



PRESSURE VESSEL REQUIREMENTS FOR WET HYDROGEN SULFIDE (H₂S) SERVICE SPECIFICATION

FOR THE

CARTAGENA REFINERY EXPANSION PROJECT

CB&I CONTRACT NO. 166000

Doc. No.: 000-SP-MV09-0004

Information Class: ☐ Confidential ☒ Business ☐ Public

Rev. No.	Rev. Date	Revision Description	Prep. By:	Chk By:	App. By:
2	09-Jul-08	ISSUED FOR DESIGN	JBS	SAA	IAR
3	24-Aug-11	ISSUED FOR CONSTRUCTION	JBS	KDB	GAD

 	Pressure Vessel Requirements for Wet Hydrogen Sulfide (H₂S) Service Specification	Document No.: 000-SP-MV09-0004
		Revision: 3
		Date: 24-Aug-11
		Page 2 of 10

TABLE OF CONTENTS

1.0	SCOPE	3
2.0	REFERENCES	3
3.0	DESIGN	4
4.0	MATERIALS	5
5.0	FABRICATION	6
6.0	EXAMINATION AND TESTING	7
	APPENDIX A – Group A or Group B Classification	10

 	Pressure Vessel Requirements for Wet Hydrogen Sulfide (H₂S) Service Specification	Document No.: 000-SP-MV09-0004
		Revision: 3
		Date: 24-Aug-11
		Page 3 of 10

1.0 SCOPE

This Specification covers additional requirements above the basic requirements established by Specification 166000-000-SP-MV09-0001, Pressure Vessels for design, fabrication, and examination of carbon steel pressure equipment for wet hydrogen sulfide (H₂S) service. Material and material related fabrication requirements are addressed in this specification.

Definitions of two classes of wet H₂S services are given in appendix A. Material selection and fabrication requirements are based on these definitions and the service classification must be indicated to the vendor through contract documents / data sheet according to Category A for wet H₂S only; or Category B for Hydrogen Induced Cracking (HIC) potential with HIC-Tested steel and fabrication requirements.

2.0 REFERENCES

- 2.1 Applicable requirements in the following referenced CONTACTOR Specifications shall be considered an integral part of this Specification. Unless otherwise specified, the latest edition/revision of the CONTRACTOR specifications shall be used.
- 2.1.1 000-SP-MV09-0001 Pressure Vessels
 - 2.1.2 000-SP-MU10-0001 General Welding Specification.
 - 2.1.3 API RP 571 Recommended Practice "Damage Mechanisms"
 - 2.1.4 NACE Publication 8X194-2006 "Materials and Fabrication Practices for New Pressure Vessels Used in Wet H₂S Refinery Service"
 - 2.1.5 NACE MR0103-2007 "Standard Material Requirements – Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments"
 - 2.1.6 NACE RP0472-2005 "Standard Recommended Practice – Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments"
 - 2.1.7 NACE TM0284 Testing Method - "Standard Test Methode, Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Stepwise Cracking"

 	Pressure Vessel Requirements for Wet Hydrogen Sulfide (H₂S) Service Specification	Document No.: 000-SP-MV09-0004
		Revision: 3
		Date: 24-Aug-11
		Page 4 of 10

3.0 DESIGN

3.1 Beyond the scope of Specification 166000-000-SP-MV09-0001, the following additional requirements are applicable to Wet Hydrogen Sulfide (Wet H₂S) Service:

3.1.1 Pressure boundary welds shall be double bevel full penetration.

3.1.2 Welds of internal attachments to the pressure boundary shall be full penetration welds.

3.1.3 Nozzle attachment welds shall be full penetration. "Set-on" nozzles are prohibited.

3.1.4 Nozzles 3 inch NPS and smaller shall be long weld neck type.

3.1.5 Nozzles shall be 2 inch NPS or larger.

3.1.6 Slip-on flanges are prohibited.

3.1.7 Internal attachments to the pressure boundary shall be designed and installed so that the attachment welds can be given a full wet fluorescent magnetic particle test (WFMT) from all sides exposed to the process.

- Removable components shall be supplied for attachments that limit WFMT access.
- Figure 2 show acceptable weldment for attachments that are perpendicular to the shell or head of the equipment such as tray rings, baffles, etc.
- Figure 4 show acceptable weldment for attachments that are not perpendicular to the shell or head of the equipment such as downcomer bars, baffles, etc.

