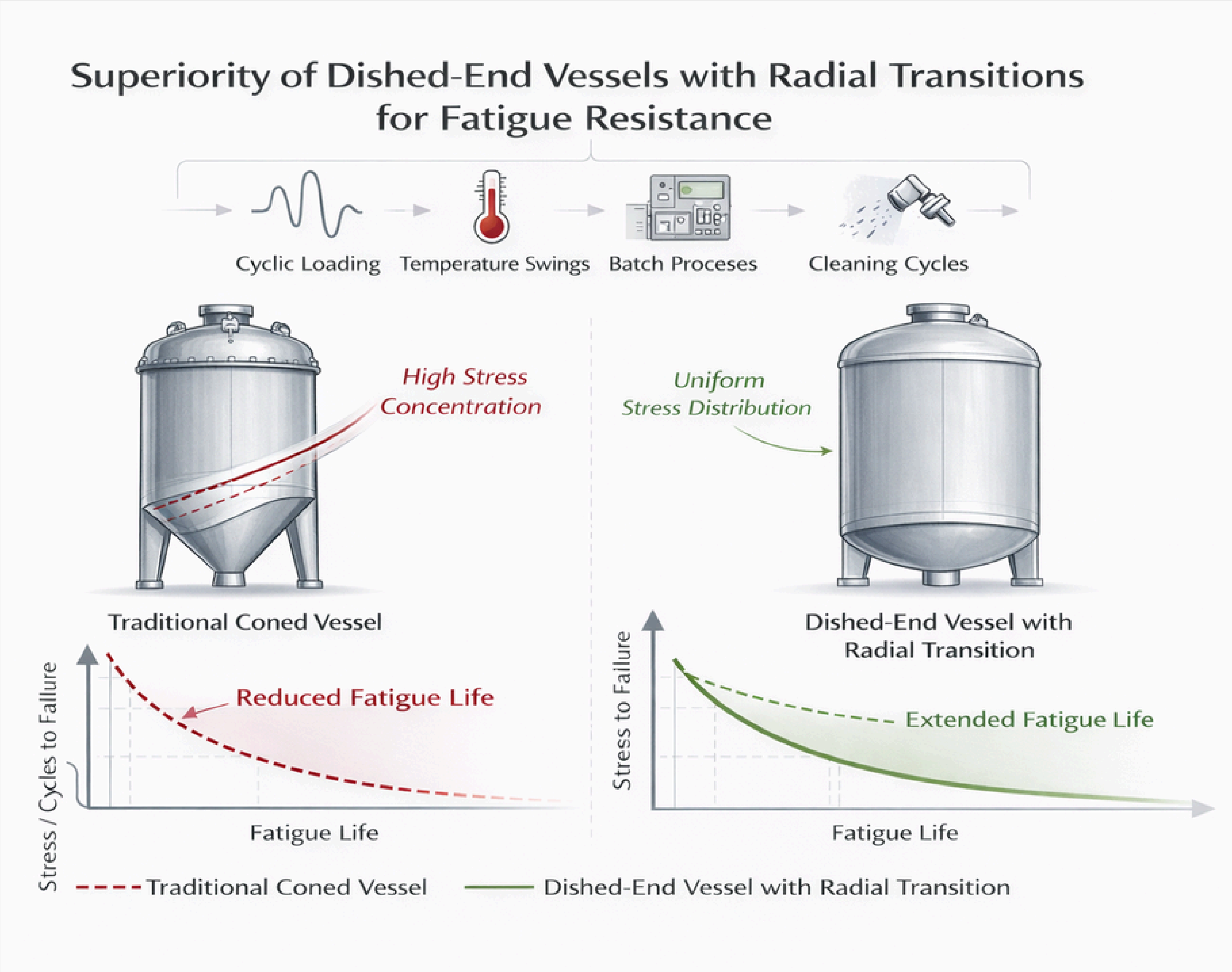
## 4.1 Pressure Equipment Directive and CE Marking

Reactor and scrubbing vessels designed to operate at pressures above 0.5 barg are classified as pressure vessels and fall within the scope of the Pressure Equipment Directive (PED 2014/68/EU). Due to the nature of their application and the potential consequences of failure, the majority of such vessels are categorised as Category IV - the highest risk classification under the PED. This classification carries significant regulatory obligations for both the manufacturer and the operator, requiring independent oversight by an approved Notified Body prior to the vessel being released from manufacture and placed into service.

