

API 579-2 / ASME PTB-14-2023 – 2nd Edition

Fitness-For-Service Example Problems Manual

API/ASME Joint Fitness-For-Service Committee



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Contact the Publishers: API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990.

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FOREWORD

This publication supersedes API 579-2, 1st Edition/ASME FFS-2, which has been redesignated by ASME as ASME PTB-14. It is provided to illustrate the calculations used in the assessment procedures in API 579-1/ASME FFS-1 published in December 2021. API 579-1/ASME FFS-1 was written to be used in conjunction with industry's existing codes for pressure vessels, piping and aboveground storage tanks (e.g., API 510, API 570, API 653, and NBBI NB 23 (NBIC)). The standardized *Fitness-For-Service* Assessment procedures presented in API 579-1/ASME FFS-1 provide technically sound consensus approaches that ensure the safety of plant personnel and the public while aging equipment continues to operate and can be used to optimize maintenance and operation practices, maintain availability and enhance the long-term economic performance of plant equipment.

This publication is written as an API/ASME PTB technical publication. Its words *shall* and *must* indicate explicit requirements that are essential for an assessment procedure to be correct. The word *should* indicates recommendations that are good practice but not essential. The word *may* indicates recommendations that are optional.

The API/ASME Joint Fitness-For-Service Committee intends to continuously improve this publication as changes are made to API 579-1/ASME FFS-1. All users are encouraged to inform the committee if they discover areas in which these procedures should be corrected, revised or expanded. Suggestions should be submitted to the Secretary, API/ASME Fitness-For-Service Joint Committee, The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016, or SecretaryFFS@asme.org or to the Standards Department, API, 200 Massachusetts Avenue NW, Suite 1100, Washington, DC 20001, standards@api.org.

Items approved as errata to this edition are published on the ASME website under Committee Pages at <http://cstools.asme.org>. Under Committee Pages, expand Board on Pressure Technology Codes & Standards and select ASME/API Joint Committee on *Fitness-For-Service*. The errata are posted under Publication Information.

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PART 1

INTRODUCTION

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1.1 Introduction

Fitness-For-Service (*FFS*) Assessments in API 579-1/ASME FFS-1 Fitness-For-Service are engineering evaluations that are performed to demonstrate the structural integrity of an in-service component that may contain a flaw or damage or that may be operating under specific conditions that could produce a failure. API 579-1/ASME FFS-1 provides guidance for conducting *FFS* Assessments using methodologies specifically prepared for pressurized equipment. The guidelines provided in this standard may be used to make run-repair-replace decisions to help determine if pressurized equipment containing flaws that have been identified by inspection can continue to operate safely for some period of time. These *FFS* Assessments of API 579-1/ASME FFS-1 are currently recognized and referenced by the API Codes and Standards (510, 570, and 653), and by NB-23 as suitable means for evaluating the structural integrity of pressure vessels, piping systems and storage tanks where inspection has revealed degradation and flaws in the equipment or where operating conditions suggest that a risk of failure may be present.

1.2 Scope

Example problems illustrating the use and calculations required for Fitness-For-Service Assessments described in API 579-1/ASME FFS-1 are provided in this document. Example problems are provided for all calculation procedures in both SI and US Customary units.

1.3 Organization and Use

An introduction to the example problems in this document is described in Part 2 of this Standard. The remaining Parts of this document contain the example problems. The Parts in this document coincide with the Parts in API 579-1/ASME FFS-1. For example, example problems illustrating calculations for local thin areas are provided in Part 5 of this document. This coincides with the assessment procedures for local thin areas contained in API 579-1/ASME FFS-1, Part 5.

1.4 References

API 579-1/ASME FFS-1 *Fitness-For-Service*.

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PART 2

FITNESS-FOR-SERVICE ENGINEERING ASSESSMENT PROCEDURE

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2.1 General

The Fitness-For-Service (*FFS*) Assessment procedures in API 579-1/ASME FFS-1 are organized by flaw type or damage mechanism. A list of flaw types and damage mechanisms and the corresponding Part that provides the *FFS* Assessment methodology is shown in API 579-1/ASME FFS-1, Part 2, Table 2.1. In some cases, it is required to use the assessment procedures from multiple Parts based on the damage mechanism being evaluated.

Example problems are provided for each Part and for each assessment level, see API 579-1/ASME FFS-1. In addition, example problems have also been provided to illustrate the interaction among Parts as required by the assessment procedures in API 579-1/ASME FFS-1. A summary of the example problems is contained in Tables E2.3-1–E2.3-12.

2.2 Calculation Precision

The calculation precision used in the example problems is intended for demonstration purposes only; an intended precision is not implied. In general, the calculation precision should be equivalent to that obtained by computer implementation, rounding of calculations should only be done on the final results.

2.3 Tables

Table E2.3-1 – Part 3 Examples on Assessment for Brittle Fracture

Example	Assessment Level	Units	Type of Equipment	Geometry	Type or Description of Analysis
1	1	US	Pressure Vessel	---	MAT calculation with PWHT
2	1	US	Pressure Vessel	Cylinder	MAT calculation without PWHT
3	1	US	Pressure Vessel	---	MAT calculation without PWHT
4	1	US	Pressure Vessel	---	MAT calculation with PWHT
5	2	US	Pressure Vessel	---	MAT reduction vs P/P _{rating} (Pressure Temperature Rating Basis)
6	2	SI	Pressure Vessel	Cylinder	MAT reduction vs S*E*/SE (Stress Basis)
7	1 and 2	US	Pressure Vessel	Sphere	MAT reduction vs S*E*/SE (Stress Basis)
8	2	US	Pressure Vessel	Sphere	MAT reduction vs S*E*/SE (Stress Basis)
9	2	US	Pressure Vessel	Sphere	MAT reduction vs operating pressure / hydrotest pressure
10	3	US	Demethanizer Tower	---	Assessment based on fracture mechanics principles of Part 9
11	1 and 2	US	Atmospheric Storage Tank	Cylinder	Level 1 and Level 2 Assessment to Determine the MAT
12	1, 2 and 3	US	Deethanizer Column	Cylinder	Level 1, 2, and 3 Assessments to Determine the MAT
13	1 and 2	US	Carbon Steel Pipe	Cylinder	Level 1 and 2 Assessments to Determine the MAT
14	2	US	Drum	Cylinder	Level 2 Assessment to Determine the MAT Envelope
15	2	US	Tower	Cylinder	Level 2 Assessment to Determine the MAT Envelope
16	2	US	Pressure Vessel	Nozzle	Level 2 Assessment to Determine the MAT for the Nozzle Assembly

Table E2.3-2 – Part 4 Examples on Assessment of General Metal Loss

Example	Assessment Level	Units	Type of Equipment	Geometry	Location of Metal Loss	Loading(s)	Average Thickness Based on
1	1 and 2	SI	Heat Exchanger	Cylinder	Away From Major Structural Discontinuity	Internal Pressure and Full Vacuum	Point thickness reading
2	1 and 2	US	Pressure Vessel	Cylinder	Away From Major Structural Discontinuity	Internal Pressure	Critical thickness profiles
3	1 and 2	SI	Pressure Vessel	Elliptical Head	Away From Major Structural Discontinuity	Internal Pressure	Critical thickness profiles
4	2	US	Pressure Vessel	Nozzle	At Major Structural Discontinuity	Internal Pressure	Inspection Data
5	1 and 2	US	Piping	Cylinder	Away From Major Structural Discontinuity	Internal Pressure	Inspection Data
6	1 and 2	US	Bottom Shell Course of an Atmospheric Storage Tank	Cylinder	Away From Major Structural Discontinuity	Liquid Head	Inspection Data
7	2	SI	Pressure Vessel	Conical Transition	At Major Structural Discontinuity	Internal Pressure	Inspection Data

Table E2.3-3 – Part 5 Examples on Assessment of Local Metal Loss

Example	Assessment Level	Units	Type of Equipment	Geometry	Location of Metal Loss	Loading(s)	Type of Metal Loss
1	1	US	Pressure Vessel	Cylinder	Away From Major Structural Discontinuity	Internal pressure	LTA
2	1 and 2	US	Pressure Vessel	Cylinder	Away From Major Structural Discontinuity	Internal pressure	2 Grooves
3	2	US	Pressure Vessel	Cylinder	Away From Major Structural Discontinuity	Internal Pressure and Supplemental Loads	LTA
4	2	US	Pressure Vessel	Cylinder	Away From Major Structural Discontinuity	Internal Pressure	LTA
5	1	SI	Pressure Vessel	Cylinder	Away From Major Structural Discontinuity	Internal Pressure	LTA
6	2	US	Pressure Vessel	Nozzle	At Major Structural Discontinuity	Internal Pressure	Uniform LTA
7	1	US	Storage Tank	Cylinder	Away From Major Structural Discontinuity	Fill Height	LTA
8	1	US	Piping	Elbow	Away From Major Structural Discontinuity	Internal Pressure	Uniform LTA
9	2	US	Pressure Vessel	Cylinder	Away From Major Structural Discontinuity	Vacuum	LTA
10	2	US	Piping System	Cylinder	Away From Major Structural Discontinuity	Internal pressure and Piping System Forces and Moments	LTA
11	1	US	Piping	Cylinder	Away From Major Structural Discontinuity	Internal pressure and Piping System Forces and Moments	LTA

Table E2.3-4 – Part 6 Examples on Assessment of Pitting Corrosion

Example	Assessment Level	Units	Type of Equipment	Geometry	Loading(s)	Type of Pitting	Comment
1	1	US	Pressure Vessel	Cylinder	Internal pressure	Widespread pitting	---
2	1	SI	Piping	Cylinder	Internal pressure	Widespread pitting	---
3	2	US	Horizontal Pressure Vessel	Cylinder	Internal pressure Supplemental loads	Widely scattered pitting	---
4	2	US	Pressure Vessel	Cylinder	Internal pressure	Localized pitting	LTA per Part 5 Level 1
5	2	US	Pressure Vessel	Cylinder	Internal pressure	Pitting in LTA	LTA per Part 5 Level 1
6	2	US	Pressure Vessel	Cylinder	Internal pressure	Widespread pitting Inside and outside	---

Table E2.3-5 – Part 7 Examples on Assessment of Blisters and HIC and SOHIC Damage