3.1.8 Nozzles and attachments shall be a minimum of 2 inches from longitudinal and circumferential pressure boundary welds.

3.1.9 Sleeve-lined nozzles or nozzles with other than integrally bonded alloy lining are not permitted.

 	Pressure Vessel Requirements for Wet Hydrogen Sulfide (H₂S) Service Specification	Document No.: 000-SP-MV09-0004
		Revision: 3
		Date: 24-Aug-11
		Page 5 of 10

4.0 MATERIALS

- 4.1 The following are requirements for **all** materials used in either Group A or Group B service as defined in Appendix A.

In addition to manufacturing practices defined in the applicable material specification, the steels shall be vacuum degassed and produced to a “fine grain practice”.

All materials shall be fully killed and normalized steels based on the following general grades:

Plate: ASME SA-516 grade 55, 60, 65 or 70
 Pipe: ASME SA-106 grade B or SA-333 grade 1 or 6
 Forgings: ASME SA-105 or ASME SA-350 grade LF1 or LF2 or SA-266 Cl 1
 Fittings: ASME SA234 Grade WCB or ASME SA-420 grade WPL6
 Castings: ASME SA216 grade WCA, WCB or WCC; or ASME SA-352 grade LCA, LCB or LCC
 Tubing: ASME SA-179 or ASME SA-214; or SA-210
 Bolting: (22 HRC Max exposed bolting) ASME SA-193 gr B7M or ASME SA-320 grade L7M.

Carbon Equivalent for Plate, Pipe, Forgings and Castings shall be calculated using the following formula and recorded on the Certified Mill Test Report:

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

- 4.1.1 CE shall be limited to the following:

≤0.43 for material less than 2” in thickness
 ≤0.45 for material 2” and over

- 4.1.2 No intentional addition of micro-alloying elements to Carbon-Manganese steels is permitted without CONTRACTOR approval. Total value of Cb + V shall be less than 0.02% by weight since these levels and carbon content along with welding heat input has an affect on HAZ hardness. Deliberate. Addition of micro-alloying elements is to be considered “intentional” where the single values of Niobium (Nb or Cb), Vanadium (V) and Titanium (Ti) are greater than 0.01 and Boron (B) is greater than 0.0005.
- 4.1.3 All equipment shall be PWHT in accordance with ASME Section VIII, Div 1 with no reduced temperature for extended time permitted.

 	Pressure Vessel Requirements for Wet Hydrogen Sulfide (H₂S) Service Specification	Document No.: 000-SP-MV09-0004
		Revision: 3
		Date: 24-Aug-11
		Page 6 of 10

- 4.2 In addition to the requirements in section 4.1, materials in Group B service, as defined in Appendix A have the following requirements:

HIC Testing - Testing for Resistance to Hydrogen-Induced Cracking according to NACE TM0284 (Low pH solution A) with test values of:

CLR = 5.0% Crack Length Ratio,
CTR = 1.5% Crack Thickness Ratio and
CSR = 0.5% Crack Sensitivity Ratio

Results are required for steels up to 1.2 inches in thickness and staggered across the thickness with additional samples when the plate steels are thicker. Tests shall include a minimum of the thickest and the thinnest plate for each heat of steel. HIC Testing is only required when identified as Group B service (per the appendix) as conducted on plate materials or on piping materials made from plate. No other forms of steels (forgings, castings, tubing, bolting or other forms) are required to be HIC tested.

5.0 FABRICATION

- 5.1 Beyond the scope of Specification 166000-000-SP-MV09-0001, the following additional requirements are applicable to Wet Hydrogen Sulfide (Wet H₂S) Service:

- 5.1.1 Nozzles with an internal protrusion shall have a smooth 3/8 inch fillet weld between the protrusion and the equipment wall. If the design includes an internal flange, ample distance between the shell and flange must be maintained to meet the Design requirements of clause 3.1.7.
- 5.1.2 Inside corner of nozzle necks shall have a smooth 1/8 inch minimum radius.
- 5.1.3 Process side of pressure retaining and attachment welds, such as tray supports, downcomers, baffles, vortex breakers, etc., shall be ground smooth (not necessarily flush). Toe of the welds shall be ground to remove undercut and to form a smooth transition into the adjacent base steel.
- 5.1.4 Weld surfaces of internal pressure boundary welds shall be finished as follows:
- Process fluid side of pressure boundary welds and welds of attachments to the pressure boundary shall be ground smooth (not necessarily flush).
 - Weld toes shall be ground to remove undercut and form a smooth transition into adjacent base metal.