For a CE mark to be awarded under the PED, the vessel designer and fabricator must demonstrate strict adherence to the requirements of the applicable harmonized standard for both design and manufacture. In the case of thermoplastic lined pressure vessels, BS EN 13121 is the relevant harmonised standard, and the incorporation of a radiused knuckle dished end is a mandatory geometric requirement of that standard. Without this design feature, third party approval of the vessel would not be achievable, and the vessel could not be CE marked under the PED.

## 4.2 Fatigue and Long-Term Performance

Pharmaceutical reactor and scrubber vessels frequently experience cyclic loading, batch processes, temperature swings, start-stop operation, and periodic cleaning cycles. Under such conditions, fatigue performance becomes a key design consideration.
Domed vessels with radial transitions exhibit superior fatigue performance due to reduced stress concentration factors and more uniform load distribution. This translates directly to extended service life and reduced risk of in-service failure.




# 5. Pharmaceutical Industry Requirements

## 5.1 Regulatory and Compliance Context

Pharmaceutical manufacturing operates under stringent regulatory oversight, including:

- Pressure Equipment Directive (PED) 2014/68/EU
- ATEX directives for explosive atmospheres
- Material traceability and validation requirements
- Documentation and change control protocols

## 5.2 Consequences of Vessel Failure

The consequences of pressure vessel failure in pharmaceutical service extend beyond immediate safety concerns:

- Process interruption and batch loss
- Product contamination requiring disposal
- Regulatory reporting and potential manufacturing suspension
- Revalidation costs and timeline impacts
- Reputational and commercial implications

In this context, vessel design decisions that enhance reliability and reduce failure probability provide quantifiable risk reduction and business value.

## 5.3 Reactor and Scrubber Interdependence

In many pharmaceutical installations, reactor off-gases are routed directly to scrubbing systems without intermediate buffering. This creates operational interdependence: scrubber unavailability forces reactor shut down, and vice-versa. Designing both vessels to equivalent standards of structural integrity and reliability is therefore essential for maintaining overall system availability and production continuity.

# 6. Integrated Design and Fabrication Capabilities

## 6.1 System-Level Engineering

Effective pharmaceutical process systems require integration of multiple engineering disciplines: chemical process design, mechanical engineering, materials science, instrumentation and control, and regulatory compliance.

The combination of skid-mounted system integration expertise with specialised plastic fabrication capabilities enables holistic design optimisation. This integrated approach facilitates:

• Materials selection matched to specific process chemistry

• Vessel design optimised for both structural and process performance

• Factory integration and testing prior to site installation

• Unified quality management and traceability

• Single-point responsibility for design, fabrication, and performance

## 6.2 Advanced Materials Integration

Modern pharmaceutical applications increasingly demand high-performance thermoplastic liners - PVDF for aggressive acids, ECTFE for broad chemical resistance, or PFA for ultra-high purity requirements. Effective integration of these materials with GRP structural shells requires both materials expertise and fabrication capability.

Radial transition geometry facilitate the installation and bonding of advanced liner materials, enabling vessels to meet demanding chemical resistance specifications without compromising structural performance.

# 7. Conclusions

The selection of vessel junction geometry represents a critical design decision in pharmaceutical reactor and scrubbing systems. Whilst conical configurations with appropriate knuckle radii remain code-compliant, they introduce inherent structural and fabrication challenges that can compromise long-term reliability.

Dished ends with radial transitions offer demonstrable advantages:

• Superior stress distribution and fatigue resistance

• Enhanced fabrication consistency and quality assurance

• Improved thermoplastic liner integrity

• Reduced lifecycle maintenance requirements

• Greater design margin for demanding operating conditions

As pharmaceutical processes become increasingly demanding and regulatory expectations continue to evolve, the importance of robust, reliable pressure vessel design will only increase. Dished end technology represents a clear advancement in engineering practice, delivering quantifiable improvements in structural performance, fabrication quality, and operational confidence.

For critical applications where process integrity, personnel safety, and regulatory compliance are paramount, dished ends should be considered the preferred engineering solution. This approach aligns with both established design principles and emerging best practice for high-specification pharmaceutical applications.

## 8. Recommendations

1. Specify radial transitions with domed end closures for new pharmaceutical reactor and scrubber vessel designs
2. Review existing coned vessels for potential upgrade or replacement, particularly those experiencing cyclic loading or approaching end of design life
3. Ensure fabrication partners possess demonstrated competence in dished end and radius knuckle technology and thermoplastic liner integration
4. Implement comprehensive quality assurance protocols covering laminate inspection, liner bond testing, and pressure testing
5. Maintain detailed documentation and traceability for regulatory validation and lifecycle management

## 8. References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