HIC Damages						
Example	HIC Area	Level	Location in Thickness	Comment	Service Condition	
1	1	1 and 2	Surface breaking	Level 2 per Part 5 Level 1	Equipment Will Remain in Hydrogen Charging Service	
	2a	1	Surface breaking	Combined		
	2b		Sub surface			
	3	1	Surface breaking	---		
	4	1 and 2	Sub surface	Level 2 per Part 5 Level 1		
3	1	1	Sub surface	---	Equipment Will Not Remain in Hydrogen Charging Service	
	2	1 and 2	Sub surface	Level 2 per Part 5 Level 1		
4		1, 2 and 3	Sub surface	Level 3 per Part 7	Equipment Will Remain in Hydrogen Charging Service	
Blisters						
Example	Blister	Level	Bulge Direction	Cracking at Periphery	Crown Cracking or Venting	Comment
2	A	1 and 2	Outside	No	Crack	Level 2 per Part 5 Level 1
	B	1	Outside	No	Vent	---
	C	1	Inside	No	Vent	---
	D	1 and 2	Inside	No	Crack	Level 2 per Part 5 Level 1
	E	1	Inside	No	Vent	---
	F	1	Inside	No	No	---
	G	1 and 2	Outside	Yes (Inward)	Crack	Level 2 per Part 5 Level 1
	H	1 and 2	Outside	No	Vent	Level 2 per Part 5 Level 1

Note: Common characteristics:

- Type of Equipment: Pressure Vessel
- Geometry: Cylinder
- Units: US
- Loading: Internal pressure

Table E2.3-6 – Part 8 Examples on Assessment of Weld Misalignment and Shell Distortions

Example	Assessment Level	Units	Type of Equipment	Geometry	Loading(s)	Type of Damage	Comment
1	1 and 2	US	Piping	Cylinder	Internal Pressure	Weld Misalignment	Peaking
2	2	US	Piping	Cylinder	Fluctuating Internal Pressure	Weld Misalignment Peaking	Fatigue Assessment By: - Elastic Stress Analysis and Equivalent Stress - Elastic Stress Analysis and Structural Stress
3	1 and 2	US	Pressure Vessel	Cylinder	Internal Pressure	Out-of-Roundness	Assessment Based On D_{max} - D_{min}
4	2	US	Pressure Vessel	Cylinder	Internal Pressure	Weld Misalignment	Center Line Offset and Peaking
5	1 and 2	US	Pressure Vessel	Cylinder	Internal Pressure	Out-of-Roundness	Assessment Based on Radius Expressed as A Fourier Series
6	1 and 3	US	Pressure Vessel	Shell - Heads - Stiffening Rings	Internal Pressure Vacuum Conditions	General Shell Distortion	Level 3 Based on Finite Element Analysis: - Limit Load Analysis (Elastic Perfectly Plastic Material Behavior) - Check Of Local Strain (Elastic-Plastic With Strain Hardening Material Behavior) - Elastic Buckling Analysis (Check Of Stability Of Deformed Shell) - Check Of Fatigue Requirements
7	1, 2 and 3	US	Pressure Vessel	Shell - Heads - Stiffening Rings	Internal Pressure, External Pressure, and Wind Loading	General Shell Distortion	Level 3 Based on Finite Element Analysis: - Elastic-Plastic Analysis (Elastic-Plastic with Strain Hardening Material Behavior) - Elastic Buckling Analysis (Check of Stability Of Deformed Shell)

Table E2.3-7 – Part 9 Examples on Assessment of Crack-Like Flaws

Example	Assessment Level	Units	Type of Equipment	Geometry	Loading(s)	Type of Crack	Comment
1	1	US	Pressure Vessel	Cylinder	Internal Pressure	- Longitudinal - Semi-Elliptical	Shallow Crack in Parallel to Weld Seam
2	1	SI	Pressure Vessel	Sphere	Internal Pressure	- Circumferential - Semi-Elliptical	Deep Crack Perpendicular to Weld Seam
3	1 and 2	US	Pressure Vessel	Cylinder	Internal Pressure	- Semi-Elliptical - Oriented At 30° From Principal Direction	Flaw Length to Be Used In Assessment
4	1 and 2	US	Pressure Vessel	Cylinder	Internal Pressure	- Semi-Elliptical - Oriented Along Bevel Angle	Flaw Depth to Be Used In Assessment
5	1 and 2	US	Pressure Vessel	Cylinder	Internal Pressure	- Longitudinal - Semi-Elliptical	- Residual Stresses Due to Welding Based On Surface Distribution - Uniform Distribution Along Thickness
6	1 and 2	SI	Piping	Cylinder	Internal Pressure Global Bending Moment	- Circumferential - 360° Crack	- Residual Stresses Due to Welding Based On Through-Thickness Distribution - Fourth Order Polynomial Along Thickness
7	2	SI	Piping	Cylinder	Internal Pressure Global Bending Moment	- Circumferential - Semi-Elliptical	- Residual Stresses Identical to Those Of Example 9.6 - Coefficients Of Polynomial Calculated by Weight Function Method
8	3	US	Pressure Vessel	Cylinder	Internal Pressure	- Longitudinal - Semi-Elliptical	- Residual Stresses Identical To Those Of Example 9.5 - Subcritical Fatigue Crack Growth - Remaining Life Assessment
9	3	US	---	---	---	---	Failure Assessment Diagram Based on Actual Material Properties
10	3	SI	---	---	---	---	Lower Bound Fracture Toughness from CVN Test Results

Table E2.3-7 – Part 9 Examples on Assessment of Crack-Like Flaws

Example	Assessment Level	Units	Type of Equipment	Geometry	Loading(s)	Type of Crack	Comment
11	3	SI	Pressure Vessel	Nozzle	Internal Pressure	- Quarter-Elliptical	Assessment Based on Elastic-Plastic Finite Element Analysis
12	2	US	Pressure Vessel	Cylinder	Internal pressure	Axial External Semi-Elliptical Surface Crack	Toughness Adjustment Using T-Stress

Table E2.3-8 – Part 10 Examples on Assessment of Components Operating in the Creep Range

Example	Assessment Level	Units	Type of Equipment	Geometry	Loading(s)	Comment
1	1	US	Pressure Vessel	Cylinder Elliptical Head	Internal Pressure	- Temperature excursion in the creep range - Check that damage is below the acceptable one
2	1	US	Heater	Tubes	Internal Pressure	- Heater operating in the creep range - Excursion at higher temperature than design one - Calculation of overall damage in the complete expected life
3	2	US	Heater	Tubes	Internal Pressure	- Same as example 10.2 with the addition of - Calculation of remaining life using Larson Miller parameters
4	3	US	Pressure Vessel	Cylinder	Internal Pressure	- Vessel operating in the creep range - Longitudinal semi-elliptical surface crack - Creep crack growth - Calculation of remaining life using MPC Omega project data
5	3	US	Pressure Vessel	Cylinder Nozzle Weld	Internal Pressure	- Dissimilar Weld Joint - Modes I and II creep-fatigue damage

Table E2.3-9 – Part 11 Examples on Assessment of Fire Damage

Example	Assessment Level	Units	Type of Equipment	Geometry	Loading(s)	Comment
1	1	US	Distillation Column Wall	---	Internal Pressure	Heat Affected Zone (HEZ) From Observation After Fire
2	1	US	Horizontal Pressure Vessel	Cylinder	Internal Pressure Supplemental Loads	Heat Affected Zone (HEZ) From Observation After Fire
	2					Allowable Stress from Hardness Results
3	1	US (+SI)	Depropanizer Tower	---	Internal Pressure	Heat Affected Zone (HEZ) From Observation After Fire
	2					Allowable Stress from Hardness Results
	3					- Stress Analysis for Shell Distortion - Testing And Metallographic Evaluation of Material Samples
4	1 and 2	SI	Distillation Column Reboiler	---	Internal Pressure	Heat Affected Zone (HEZ) From Observation After Fire and Level 2 Assessment
5	1 and 2	US	Vessels, Piping and Bolting	---	Internal Pressure	Heat Affected Zone (HEZ) From Observation After Fire and Level 2 Assessment
6	1, 2, and 3	US	FCC Unit	---	Internal Pressure	Heat Affected Zone (HEZ) From Observation After Fire, Level 2 and Level 3 Assessments
7	1 and 2	US	Pressure Vessel	---	Internal Pressure	Heat Affected Zone (HEZ) From Observation After Fire and Level 2 Assessment

Table E2.3-10 – Part 12 Examples on Assessment of Dents, Gouges and Dent-Gouge Combinations

Example	Assessment Level	Units	Type of Equipment	Geometry	Type of Damage	Loading(s)	Comment
1	1	SI	Piping	Cylinder	Dent	Internal Pressure	---
2	2	SI	Piping	Cylinder	Dent	Fluctuating Internal Pressure	Fatigue analysis
3	1	SI	Piping	Cylinder	Gouge	Internal Pressure	---
4	1	SI	Piping	Cylinder	Dent-Gouge	Internal Pressure	---
5	2	SI	Piping	Cylinder	Dent-Gouge	Internal Pressure	---

Table E2.3-11 – Part 13 Examples on Assessment of Laminations

Example	Assessment Level	Units	Type of Equipment	Geometry	Loading(s)	Comment
1	1	US	Pressure Vessel	Cylinder	Internal Pressure	- 2 laminations away from major structural discontinuity - Not in hydrogen charging service
2	2	US	Pressure Vessel	Cylinder	Internal Pressure	---

Table E2.3-12 – Part 14 Examples on Assessment of Fatigue Damage

Example	Assessment Level	Units	Type of Equipment	Geometry	Loading(s)	Comment
1	1	US	Pressure Vessel	Cylinder With Hemispherical Head	Internal Pressure	Level 1 Method B Screening Analysis
2	2	US	Pressure Vessel	Cylinder With Hemispherical Head	Internal Pressure	Level 1 Method B and Method C Screening Analyses
3	2	US	Pressure Vessel	Hemispherical Head with Full-Penetration Welded Nozzle	Internal Pressure	Level 2 Method B and method C fatigue Assessment at a Weld Toe Location
4	2	US	Pressure Vessel	Hemispherical Head With Petal-Forged Nozzle	Internal Pressure	- Level 2 Method A And Method B Fatigue Analysis - Fatigue Lives Are Identical as Material's Response Is Elastic
5	2 and 3	US	Pressure Vessel	Hemispherical Head with Petal-Forged Nozzle	Internal Pressure with Variable Amplitude Axial Force	- Demonstration of Level 2 And Level 3 Cycle Counting Methods - Vessel Fails Level 2 Method A and Method B, Passes Level 3 Method B at the Critical Forging Location - Vessel Passes Level 2 Method C at a Weld Toe Location
6	2	US	Pressure Vessel	Cylinder With Peaking	Internal Pressure	Peaking In the Cylindrical Shell Significantly Reduces The Fatigue Life
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PART 3

ASSESSMENT OF EXISTING EQUIPMENT FOR BRITTLE FRACTURE

EXAMPLE PROBLEMS

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3.1 Example Problem 1

A pressure vessel, 1 in thick, fabricated from *SA – 285 Grade C* was originally subject to *PWHT* at the time of construction. The vessel was constructed to the ASME B&PV Code, Section VIII, Division 1. Determine the Level 1 *MAT* for the shell section.