5.2 Welding Procedure Qualification

- 5.2.1 Welding Procedure Qualification Records shall include micro-hardness traverses covering Base Metal and Heat Affected Zone and Weld Metal. Maximum hardness shall be 235 HV10.

 	Pressure Vessel Requirements for Wet Hydrogen Sulfide (H₂S) Service Specification	Document No.: 000-SP-MV09-0004
		Revision: 3
		Date: 24-Aug-11
		Page 7 of 10

5.2.2 Welding Procedures shall be qualified with PWHT time not greater than 10% more than is anticipated for fabrication.

6.0 EXAMINATION AND TESTING

Beyond the scope of Specification 166000-SP-MV09-0001, the following additional requirements are applicable to Wet Hydrogen Sulfide (Wet H₂S) Service:

- 6.1 Examination and testing requirements shall conform to datasheet.
- 6.2 Weld deposits, HAZ and base metal shall have a maximum hardness of 200HB.
- 6.3 Wet fluorescent magnetic particle testing (WFMT) shall be performed on all accessible internal welds on the pressure boundary following PWHT.
- 6.4 Ultra-sonic examination of plate per A578 to meet the S12 supplemental requirements of A516 shall be performed.

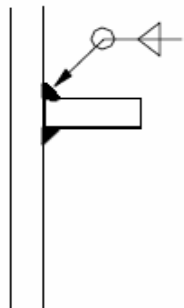
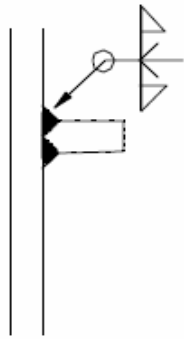
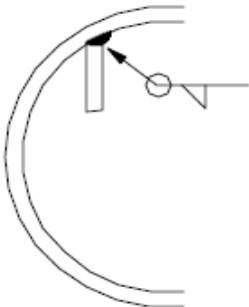
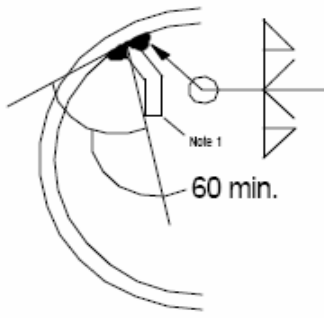
  Refineria de Cartagena S.A.	Pressure Vessel Requirements for Wet Hydrogen Sulfide (H₂S) Service Specification	Document No.: 000-SP-MV09-0004
		Revision: 3
		Date: 24-Aug-11
		Page 8 of 10

**PRESSURE EQUIPMENT FOR WET H₂S SERVICE
INSEPCION AND TESTING REQUIREMENTS**

NO.	INSPECTION, OR TEST DESCRIPTION	VENDOR/ CONTRACTOR SUPPLIED (YES/NO)	CB&I WITNESSED (YES/ NO)	DOCUMENTED RESULTS (YES/NO)	COMMENTS
1	RADIOGRAPHY	YES	YES	YES	100% ON ALL BUTT WELDS SHALL BE PERFORMED. PERFORMANCE AND ACCEPTABLE PER CB&I SPECIFICATION 166000-000-SP-MV09-0001
2	ULTRASONIC TEST	YES	YES	YES	100% ON ALL NOZZLE-TO-SHELL WELDS SHALL BE PERFORMED. PERFORMANCE AND ACCEPTABLE PER CB&I SPECIFICATION 166000-000-SP-MV09-0001
3	1ST WET FLUORESCENT MAGNETIC PARTICLE TEST	YES	YES	YES	PRIOR TO TEST, TEST AREA SHALL BE LIGHTLY GROUND OR BLASTED TO A SMOOTH SURFACE FINISH. POWER GRINDING MAY BE REQUIRED TO REMOVE SHALLOW INDICATIONS TEST SHALL BE PERFORMED AS FOLLOWS - PRIOR TO PWHT AND HYDROTEST - ON INTERNAL WELDS OF AND TO THE PRESSURE CONTAINMENT AND 3" TO EITHER SIDE OF A WELD - ON INTERNAL SURFACES WHERE THERE ARE ARC STRIKES - ON INTERNAL SURFACES WHERE TEMPORARY SUPPORTS/ CLIPS HAVE BEEN REMOVED - IN ACCORDANCE WITH 166000-000-SP-MV09-0001 WHERE APPLICABLE
4	2ND WET FLUORESCENT MAGNETIC PARTICLE TEST	YES	YES	YES	TEST SHALL BE PERFORMED WITH SAME REQUIREMENTS AS 1ST TEST ,EXCEPT 2ND TEST MUST BE AFTER PWHT LINEAR INDICATIONS SHALL BE REMOVED. SMALL DEFECTS SHALL BE GROUND OUT WITHOUT WELD REPAIR IF DEPTH OF GRINDING DOES NOT EXCEED 25% OF THE DESIGN CORROSION ALLOWANCE AND GRIND AREA DOES NOT EXCEED 2 SQ. INCHES IN ANY ø10 INCH CIRCLE.
5	HARDNESS TEST	YES	YES	YES	TEST SHALL BE PERFORMED AS FOLLOWS: - NUMER AND LOCATION OF TEST ON SEAM WELDS SHALL BE PER 166000-000-SP-MV09-0001, AS APPLICABLE - ON NOZZLE ATTACHMENT WELDS: (2) TEST ON 20% OF EACH NOZZLE SIZE WITH A MINIMUM OF (2) TEST ON EACH NOZZLE SIZE WITH EACH WELD PROCEDURE TO BE USED - ON INTERNAL ATTACHMENT WELDS: (2) TEST FOR EVERY 50 FEET OF WELD WELDED WITH DIFFERENT PROCEDURES