Vessel Data:

- Material = *SA – 285 Grade C*
- Uncorroded Thickness = *1.0 in*
- Impact Test Data = *None Available*
- Stress Relief (i.e., *PWHT*) = *Yes*

Perform a Level 1 Assessment per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1 – Option A.

Since the equipment was constructed to the ASME B&PV Code, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1.

- a) STEP 1 – Determine the starting point for the *MAT* (Minimum Allowable Temperature) using a governing thickness and the exemption curves shown in API 579-1/ASME FFS-1, Part 3, Figure 3.5 (or Table 3.4).

- 1) STEP 1.1 – For the component under consideration, determine the following parameters:
 - i. Nominal uncorroded thickness at each weld joint, $t_n = 1.0$.
 - ii. Material of construction: *SA – 285 Grade C*.
- 2) STEP 1.2 – Determine the uncorroded governing thickness, $t_g = 1.0$ in (only one component).
- 3) STEP 1.3 – Determine the applicable material impact test exemption curve of API 579-1/ASME FFS-1, Part 3, Figure 3.5, *Curve A*.
- 4) STEP 1.4 – Determine the *MAT* from API 579-1/ASME FFS-1, Part 3, Figure 3.5 based on the applicable material impact test exemption curve and the governing thickness, t_g . Based on Curve A in API 579-1/ASME FFS-1, Part 3, Figure 3.5, *MAT* for the component without any allowance for *PWHT*, *MAT* = 68°F.
- 5) STEP 1.5 – The *MAT* determined in STEP 1.4 can be reduced further using API 579-1/ASME FFS-1, Part 3, Equation (3.1) if all the following are true:
 - i. The *MAT* in STEP 1.4 was determined using API 579-1/ASME FFS-1, Part 3, Figure 3.5, *True*.
 - ii. The component was fabricated from ASME P1 Group 1 or P1 Group 2 material, *True*.
 - iii. The component has a weld thickness that is less than or equal to 38 mm (1.5 in), and *True*.
 - iv. The component was subject to *PWHT* and the status of the *PWHT* has not been changed because of repairs and/or alterations, *True*.

$$MAT = \max \left[\left(MAT_{STEP\ 1.4} - 30^{\circ}F \right), -55^{\circ}F \right]$$

$$MAT = \max \left[\left(68^{\circ}F - 30^{\circ}F \right), -55^{\circ}F \right] = 38^{\circ}F$$

- b) STEP 2 – Repeat STEP 1 for all components that make-up the piece of equipment being evaluated.

No further evaluation is required since there is only one component.

3.2 Example Problem 2

The cylindrical shell of a horizontal vessel of 0.5 *in* thickness is fabricated from *SA – 53 Grade B* seamless pipe. There is no toughness data on the material. The vessel was constructed to the ASME B&PV Code, Section VIII, Division 1. Determine the Level 1 *MAT*.

Vessel Data:

- Material = *SA – 53 Grade B*
- Uncorroded Thickness = *0.50 in*
- Impact Test Data = *None Available*
- Stress Relief (i.e., *PWHT*) = *No*

Perform a Level 1 Assessment per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1 – Option A.

Since the equipment was constructed to the ASME B&PV Code, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1.

- a) STEP 1 – Determine the starting point for the *MAT* (Minimum Allowable Temperature) using a governing thickness and the exemption curves shown in API 579-1/ASME FFS-1, Part 3, Figure 3.5 (or Table 3.4).
 - 1) STEP 1.1 – For the component under consideration, determine the following parameters:
 - i. Nominal uncorroded thickness at each weld joint, $t_n = 0.50 \text{ in}$.
 - ii. Material of construction: *SA – 53 Grade B*.
 - 2) STEP 1.2 – Determine the uncorroded governing thickness, $t_g = 0.5 \text{ in}$, (only one component).
 - 3) STEP 1.3 – Determine the applicable material impact test exemption curve of API 579-1/ASME FFS-1, Part 3, Figure 3.5 (all pipe, fittings, forgings, and tubing not listed for Curves A, C and D are included in the Curve B material group), *Curve B*.
 - 4) STEP 1.4 – Determine the *MAT* from API 579-1/ASME FFS-1, Part 3, Figure 3.5 based on the applicable material impact test exemption curve and the governing thickness, t_g . Based on Curve B in API 579-1/ASME FFS-1, Part 3, Figure 3.5, *MAT* for the component without any allowance for *PWHT*, $MAT = -7^\circ\text{F}$.
 - 5) STEP 1.5 – The *MAT* determined in STEP 1.4 can be reduced further using API 579-1/ASME FFS-1, Part 3, Equation (3.1) if all the following are true:
 - i. The *MAT* in STEP 1.4 was determined using API 579-1/ASME FFS-1, Part 3, Figure 3.5, *True*.
 - ii. The component was fabricated from ASME P1 Group 1 or P1 Group 2 material, *True*.
 - iii. The component has a weld thickness that is less than or equal to 38 *mm* (1.5 *in*), and *True*.
 - iv. The component was subject to *PWHT* and the status of the *PWHT* has not been changed because of repairs and/or alterations, *False*.

$$MAT = -7^\circ F$$

- b) STEP 2 – Repeat STEP 1 for all components that make-up the piece of equipment being evaluated.

No further evaluation is required since there is only one component.

Note: For comparison, the Minimum Design Metal Temperature (*MDMT*) from ASME B&PV Code Section VIII, Division 1 for a pressure vessel made using Curve B material of wall thickness below 1 *inch* is $-20^{\circ}F$ (per paragraph UG-20(f)). This is provided that the pressure vessel design is not governed by thermal or mechanical shock loading or by cyclic loading and that the constructed vessel was subjected to either hydrostatic or pneumatic test as required by the construction code.

3.3 Example Problem 3

A horizontal drum 1.5 *in* thick is fabricated from *SA – 516 Grade 70* steel that was supplied in the normalized condition. There is no toughness data on the steel. The vessel was constructed to the 2021 edition of the ASME B&PV Code, Section VIII, Division 1. Determine the Level 1 *MAT* for the shell section and compare to the *CET* to determine acceptability.

Vessel Data:

- Material = *SA – 516 Grade 70, Normalized*
- Design conditions = *420 psig @ 70°F*
- Uncorroded Thickness = *1.5 in*
- Inside diameter (*ID*) = *120 in*
- Impact Test Data = *None Available*
- Stress Relief (i.e., *PWHT*) = *Yes* (see ASME BPVC VIII.1, UCS-56-1 for *PWHT* requirements of P-No. 1 materials)
- *CET* (Critical Exposure Temperature) = *–20°F*

Perform a Level 1 Assessment per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1 – Option A.

Since the equipment was constructed to the ASME B&PV Code, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1. The owner-operator confirmed all other requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2 is satisfied.

- a) STEP 1 – Determine the starting point for the *MAT* (Minimum Allowable Temperature) using a governing thickness and the exemption curves shown in API 579-1/ASME FFS-1, Part 3, Figure 3.5 (or Table 3.4).
 - 1) STEP 1.1 – For the component under consideration, determine the following parameters:
 - i. Nominal uncorroded thickness at each weld joint, $t_n = 1.5 \text{ in}$.
 - ii. Material of construction: *SA – 516 Grade 70, Normalized*.
 - 2) STEP 1.2 – Determine the uncorroded governing thickness, $t_g = 1.5 \text{ in}$ (only one component).
 - 3) STEP 1.3 – Determine the applicable material impact test exemption curve of API 579-1/ASME FFS-1, Part 3, Figure 3.5 (*SA – 516 Grade 70* is manufactured to a fine grain practice and was supplied in this case in the normalized condition), *Curve D*.
 - 4) STEP 1.4 – Determine the *MAT* from API 579-1/ASME FFS-1, Part 3, Figure 3.5 based on the applicable material impact test exemption curve and the governing thickness, t_g . Based on Curve D in API 579-1/ASME FFS-1, Part 3, Figure 3.5, *MAT* for the component without any allowance for *PWHT*, *MAT* = *–14°F*.
 - 5) STEP 1.5 – The *MAT* determined in STEP 1.4 can be reduced further using API 579-1/ASME FFS-1, Part 3, Equation (3.1) if all the following are true:
 - i. The *MAT* in STEP 1.4 was determined using API 579-1/ASME FFS-1, Figure 3.5, *True*.
 - ii. The component was fabricated from ASME P1 Group 1 or P1 Group 2 material, *True*.
 - iii. The component has a weld thickness that is less than or equal to 38 *mm* (1.5 *in*), and *True*.

- iv. The component was subject to *PWHT* and the status of the *PWHT* has not been changed because of repairs and/or alterations, *True*.

$$MAT = \max \left[\left(MAT_{Step1.4} - 30^{\circ}F \right), -55^{\circ}F \right]$$

$$MAT = \max \left[\left(-14^{\circ}F - 30^{\circ}F \right), -55^{\circ}F \right] = -44^{\circ}F$$

Assuming the vessel underwent weld repairs that were not stress relieved (e.g., temper bead, high preheat, etc.), the *MAT* may not be reduced further per API 579-1/ASME FFS-1, Part 3, Equation (3.1) shown above. In such a scenario, the *MAT* would remain as $-14^{\circ}F$. The *MAT* of $-14^{\circ}F$ is higher than the *CET* of $-20^{\circ}F$.

- b) STEP 2 – Repeat STEP 1 for all components that make-up the piece of equipment being evaluated.

The *MAT* for the component is $-44^{\circ}F$ and thus the component is acceptable at the *CET* of $-20^{\circ}F$.

3.4 Example Problem 4

A stripper column was constructed following the rules of the ASME B&PV Code, Section VIII, Division 1. Perform a brittle fracture assessment to determine the *MAT*. This vessel has the following material properties and dimensions.

Vessel Data:

• Material	=	<i>SA – 516 Grade 65 Year 1968</i>
• Design Conditions	=	<i>250 psi @ 300°F</i>
• Original Design Allowable Stress	=	<i>16,250 psi</i>
• New Allowable Stress (Post 1999)	=	<i>18,600 psi</i>
• Inside Diameter	=	<i>90 in</i>
• Operating Pressure	=	<i>240 psi</i>
• Wall Thickness	=	<i>1.00 in</i>
• Critical Exposure Temperature	=	<i>–10°F</i>
• Impact Test Data	=	<i>None Available</i>
• Stress Relief (i.e., <i>PWHT</i>)	=	<i>Yes</i>
• <i>LOSS</i>	=	<i>0.0 in</i>
• <i>FCA</i>	=	<i>0.125 in</i>
• Joint Efficiency	=	<i>1.0</i>

Perform a Level 1 Assessment for the shell section per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1, Option A.

Since the equipment was constructed to the ASME B&PV Code, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1.

- a) STEP 1 – Determine the starting point for the *MAT* (Minimum Allowable Temperature) using a governing thickness and the exemption curves shown in API 579-1/ASME FFS-1, Part 3, Figure 3.5 (or Table 3.4).
 - 1) STEP 1.1 – For the component under consideration, determine the following parameters:
 - i. Nominal uncorroded thickness at each weld joint, $t_n = 1.0 \text{ in}$.
 - ii. Material of construction: *SA – 516 Grade 65, not Normalized*.
 - 2) STEP 1.2 – Determine the uncorroded governing thickness, $t_g = 1.0 \text{ in}$ (only one component).
 - 3) STEP 1.3 – Determine the applicable material impact test exemption curve of API 579-1/ASME FFS-1, Part 3, Figure 3.5 (*SA – 516 Grade 65* is manufactured to a fine grain practice not normalized), *Curve B*.
 - 4) STEP 1.4 – Determine the *MAT* from API 579-1/ASME FFS-1, Part 3, Figure 3.5 based on the applicable material impact test exemption curve and the governing thickness, t_g . Based on Curve B in API 579-1/ASME FFS-1, Part 3, Figure 3.5, *MAT* for the component without any allowance for *PWHT*, *MAT* = 31°F.

- 5) STEP 1.5 – The MAT determined in STEP 1.4 can be reduced further using API 579-1/ASME FFS-1, Part 3, Equation (3.1) if all the following are true:

The MAT in STEP 1.4 was determined using API 579-1/ASME FFS-1, Part 3, Figure 3.5, *True*.

- i. The component was fabricated from ASME P1 Group 1 or P1 Group 2 material, *True*.
- ii. The component has a weld thickness that is less than or equal to 38 mm (1.5 in), and *True*.
- iii. The component was subject to $PWHT$ and the status of the $PWHT$ has not been changed because of repairs and/or alterations, *True*.

$$MAT = \max \left[MAT_{STEP1.4} - 17^{\circ}C (30^{\circ}F), -48^{\circ}C (-55^{\circ}F) \right] = \max [31 - 30, -55] = 1^{\circ}F$$

- b) STEP 2 – Repeat STEP 1 for all components that make-up the piece of equipment being evaluated (only one component).

The reduced MAT of this section is equal to 1°F, which is higher (i.e., warmer) than the $CET = -10^{\circ}F$.

The Level 1 Assessment Criteria is Not Satisfied for the shell section.

Perform a Level 2 Assessment per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1(b) and develop a table of MAT as a function of pressure based on the allowances given in Figure 3.7 and Table 3.4.

- 1) STEP 1 – Determine the starting point for the MAT (Minimum Allowable Temperature) – in this case using Option A, STEP 1.4 of API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1(d). Based on Curve B in API 579-1/ASME FFS-1, Part 3, Figure 3.5 and the governing thickness, t_g , MAT for the component, without any reduction for $PWHT$ in STEP 1.5, $MAT = 31^{\circ}F$.
- 2) STEP 2 – Determine the following parameters:
 - i) All applicable loads and coincident CET (API-579/ASME FFS-1, Annex 2C, Table 2C.2), *internal pressure loading at 300°F*.
 - ii) Metal Loss, $LOSS = 0\text{ mm}$.
 - iii) Future corrosion allowance, $FCA = 0.125\text{ in}$.
 - iv) Weld joint efficiencies, $E = 1.0$, and $E^* = 1.0$.
 - v) Required thickness in the corroded condition for all applicable loads, t_{min} , using API 579-1/ASME FFS-1, Annex 2C (Equation (2C.9)) for the applicable weld joint efficiency, E , and evaluated at the low temperature operating condition under consideration. Note that, if the requirements of API 579-1/ASME FFS-1, Annex 2C, paragraph 2C.2.4.b) are met, the allowable stress, S , from the current ASME B&PV Code, rather than the original design year, may be used.

$$R = \left(\frac{D}{2} \right) + FCA + LOSS = \left(\frac{90}{2} \right) + 0.125 + 0.0 = 45.125\text{ in}$$

$$t_{min}^C = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} = \frac{250 \cdot 45.125}{18,600 \cdot 1.0 - 0.6 \cdot 250} = 0.611\text{ in}$$

- 3) STEP 3 – Determine the stress ratio, R_{ts} , (in this case using API 579-1/ASME FFS-1, Part 3, Equation (3.2), Thickness Basis).

$$R_{ts} = \frac{t_{min} \cdot E^*}{t_n - LOSS - FCA} = \frac{0.611 \cdot 1.0}{1.0 - 0.0 - 0.125} = 0.699$$

- 4) STEP 4 – Determine the reduction in the MAT based on the R_{ts} ratio.

i) If the starting point for the MAT is established using Option A in STEP 1, then:

ii) If the computed value of the R_{ts} ratio from STEP 3 is greater than the R_{ts} ratio threshold from API 579-1/ASME FFS-1, Part 3, Figure 3.7, then determine the temperature reduction, T_R , based on the R_{ts} ratio using Figure 3.7. The reduced MAT can be calculated using API 579-1/ASME FFS-1, Part 3, Equation (3.5).

$$MAT = \max \left[\left(MAT_{STEP1} - T_R \right), -55^\circ F \right] = \max \left[\left(31 - 55^\circ F - 30^\circ F \right), -55^\circ F \right] = 1^\circ F$$

- 5) STEP 5 – The MAT determined in STEP 4 can be reduced further if all the following conditions are met:

- i) The starting point for the MAT in STEP 1 was determined using API 579-1/ASME FFS-1, Part 3, Figure 3.5, *True*.
- ii) The component was fabricated from ASME P1 Group 1 or P1 Group 2 material, *True*.
- iii) The component has a weld thickness that is less than or equal to 38 mm (1.5 in) and *True*.
- iv) The component was subject to *PWHT* and the status of the *PWHT* has not been changed because of repairs and/or alterations, *True*.

$$MAT = \max \left[MAT_{STEP4} - 17^\circ C \left(30^\circ F \right), -104^\circ C \left(-155^\circ F \right) \right] = \max \left[1 - 30, -155 \right] = -29^\circ F$$

Using this relationship, a table of MAT can be established for the shell section as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and the allowances given in Figure 3.7 and Table 3.4.

Table E3.4-1 – MAT as a Function of Pressure for the Shell

P (psi)	t_{min} (in)	$R_{ts} = \frac{t_{min} \cdot E^*}{t_n - LOSS - FCA}$	T_R (°F)	MAT (°F)
250	0.611	0.699	30	-29
240	0.587	0.671	33	-32
200	0.488	0.558	44	-43
150	0.366	0.418	58	-85
100	0.243	0.278	—	-155
50	0.121	0.139	—	-155

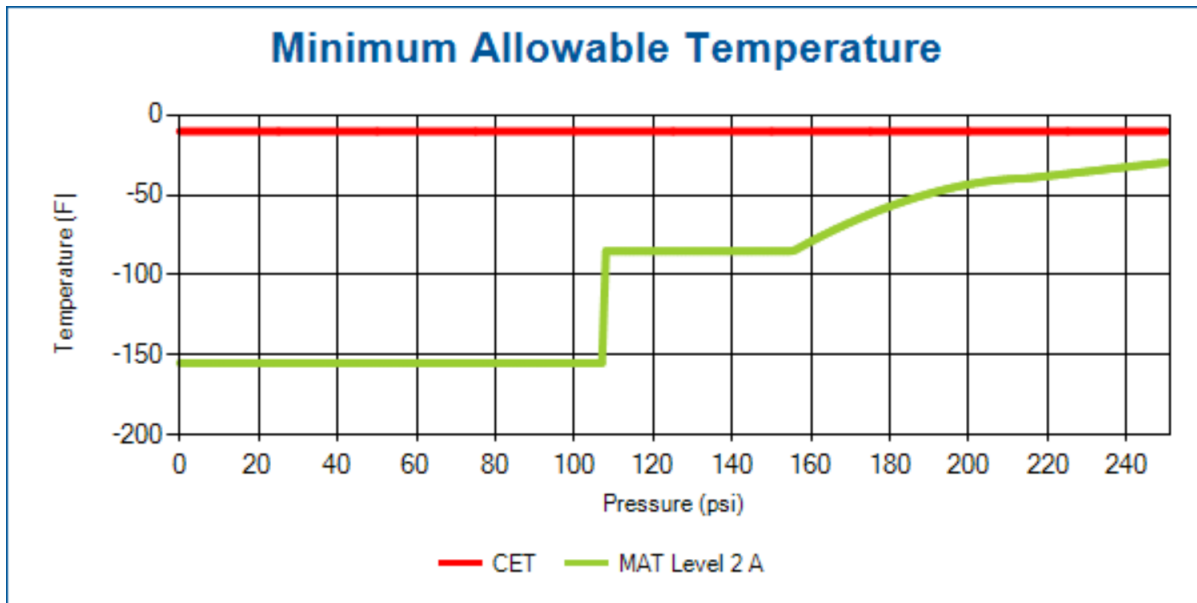


Figure E3.4-1 – *MAT* versus *CET* for the Vessel

The operating pressures and corresponding values of the *MAT* in this table must be compared to the actual vessel operating conditions to confirm that the metal temperature *CET* cannot be below the *MAT* at the corresponding operating pressure. In this case the column is designed for 250 *psig* and operating at 240 *psig*, and the *CET* is equal to -10°F . According to this table, at 250 *psig* the reduced *MAT* is equal to -29°F , and at 240 *psig* the reduced *MAT* is equal to -32°F , which are both lower than the *CET*.

The Level 2 Assessment Criteria are Satisfied for the design and operating conditions.

3.5 Example Problem 5

A reactor vessel fabricated in 1993 from *SA – 204 Grade B Year 1993* ($C - \frac{1}{2} Mo$) has the following material properties and dimensions. The reactor was constructed to the ASME B&PV Code, Section VIII, Division 1. The owner-operator determined that the equipment is not subject to environmental cracking (e.g., wet H_2S , $HTHA$, etc.) and it is not subject to any service condition that may result in a loss in the material toughness. Develop a table of *MAT* for the shell section as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and the allowances given in Figure 3.7 and Table 3.4.