 	Pressure Vessel Requirements for Wet Hydrogen Sulfide (H₂S) Service Specification	Document No.: 000-SP-MV09-0004
		Revision: 3
		Date: 24-Aug-11
		Page 9 of 10

**ACCEPTABLE ATTACHMENT WELDMENTS FOR
PRESSURE EQUIPMENT IN WET H₂S SERVICE**

 FIGURE 1 STANDARD DESIGN	 FIGURE 2 WET H₂S DESIGN
 FIGURE 3 STANDARD DESIGN	 FIGURE 4 WET H₂S DESIGN
Note 1: Attachments to clips shall be bolted to allow future in-service inspection of welds	

 	Pressure Vessel Requirements for Wet Hydrogen Sulfide (H₂S) Service Specification	Document No.: 000-SP-MV09-0004
		Revision: 3
		Date: 24-Aug-11
		Page 10 of 10

APPENDIX A – Group A or Group B Classification

“NACE” Standard Recommended Practice RP0472-2005 “Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Environments” – is a practice that has replaced the earlier API 942 document and provides the road map including coverage of Wet H₂S service / HSC (hydrogen stress corrosion) / SCC (sulfide stress cracking) prevention via hardness controls; along with ASCC or Alkaline Stress Corrosion Cracking which are controlled by PWHT.

Service will be classified as group A or B using the following criteria:

Group A - Service that meets the above definition for wet H₂S service where the primary failure concern is Sulfide Stress Corrosion Cracking (SSCC)

Wet H₂S service is defined as an environment with:

- **>50ppmw dissolved H₂S in the free water**, or
- Free water pH <4 and some dissolved H₂S present, or
- Free water pH >7.6 and 20 ppmw dissolved hydrogen cyanide (HCN) in the water and some dissolved H₂S present, or
- **>0.0003 MPa absolute (>0.05 psia) partial pressure H₂S in the gas** in processes with a gas phase

Wet H₂S service shall include those definitions API Recommended Practice 571 “Damage Mechanisms” and within NACE Publication 8X194 “Materials and Fabrication Practices for New Pressure Vessels Used in Wet H₂S Refinery Service: and otherwise shall extend to those services defined within NACE MR-0103 “Standard Material Requirements – Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments”.

Group B - Service that meets the criteria below and will require HIC-Testing for plate materials (as derived from NACE Publication 8X194-December 2006). This service has not only a risk for SSCC, but the additional risk of Stress Oriented Hydrogen Induced Cracking (SOHIC) or Hydrogen Induced Cracking (HIC) or blistering.

- >50 ppmw total sulfide; or
- Greater than 0.0003 MPa (0.05 psia) partial pressure of H₂S in the gas phase, and an aqueous phase with >2,000 ppmw total sulfide and pH <4; or
- Aqueous phase with >2,000 ppmw total sulfide, pH >7.6, and HCN >20 ppmw; or
- Aqueous phase with > 2 wt% NH₄HS; or
- Aqueous phase with 4% to >6 wt% NH₄HS; or
- Conditions defined in API 581 for moderate to severe service