Vessel Data:

• Material	=	<i>SA – 204 Grade B Year 1993</i>
• Design Conditions	=	<i>390 psi @ 300°F</i>
• Allowable Stress	=	<i>17,500 psi</i>
• Inside Diameter	=	<i>232 in</i>
• Operating Pressure	=	<i>240 psi</i>
• Wall Thickness	=	<i>2.75 in</i>
• Startup Pressure	=	<i>157 psi</i>
• Weld Joint Efficiency	=	<i>1.0</i>
• Corrosion Allowance	=	<i>$\frac{1}{8}$ in</i>
• <i>LOSS</i>	=	<i>None</i>
• Impact Test Data	=	<i>None Available</i>
• Stress Relief (i.e., <i>PWHT</i>)	=	<i>Yes</i>

Perform a Level 2 Assessment for the shell section per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 to develop the table of *MAT* for the shell section as a function of pressure.

Since the equipment was constructed to the ASME B&PV Code, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1.

- a) STEP 1 – Determine the starting point for the *MAT* (Minimum Allowable Temperature) – in this case using Option A, STEP 1.4 of API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1(d) (without reduction for *PWHT* in STEP 1.5).
 - 1) STEP 1.4 – Determine the *MAT* from API 579-1/ASME FFS-1, Part 3, Figure 3.5 based on the applicable toughness curve and the governing thickness, t_g . Based on Curve A in API 579-1/ASME FFS-1, Part 3, Figure 3.5 (or Table 3.4), *MAT* for the component without any allowance for *PWHT*, *MAT* = 108°F.
- b) STEP 2 – Determine the following parameters:
 - 1) All applicable loads and coincident *CET* (API 579-1/ASME FFS-1, Annex 2C, Table 2C.3), *internal pressure loading at 300°F*.
 - 2) Metal Loss, *LOSS* = 0 in.
 - 3) Future corrosion allowance, *FCA* = $\frac{1}{8}$ in.

- 4) Weld joint efficiencies, $E = 1.0$, and $E^* = 1.0$.
- 5) Required thickness in the corroded condition for all applicable loads, t_{min} , using the applicable weld joint efficiency (using API 579-1/ASME FFS-1, Annex 2C, Equation (2C.9)).

$$R = \frac{D}{2} + FCA + LOSS = \frac{232}{2} + 0.125 + 0.000 = 116.125 \text{ in}$$

$$t_{min}^C = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} = \frac{390 \cdot 116.125}{17,500 \cdot 1.0 - 0.6 \cdot 390} = 2.623 \text{ in}$$

- c) STEP 3 – Determine the stress ratio, R_{ts} , (in this case using API 579-1/ASME FFS-1, Part 3, Equation (3.4), Pressure-Temperature Rating Basis).

$$R_{ts} = \frac{P_a}{P_{rating}} \quad (\text{Pressure-Temperature Rating Basis})$$

Using this relationship, a table of MAT can be established for the shell section as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and the allowances given in Figure 3.7 and Table 3.4.

Table E3.5-1 – MAT for the Shell as a Function of Pressure

P (psi)	P/P_{rating}	T_R (°F)	MAT (°F)
390	1.00	0	108
351	0.90	10	98
312	0.80	20	88
273	0.70	30	78
234	0.60	40	68
195	0.50	60	48
156	0.40	—	-155

The operating pressures and corresponding values of the shell section MAT in this table must be compared to the actual vessel operating conditions to confirm that the metal temperature (CET) cannot be below the MAT at the corresponding operating pressure.

3.6 Example Problem 6

A CO_2 storage vessel with an internal diameter of 2032.0 mm and a nominal thickness of 17.5 mm, was constructed in 1982 according to the ASME Code Section VIII, Division 1. The material of construction was SA – 612 *not normalized*, which is a carbon steel. It was designed for a non-corrosion service (corrosion allowance equals zero), with a joint efficiency of 100% (full X-ray inspection), and without Post-Weld Heat Treatment. This storage vessel has the following characteristics.

Tank Data:

• Material	=	SA – 612 Year 1982
• Design Conditions	=	2.374 MPa @ 93°C
• Allowable Stress	=	139.25 MPa
• Inside Diameter	=	2032.0 mm
• Operating Pressure	=	2.374 MPa @ 16°C
• Wall Thickness	=	17.5 mm
• Weld Joint Efficiency	=	1.0
• Corrosion Allowance	=	None
• LOSS	=	None
• Impact Test Data	=	None Available
• Stress Relief (i.e., PWHT)	=	No

For the shell section, calculate *MAT* for the design conditions and develop a table of *MAT* as a function of reduced pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and the allowances given in Figure 3.7M and Table 3.4.

Perform a Level 2 Assessment for the shell section per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1, Method A for Pressure Vessels, to develop the table of *MAT* for the shell section as a function of pressure.

Since the equipment was constructed to the ASME B&PV Code Section VIII, Division 1, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1.

a) STEP 1 – Determine the starting point for the *MAT* (Minimum Allowable Temperature) – in this case using Option A, STEP 1.4 of API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1(d), (without reduction for *PWHT* in STEP 1.5).

1) STEP 1.4 – Determine the *MAT* from API 579-1/ASME FFS-1, Part 3, Figure 3.5M (or Table 3.4) based on the applicable material impact test exemption curve and the governing thickness, t_g .

Per API 579-1/ASME FFS-1, Part 3, Table 3.2, the applicable impact test exemption curve for SA – 612 *not normalized* is Curve B. The governing thickness is $t_g = 17.5$ mm.

Per ASME Section II Part A the specified minimum yield strength of SA – 612 is 345 MPa, which is less than 450 MPa. The condition for using the impact test exemption curves in API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1(d)(1)(i) is fulfilled.

Based on Curve B in API 579-1/ASME FFS-1, Part 3, Figure 3.5M, MAT for the component without any allowance for $PWHT$, $MAT = -12^\circ\text{C}$ for design conditions.

If the equation in API 579-1/ASME FFS-1, Part 3, Table 3.4 is used, the thickness must be expressed in inches.

$$t = 17.5 \text{ mm} = 0.6890 \text{ in}$$

For Curve B,

$$\begin{aligned} MAT &= \left(\begin{array}{l} -135.79 + 171.56t^{0.5} + 103.63t \\ -172.0t^{1.5} + 73.737t^2 - 10.535t^{2.5} \end{array} \right) \\ &= \left(\begin{array}{l} -135.79 + 171.56(0.6890)^{0.5} + 103.63(0.6890) \\ -172.0(0.6890)^{1.5} + 73.737(0.6890)^2 - 10.535(0.6890)^{2.5} \end{array} \right) \\ &= 10.499^\circ\text{F} = -11.95^\circ\text{C} \text{ rounded to } -12^\circ\text{C} \end{aligned}$$

b) STEP 2 – Determine the following parameters:

- 1) All applicable loads and coincident Critical Exposure Temperatures (API 579-1/ASME FFS-1, Annex 2C, Table 2C.2), *internal pressure loading at 93°C*.
- 2) Metal Loss, $LOSS = 0 \text{ mm}$.
- 3) Future corrosion allowance, $FCA = 0 \text{ mm}$.
- 4) Weld joint efficiencies, $E = 1.0$, and $E^* = 1.0$.
- 5) Required thickness in the corroded condition for all applicable loads, t_{min} , using the applicable weld joint efficiency. API 579-1/ASME FFS-1, Annex 2C, Equation (2C.9) is used.

$$R = \frac{D}{2} + FCA + LOSS = \frac{2032}{2} + 0.000 + 0.000 = 1016 \text{ mm}$$

$$t_{min}^C = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} = \frac{2.374 \cdot 1016}{139.252 \cdot 1.0 - 0.6 \cdot 2.374} = 17.5 \text{ mm}$$

c) STEP 3 – Determine the stress ratio, R_{ts} , (in this case using API 579-1/ASME FFS-1, Part 3, Equation (3.3), Stress Basis).

$$R_{ts} = \frac{S^* E^*}{SE} \quad (\text{Stress Basis})$$

Using this relationship, a table of MAT can be established for the shell section as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and the allowances given in Figure 3.7M and Table 3.4.

To facilitate calculations, the membrane stress for a cylindrical pressure vessel as a function of pressure (see API 579-1/ASME FFS-1, Annex 2C, Equation (2C.11)) is obtained:

$$R = \left(\frac{D}{2} \right) + FCA + LOSS = \left(\frac{2032.0}{2} \right) + 0.0 + 0.0 = 1016 \text{ mm}$$

$$t_c = t - FCA - LOSS = 17.5 - 0.0 - 0.0 = 17.5 \text{ mm}$$

$$S^*E^* = P \cdot \left(\left(\frac{R_c}{t_c} \right) + 0.6 \right) \cdot E^* = P \cdot \left(\left(\frac{1016}{17.5} \right) + 0.6 \right) \cdot 1.0 = 58.657 \cdot P$$

d) STEP 4 – Determine the reduction in the MAT based on the R_{ts} ratios.

Using this relationship, a table of MAT can be established as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and the allowances given in Figure 3.7M and Table 3.4.

The equipment was constructed in 1982 according to the ASME Code Section VIII, Division 1. According to Note 2 of API 579-1/ASME FFS-1, Part 3, Figure 3.7M the applicable threshold on R_{ts} is equal to 0.4. According to API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1(b)(4)(i)(I): $MAT = -104^\circ\text{C}$ for conditions with stress ratio less than or equal this threshold.

Table E3.6 – MAT Calculated as a Function of Reduced Pressure

P (MPa)	S^*E^* (MPa)	$R_{ts} = \frac{S^*E^*}{SE}$	T_R (°C)	MAT (°C)
2.3740	139.25	1.00	0	-12
2.1366	123.33	0.90	6	-18
1.8992	111.40	0.80	11	-23
1.6618	97.48	0.70	17	-29
1.4244	83.55	0.60	22	-34
1.1870	69.63	0.50	28	-45
0.9496	55.70	0.40	—	-104
0.7122	41.78	0.30	—	-104
0.4748	27.85	0.20	—	-104

The operating pressures and corresponding values of the MAT in this table must be compared to the actual vessel operating conditions to confirm that the metal temperature (CET) cannot be below the MAT at the corresponding operating pressure.

3.7 Example Problem 7

A spherical platformer reactor was constructed in 1958 according to the ASME Code, Section VIII. The material of construction is $C - \frac{1}{2}Mo$, specification $SA - 204 \text{ Grade A}$. The vessel has the following information available:

Vessel Data:

• Material	=	$SA - 204 \text{ Grade A Year 1958}$
• Design Conditions	=	$650 \text{ psig @ } 300^\circ\text{F}$
• Allowable Stress	=	$16,250 \text{ psi}$
• Inside Diameter	=	144 in
• Operating Pressure	=	390 psig
• Nominal Thickness	=	1.6875 in
• Actual Wall Thickness	=	1.7165 in
• Weld Joint Efficiency	=	0.95
• Future Corrosion Allowance (FCA)	=	0.1563 in
• $LOSS$	=	$None$
• Impact Test Data	=	$None \text{ Available}$
• Stress Relief (i.e., $PWHT$)	=	Yes
• Critical Exposure Temperature	=	60°F

Perform a Level 1 Assessment for the shell section per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1 – Option A.

Since the equipment was constructed to the ASME B&PV Code, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1.

- a) STEP 1 – Determine the starting point for the MAT (Minimum Allowable Temperature) using a governing thickness and the exemption curves shown in API 579-1/ASME FFS-1, Part 3, Figure 3.5 (or Table 3.4).
 - 1) STEP 1.1 – For the component under consideration, determine the following parameters:
 - i. Nominal uncorroded thickness at each weld joint, $t_n = 1.6875 \text{ in}$.
 - ii. Material of construction: $SA - 204 \text{ Grade A}$.
 - 2) STEP 1.2 – Determine the uncorroded governing thickness, $t_g = 1.7165 \text{ in}$ (only one component and the actual thickness is used).
 - 3) STEP 1.3 – Determine the applicable material impact test exemption curve of API 579-1/ASME FFS-1, Part 3, Figure 3.5 ($SA - 204 \text{ Grade A}$ is one of the low alloy steel plates not listed in Curves B, C, and D). Therefore, Curve A of API 579-1/ASME FFS-1, Part 3, Figure 3.5 shall be used to determine the MAT .
 - 4) STEP 1.4 – Determine the MAT from API 579-1/ASME FFS-1, Part 3, Figure 3.5 based on the applicable impact test exemption curve and the governing thickness, t_g . Based on Curve A in API 579-1/ASME FFS-1, Part 3, Figure 3.5, MAT for the component without any allowance for $PWHT$, $MAT = 93^\circ\text{F}$.

- 5) STEP 1.5 – The *MAT* determined in STEP 1.4 can be reduced further using API 579-1/ASME FFS-1, Part 3, Equation (3.1) if all the following are true:
- The *MAT* in STEP 1.4 was determined using API 579-1/ASME FFS-1, Part 3, Figure 3.5, *True*.
 - The component was fabricated from ASME P1 Group 1 or P1 Group 2 material (The reactor was *PWHT*; however, an ASME P3 Group 1 material was used.) Therefore, the *MAT* determined before cannot be reduced further using API 579-1/ASME FFS-1, Part 3, Equation (3.1), *False*.
 - The component has a weld thickness that is less than or equal to 38 mm (1.5 in), and *False*.
 - The component was subject to *PWHT* and the status of the *PWHT* has not been changed because of repairs and/or alterations, *True*.

$$MAT = 93^{\circ}F$$

- b) STEP 2 – Repeat STEP 1 for all components that make-up the piece of equipment being evaluated.

The *MAT* is equal to 93°F, which is higher (i.e., warmer) than the *CET* of 60°F.

The Level 1 Assessment Criteria is Not Satisfied.

Perform a Level 2 Assessment per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and develop a table of *MAT* as a function of pressure based on the allowances given in Figure 3.7 and Table 3.5.

- a) STEP 1 – Determine the starting point for the *MAT* (Minimum Allowable Temperature) – in this case using Option A, STEP 1.4 of API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1(d) (without reduction for *PWHT* in STEP 1.5).
- STEP 1.4 – Determine the *MAT* from API 579-1/ASME FFS-1, Part 3, Figure 3.4 based on the applicable impact test exemption curve and the governing thickness, t_g . Based on Curve A in API 579-1/ASME FFS-1, Part 3, Figure 3.5, *MAT* for the component without any allowance for *PWHT*, $MAT = 93^{\circ}F$.
- b) STEP 2 – Determine the following parameters:
- All applicable loads and coincident *CET* (API 579-1/ASME FFS-1, Annex 2C, Table 2C.3), *interanal pressure loading at 300°F*.
 - Metal Loss, $LOSS = 0$ in.
 - Future corrosion allowance, $FCA = 0.1563$ in.
 - Weld joint efficiencies, $E = 0.95$, and $E^* = 0.95$.
 - Required thickness in the corroded condition for all applicable loads, t_{min} , using the applicable weld joint efficiency (using API 579-1/ASME FFS-1, Annex 2C, equation 2C.24).

$$R = \left(\frac{D}{2} \right) + FCA + LOSS = \left(\frac{144}{2} \right) + 0.1563 + 0.0 = 72.1563 \text{ in}$$

$$t_{min}^C = \frac{P \cdot R}{2 \cdot S \cdot E - 0.2 \cdot P} = \frac{650 \cdot 72.1563}{2 \cdot 16,250 \cdot 0.95 - 0.2 \cdot 650} = 1.526 \text{ in}$$

- c) STEP 3 – Determine the stress ratio, R_{ts} , (in this case using API 579-1/ASME FFS-1, Part 3, Equation (3.3), Stress Basis).

$$R_{ts} = \frac{S^* E^*}{SE} \quad (\text{Stress Basis})$$

Using this relationship, a table of MAT can be established for the shell section as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and the allowances given in Figure 3.7 and Table 3.4.

To facilitate calculations, the membrane stress for a spherical pressure vessel as a function of pressure (see API 579-1/ASME FFS-1, Annex 2C) is obtained:

$$R = \left(\frac{D}{2} \right) + FCA + LOSS = \left(\frac{144}{2} \right) + 0.1563 + 0.0 = 72.1563 \text{ in}$$

$$t_c = t - FCA - LOSS = 1.7165 - 0.1563 - 0.0 = 1.5602 \text{ in}$$

$$S^* E^* = P \cdot \left(\left(\frac{R}{t_c} \right) + 0.2 \right) \cdot E^* = \frac{P}{2} \cdot \left(\left(\frac{72.1563}{1.5602} \right) + 0.2 \right) \cdot 0.95 = 22.063 \cdot P$$

Using this relationship, a table of MAT can be established as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1, the procedure in Table 3.4, and the allowances given by the appropriate curve in Figure 3.7.

Table E3.7-1 – MAT of the Shell as a Function of Pressure

P (psi)	$S^* E^*$ (psi)	$R_{ts} = \frac{S^* E^*}{SE}$	T_R (°F)	MAT (°F)
650	14,341	0.93	7	86
585	12,907	0.84	16	77
520	11,474	0.74	26	67
455	10,039	0.65	35	58
390	8,605	0.56	44	49
325	7,170	0.46	72	21
260	5,736	0.37	—	-155
195	4,302	0.28	—	-155
130	2,868	0.19	—	-155

The operating pressures and corresponding values of the MAT in this table must be compared to the actual vessel operating conditions to confirm that the metal temperature CET cannot be below (i.e., colder than) the MAT at the corresponding operating pressure. In this case the reactor is operating at 390 *psig*, and the CET is equal to 60°F. According to this table at 390 *psig* the reduced MAT is equal to 49°F, which is lower than the CET .

The Level 2 Assessment Criteria are Satisfied for the operating conditions.

3.8 Example Problem 8

A sphere fabricated from *SA – 414 Grade G* was constructed to the ASME B&PV Code, Section VIII, Division 1. The vessel has the following information available:

Vessel Data:

• Material	=	<i>SA – 414 Grade G Year 2005</i>
• Design Conditions	=	<i>175.0 psig @ 300°F</i>
• Allowable Stress	=	<i>21,400 psi</i>
• Inside Diameter	=	<i>585.6 in</i>
• Wall Thickness	=	<i>1.26 in</i>
• Weld Joint Efficiency	=	<i>1.0</i>
• Corrosion Allowance	=	<i>0.060 in</i>
• <i>LOSS</i>	=	<i>None</i>
• Impact Test Data	=	<i>None Available</i>
• Stress Relief (i.e., <i>PWHT</i>)	=	<i>No</i>

Develop a table of *MAT* for the shell section as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and the allowances given in Figure 3.7 and Table 3.4.

Perform a Level 2 Assessment for the shell section per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 to develop the table of *MAT* for the shell section as a function of pressure.

Since the equipment was constructed to the ASME B&PV Code, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1.

- a) STEP 1 – Determine the starting point for the *MAT* (Minimum Allowable Temperature) – in this case using Option A, STEP 1.4 of API 579-1/ASME FFS-1, Part 3, paragraph 3.4.2.1(d), (without reduction for *PWHT* in STEP 1.5).
 - 1) STEP 1.4 – Determine the *MAT* from API 579-1/ASME FFS-1, Part 3, Figure 3.5 (or Table 3.4) based on the applicable impact test exemption curve and the governing thickness, t_g . Based on Curve A in API 579-1/ASME FFS-1, Part 3, Figure 3.5, *MAT* for the component without any allowance for *PWHT*, *MAT* = 80°F.
- b) STEP 2 – Determine the following parameters:
 - 1) All applicable loads and coincident *CET* (API 579-1/ASME FFS-1, Annex 2C, Table 2C.3), *internal pressure loading at 300°F*.
 - 2) Metal Loss, *LOSS* = 0 in.
 - 3) Future corrosion allowance, *FCA* = 0.060 in.
 - 4) Weld joint efficiencies, $E = 1.0$, and $E^* = 1.0$.
 - 5) Required thickness in the corroded condition for all applicable loads, t_{min} , using the applicable weld joint efficiency (using API 579-1/ASME FFS-1, Annex 2C, Equation (2C.24)).

$$R = \frac{D}{2} + FCA + LOSS = \frac{585.6}{2} + 0.060 + 0.000 = 292.86 \text{ in}$$

$$t_{\min}^C = \frac{P \cdot R}{2 \cdot S \cdot E - 0.2 \cdot P} = \frac{175 \cdot 292.86}{2 \cdot 21,400 \cdot 1.0 - 0.2 \cdot 175} = 1.198 \text{ in}$$

- c) STEP 3 – Determine the stress ratio, R_{ts} , (in this case using API 579-1/ASME FFS-1, Part 3, Equation (3.3), Stress Basis).

$$R_{ts} = \frac{S^* E^*}{SE} \quad (\text{Stress Basis})$$

Using this relationship, a table of MAT can be established for the shell section as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 and the allowances given in Figure 3.7 and Table 3.4.

To facilitate calculations, the membrane stress for a spherical pressure vessel as a function of pressure (see API 579-1/ASME FFS-1, Annex 2C) is obtained:

$$R = \frac{D}{2} + FCA + LOSS = \frac{585.6}{2} + 0.060 + 0.000 = 292.86 \text{ in}$$

$$t_c = t - FCA - LOSS = 1.260 - 0.060 - 0.000 = 1.200 \text{ in}$$

$$S^* E^* = \frac{P}{2} \cdot \left(\left(\frac{R}{t_c} \right) + 0.2 \right) \cdot E^* = \frac{P}{2} \cdot \left(\left(\frac{292.86}{1.200} \right) + 0.2 \right) \cdot 1.0 = 122.125 \cdot P$$

Using this relationship, a table of MAT can be established as a function of pressure based on API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1, the procedure in Table 3.4, and the allowances given by the appropriate curve in Figure 3.7.

Table E3.8-1 – MAT of the Shell as a Function of Pressure

P (psi)	$S^* E^*$ (psi)	$R_{ts} = \frac{S^* E^*}{SE}$	T_R (°F)	MAT (°F)
175.0	21,372	1.00	0	80
157.5	19,235	0.90	10	70
140.0	17,098	0.80	20	60
122.5	14,960	0.70	30	50
105.0	12,823	0.60	41	39
87.5	10,686	0.50	57	23
70.0	8,549	0.40	93	-13
52.5	6,412	0.30	—	-155
35.0	4,274	0.20	—	-155

The operating pressures and corresponding values of the MAT in this table must be compared to the actual sphere operating conditions to confirm that the metal temperature CET cannot be below (i.e., colder than) the MAT at the corresponding operating pressure.

3.9 Example Problem 9

A spherical pressure vessel has the following properties and has experienced the following hydrotest conditions. The vessel was constructed to the ASME B&PV Code, Section VIII, Division 1. Using API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.2 and Figure 3.8, prepare a table showing the relationship between operating pressure and *MAT* for the shell section.

Vessel Data:

- Hydrotest pressure = 300 *psig* or 150% of design pressure
- Design pressure = 200 *psig*
- Metal temperature during hydrotest = 50°F
- Material allowable stress = 17.5 *ksi*

Since the equipment was constructed to the ASME B&PV Code, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1 and the material allowable stress is below the 25 *ksi* threshold per paragraph 3.4.3.2(a) so the use of Method B is permitted.

The maximum measured metal temperature during hydrotest was 50°F. To be conservative, 10°F is added to this and the analysis is based on a hydrotest metal temperature of 60°F.

Table E3.9-1 – *MAT* of the Shell as a Function of Pressure

Operating Pressure, (<i>psig</i>)	$\frac{\text{Operating Pressure}}{\text{Hydrotest Pressure}}$	Temperature Reduction, (°F)	<i>MAT</i> (°F)
200	0.67	35	25
180	0.6	43	17
150	0.5	55	5
120	0.4	70	-10
90	0.3	90	-30
75	0.25	—	-155

The operating pressures and corresponding values of the *MAT* in this table must be compared to the actual sphere operating conditions to confirm that the metal temperature *CET* cannot be below (i.e., colder than) the *MAT* at the corresponding operating pressure.

3.10 Example Problem 10

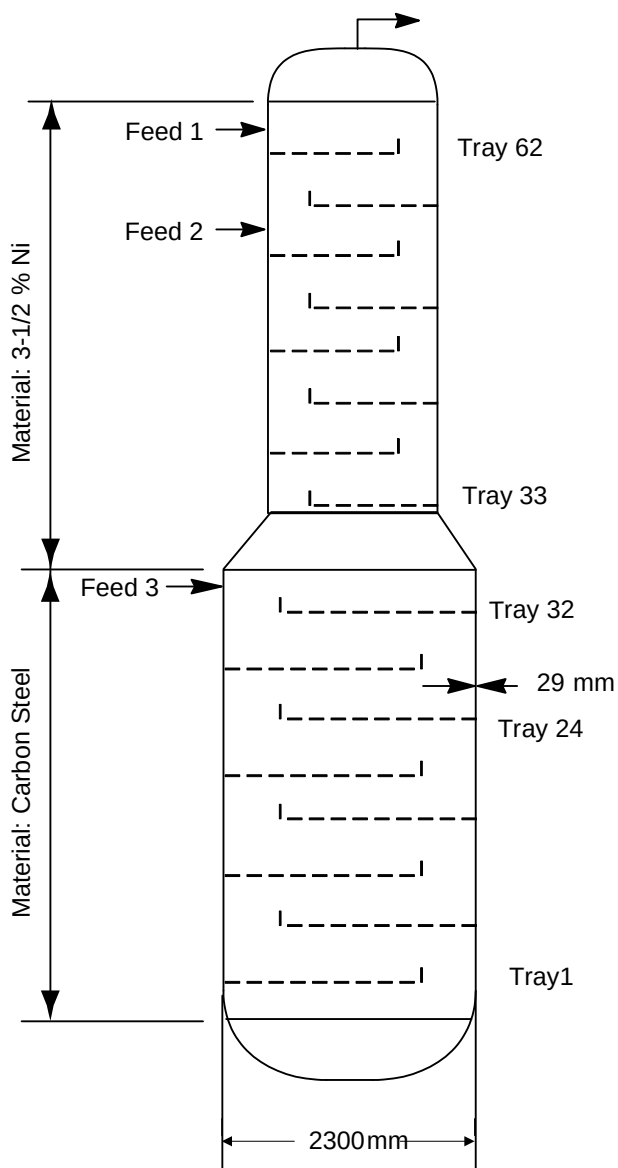
A demethanizer tower in the cold end of an ethylene plant typically operates colder in the top portion of the tower and warmer at the bottom of the tower. The bottom of the tower is kept warm with a side stream circulated through a reboiler. The top portion of the tower is constructed from a 3½% *Ni* steel which has been impact tested for toughness at -101°C . The lower portion of the tower is constructed from a fully killed, fine grained and normalized carbon steel (*SA – 516 Grade 70 normalized*) which was impact tested for toughness at -46°C , with an average value of 33 *Joules* and a minimum value of 32 *Joules*. A potential for brittle fracture exists if the reboiler does not operate because cold liquid will flow down the tower into the carbon steel section resulting in operating temperatures significantly lower than -46°C . The vessel was constructed to the 1972 Edition of the ASME B&PV Code, Section VIII, Division 1. Perform a brittle fracture assessment of the ethylene plant demethanizer tower considering all aspects of operation. The upset condition of the reboiler not operating properly should be included in the assessment.

Since the equipment was constructed to the ASME B&PV Code, it meets the requirements of API 579-1/ASME FFS-1, Part 3, paragraph 3.2.1.

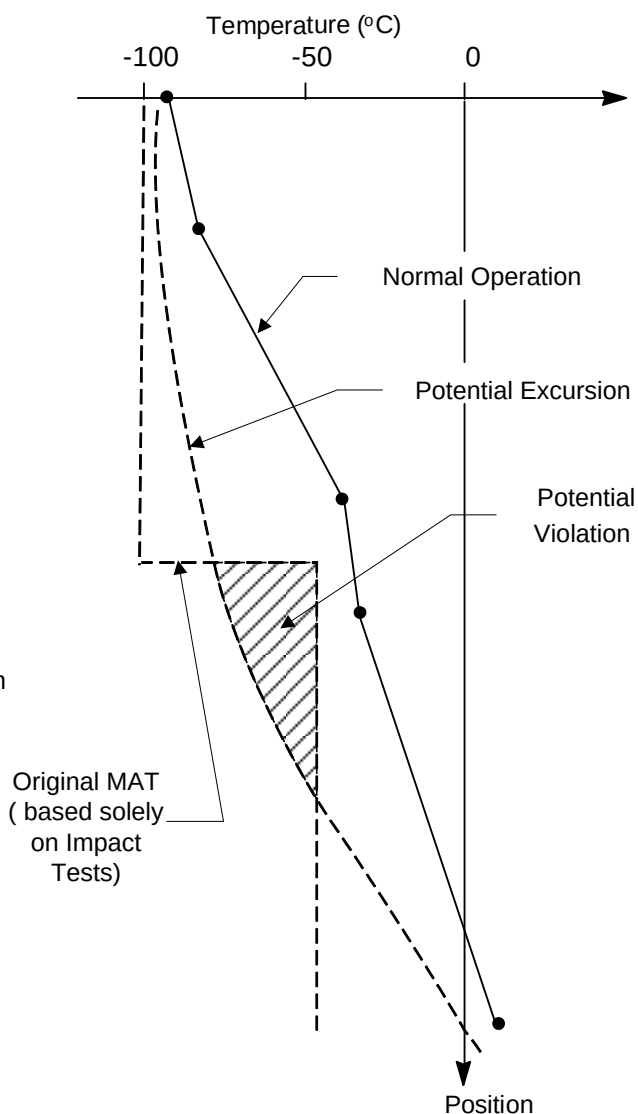
A brittle fracture assessment consistent with API 579-1/ASME FFS-1, Part 3, paragraph 3.4.4 (Level 3 Assessment) can be performed on the demethanizer tower. Figure E3.10-1 provides additional details on the tower.

As a first step, the Minimum Allowable Temperature (*MAT*) envelope will be determined using the Level 2 assessment techniques in API 579-1/ASME FFS-1, Part 3 and compared against both normal operating and upset conditions. Assessment of the upset condition will require use of the fracture mechanics principles presented in API 579-1/ASME FFS-1, Part 9. The limiting flaw size in the tower will be established considering the thermal shock transient and will be compared against the limiting flaw size for steady-state operating conditions. A sensitivity study will be performed on steady-state operating conditions to determine how the limiting flaw size changes with metal temperature. Based on the results of the assessment, a graph of limiting flaw size versus temperature will be constructed using two different approaches for determining the fracture toughness; this graph is referred to as a Fracture Tolerance Signature (*FTS*) and provides an indication of the safety margin in terms of limiting flaw size.

An assumption in the assessment is that the tower has been correctly fabricated to codes and standards at the time of construction. It is also a requirement that the vessel material specifications and inspection history are known and documented. These are essential to enable reasonable assumptions to be made about the material toughness properties, stress levels, and likelihood of fabrication or service induced flaws.



Detail A
Typical Design



Detail B
Temperature Profile Along The Length Of The Tower

Material: SA-516 Grade 70 (KCS)
 Minimum Yield Strength at operating conditions 262 MPa
 Pressure: 3.72 MPa-g
 Toughness: 33/32J @ -46°C
 PWHT: Yes
 Weld Joint Efficiency: 1.0

Figure E3.10-1 – Schematic of Demethanizer

Assessment Approach:

The *MAT* envelope will be determined using the Level 2 Assessment techniques in API 579-1/ASME FFS-1, Part 3. The fracture analysis part of the assessment will be based on the methodology in API 579-1/ASME FFS-1, Part 9; to perform this analysis, a flaw size must be assumed, and the applied stress and material toughness must be known or conservatively estimated. Only the lower carbon steel section of the tower will be assessed since this is the only section to experience an *MAT* violation (see Figure E3.10-1).

API 579-1/ASME FFS-1, Part 3, Level 2 Assessment:

Perform a Level 2 Assessment per API 579-1/ASME FFS-1, Part 3, paragraph 3.4.3.1 (Pressure Vessels – Method A).

- a) STEP 1 – Starting point for the *MAT* will be -46°C per Option B since the carbon steel material was impact tested at this temperature.
- b) STEP 2 – Reasonable assumption is being made that the vessel design pressure represents the loading under consideration (except for the upset scenario, which will be assessed separately below using API 579-1/ASME FFS-1, Part 9 techniques); it is assumed that the vessel *MAWP* is equal to the design pressure shown in Figure E3.10-1.
- c) STEP 3 – The operating pressure will be iterated to calculate the acceptable temperature at pressures up to the vessel design pressure (i.e., assumed *MAWP*); the Pressure-Temperature Rating Basis shown in API 579-1/ASME FFS-1, Part 3, Equation (3.4) will be used to determine the R_{ts} value at each pressure.
- d) STEP 4 – Since the starting point for the *MAT* was determined using Option B and the impact test temperature was above -48°C , the reduced *MAT* will be calculated using API 579-1/ASME FFS-1, Part 3, Equation (3.8) for the *PWHT* condition.
- e) STEP 5 – Since Option B was used, additional temperature reduction based on *PWHT* is not permitted.

Table E3.10-1 shows the tabulated results for STEPs 1-4 at different pressures, while Figure E3.10-2 shows the *MAT* curve; note that 1,000 pressure increments were used to generate the curve but only a few points are shown in the table as an illustration.

Table E3.10-1 – *MAT* of the Shell as a Function of Pressure

P (MPa)	P/P_{rating}	T_R ($^{\circ}\text{C}$)	<i>MAT</i> ($^{\circ}\text{C}$)
3.720	1.00	0	-46
3.348	0.90	6	-52
2.976	0.80	11	-57
2.604	0.70	17	-63
2.232	0.60	22	-68
1.860	0.50	32	-78
1.488	0.40	—	-104

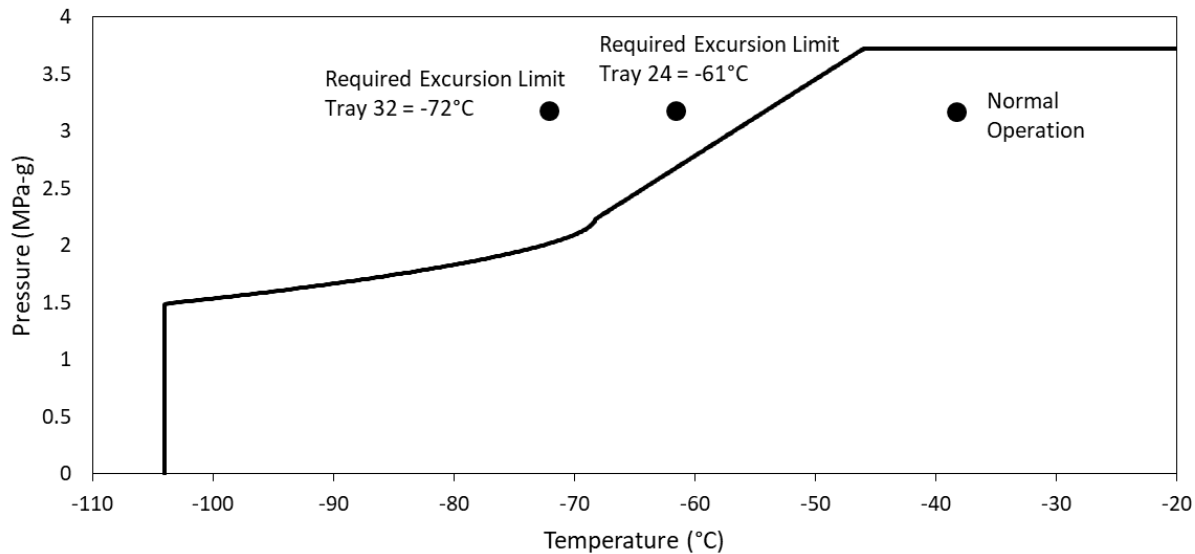


Figure E3.10-2 – Level 2 *MAT* Curve

It is worth noting that the starting point for the *MAT* using Option A (i.e., exemption curve basis) would have been -31°C , and the additional temperature reduction of 17°C in STEP 5 for *PWHT* could have been applied had this option been used. The resulting *MAT* at *MAWP* would have been -48°C , which coincidentally is remarkably close to the impact test temperature of -46°C . For this example, Option B was used in determining the *MAT* as described above.

Since the excursion temperatures are outside of the Level 2 *MAT* curve, the excursion will be assessed using API-579/ASME FFS-1, Part 9 techniques.

Assumed Flaw Size – A conservative yet representative hypothetical surface breaking elliptical crack with an aspect ratio of 6:1 (2c:a) is assumed to be located on the inside surface of the vessel. The crack is also assumed to be parallel to a longitudinal weld seam. Other representative flaws elsewhere in the vessel should also be considered, although this example will focus on the vessel cylinder (with a multiplier on stress to account for other discontinuities as described later).

Applied Stress – In order to utilize the assessment procedures of API-579/ASME FFS-1, Part 9, the applied stress at the location of the flaw must be computed and categorized. Based on the operation sequence of the tower, stresses from four load sources are present: the hoop stress from internal pressure, the residual stress in welds, local stress effects from nozzles and attachments, and thermal transient stresses during the upset. In addition, consideration should be given to occasional loads such as wind or earthquake loads, although these loads are ignored in this example.

Hoop Stress from Internal Pressure – The pressure stress can be described by Lamé's equation for circumferential stress in a cylinder. This stress is categorized as a primary membrane stress, with a small amount of bending stress present which will be treated as primary.

$$\sigma_t(x) = \frac{(r_i)^2 P}{(r_o)^2 - (r_i)^2} \left[1 + \frac{(r_o)^2}{(r_i + x)^2} \right]$$

Residual Stress in Welds – The residual stress can be estimated based on whether post weld heat treatment (*PWHT*) has been performed (see API 579-1/ASME FFS-1, Annex 9D). Because the tower was subject to *PWHT* at the time of construction, the residual stress is taken as 20% of the weld metal room temperature yield strength plus 69 MPa. This stress is classified as a secondary membrane stress.

Local Stress Effects from Nozzles and Attachments – In this screening study, a detailed analysis of the local stresses at the nozzles and attachments was not performed. To account for a level of stress concentration at these locations a stress concentration factor is used. In this example a stress concentration factor of 1.3 will be applied to all primary membrane and bending stresses.

Transient Thermal Stresses – These stresses may be evaluated by using closed form solutions or a finite element analysis. In this example, a temperature excursion model consisting of a "cold front" of liquid is assumed to move down the tower. The liquid temperature in the cold front is defined by the process upset condition. The vessel wall is subsequently cooled from its pre-excursion steady-state temperature to the cold liquid temperature. Convective heat transfer is assumed between the cold fluid and the vessel shell, and heat loss to the atmosphere is neglected. In this example, the liquid temperature during the excursion is -72°C , and the shell metal temperature prior to the excursion is -35°C . Temperature as a function of position and time is calculated using the equation below. Thermal stress was treated as primary.

$$\frac{T(z,t) - T_i}{T_i - T_{\infty}} = -1 + 2 \sum_{n=1}^{\infty} \left[\exp\left(-\beta_n^2 \frac{\kappa_z t}{H^2}\right) \cdot \frac{\sin \beta_n \cos(\beta_n z / H)}{\beta_n + \sin \beta_n \cos \beta_n} \right]$$

Figure E3.10-3 shows the stress versus time history at a point on the vessel inside wall computed using the thermoelastic solution for a flat plate, which is the same basis as the empirical equation used to develop API 579-1/ASME FFS-1, Part 3, Figure 3.3. In the equation below, β_n are the roots of the transcendental equation $\beta_n \tan \beta_n = Bi$, where Bi is the Biot modulus ($Bi = h \cdot thk/k$).

$$\sigma(x) = \frac{\alpha E}{1-\nu} (T_i - T_{\infty}) (2) \sum_{n=1}^{\infty} \left[\exp\left[-\beta_n^2 \frac{\kappa \cdot t}{thk^2}\right] \frac{\sin[\beta_n]}{\beta_n + \sin[\beta_n] \cos[\beta_n]} \left(\cos\left[\beta_n \left(1 - \frac{x}{thk}\right)\right] - \frac{\sin[\beta_n]}{\beta_n} \right) \right]$$

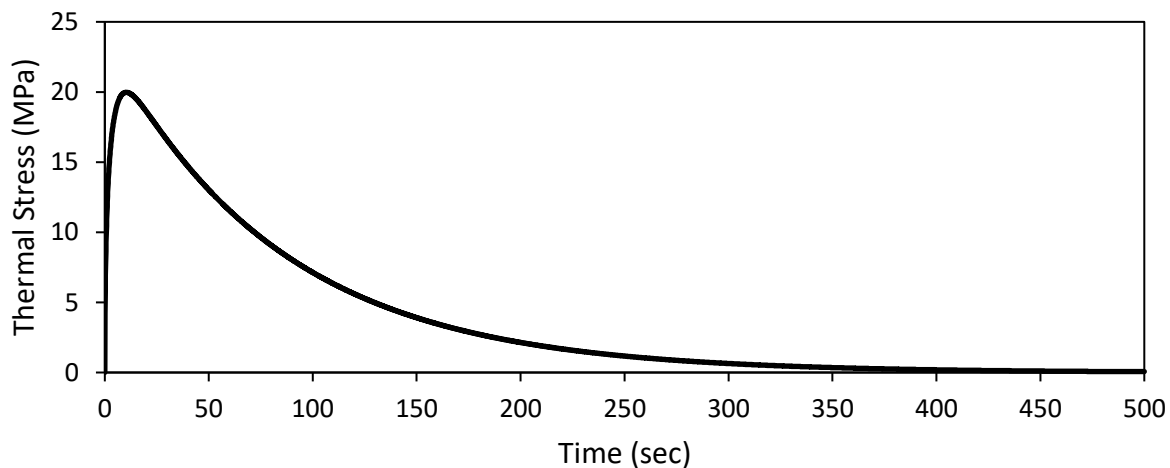


Figure E3.10-3 – Transient Thermal Stress on Inside Surface Computed from Above Equation