Mechanical Design of Slug Catcher

Ayende^{1*}, Mohammad Zafrullah Arsyad², Totok Widiyanto³

^{1,2,3}Politeknik Energi dan Mineral [PEM] Akamigas, Jln Gadjah Mada No. 38, Cepu 58315

ABSTRACT

In the upstream oil and gas industry Slug Catcher is a separator to separate heavy liquid hydrocarbons and the gaseous lighter fraction. Slug Catcher is a cylindrical pressure vessel which has a horizontal orientation designed with an internal pressure of 84.37 kg/cm², 73,89 °C temperature, 3 mm corrosion allowance, 3,500 mm length, and 1,750 mm diameter. This paper aims to design a Slug Catcher from a mechanical side that is safe and able to withstand the stress caused by internal pressure. General design which includes calculation of thickness of shell, heads, and nozzles, maximum allowable working pressure (MAWP), and minimum design metal temperature (MDMT) using ASME BPVC Section VIII Division 1. Based on the results obtained the nominal shell thickness is 60 mm, head minimum thickness 58 mm, material specification for shell and head is SA 516 Gr 70. In general, the selected material uses low carbon steel; flange rating class 600; vessel's Maximum Allowable Working Pressure is 87.60 kg/cm²; hydrostatic test pressure is 113 kg/cm².

Keywords : pressure vessel, slug catcher, thickness, circumferential stress, saddle support

ayende2018@gmail.com

1. Introduction

Pressure vessel is most common non-rotating equipment in the oil and gas industry. Pressure vessel used to separate fluids into different phases or temporarily store the fluid before it processed to the next stage. Slug Catcher is one of the type of pressure vessel, this equipment used in the upstream oil and gas industry.

The design of a Slug Catcher should consider suitability to the operating conditions, comply to the applicable code & standard, also take into account the construction design such as dimensions, Maximum Allowable

Working Pressure (MAWP), and material strength. Generally, the standard & code applies to the design of the construction of pressure vessels is ASME BPVC Section VIII, Division 1.

2. Materials and Methods

Design data uses ASME Sect. VIII Div. 1 as code standard. The methodology design of this slug catcher is shown in Figure 1 as follows:

Figure 1. Slug catcher Design flowchart

A. Design Data

Design data of the pressure vessel show at table 2.1 as follow :

Table 1. Design Data

Code Standard	ASME Sect. VIII Div. 1
Orientation	Horizontal
Diameter (ID)	1750 cm
Radius (Ri)	875 mm
Length (T/T)	3500 mm
Design Temperature	73,89 °C
Design Pressure	84,37 kg/cm ²
Corrosion Allowance	3 mm

B. Material Selection

The material selection based on following consideration :

1) Service fluids

The service fluid to this Slug Catcher is a mixture of natural gas and water, the composition of natural gas show at table 2.2 as follow :

Table 2. Natural Gas Composition

Component	Mole Fraction (%)	Concentration (ppm)
Methane	0.83	8300
Ethane	0.044	440
Propane	0.036	360
i-Butane	0.01	100
n-Butane	0.011	110
i-Pentane	0.005	50
n-Pentane	0.003	30
Hexane+	0.005	50
Helium	0.00	0
Argon	0.008	80
Oxygen	0.00	0
CO ₂	0.046	460
Nitrogen	0.002	20
H ₂ S	0.00	0

From the natural gas composition above, compared to the API Spec 12J, Specification for Oil and Gas Separator Appendix B, the operating fluid in the Slug Catcher is not a corrosive fluids based on the data below :

- Oxygen 0 ppm (< 0,0005 ppm),
- Carbon Dioxide 460 ppm (< 600 ppm)
- Hydrogen Sulfide content 0 ppm.

The construction of Slug Catcher does not require corrosion resistant material specifications. Several choices of materials that can be used such as steel (carbon steel, low alloy steel), lead, nickel, inconel, monel, and stainless steel.

2) Design Temperature

Temperature will have an impact on tensile strength and modulus of elasticity, which of course will affect the allowable stress of the material. For example, mild steel (low carbon steel, carbon < 0.3 percent) has an allowable stress of 20 ksi at 100 °F, which changes to only 12 ksi at 800 °F. Thus, if an equipment is designed to operate at high temperatures, a material that can withstand its strength must be chosen. The design temperature of the Slug Catcher is 73.89 ° C which is included in the lower service temperature. Since the material chosen is used for intermediate temperature services, it does not require special specifications such as high temperature service or cryogenic service.

3) Fabricability

The fabricability of materials must be considered according to the capability of shop work, in the end, it is related to the fabrication cost and time. Generally the main fabrication process carried out on vessels includes machining, forming (cold working), and welding.

4) Cost

Because material costs vary widely, designers must evaluate material costs with other factors such as corrosion, replacement costs, and expected equipment life. Estimated material prices use references from Structural Analysis and Design of Process Equipment, Maan H. Jawad and James R. Farr 3rd per year 2017 [9]. Material choices are suitable for operating fluids in Slug Catcher, then ranked to choose the material with the most cost minimum, and consider the ease of

fabrication of each material. Thus, carbon steel is the most suitable material.

Table 3. Rank of Materials

Rank	Material	Cost (\$/lb)	Machining & Welding
1	Carbon steel	0,80	S
2	Low alloy steel	1,60	S
3	Stainless steel	2,70	S
4	Monel	15,00	S
5	Inconel	18,00	S

Note : S (*Satisfactory*) means no special techniques are needed.

5) Material Specification

Material specifications used for vessel construction must be registered in ASME Section II part D. Generally, the material chosen is materials that commonly used in the industry and easily available in the market to make it easier for future needs such as repair. Material specifications for each part of the vessel can be seen in the following table.

Table 4. Material Specification Used

Part	Material Specification
Shell	SA-516 gr. 70
Head	SA-516 gr. 70
Reinforcing Pad	SA-516 gr. 70
Nozzle neck	SA-105 (Forging) SA-516 gr. 70 (Plate) SA-106 gr. B
Flange	SA-105
Fittings	SA-234 gr. WPB
Bolt / Nuts	SA 193 B7 / SA 194 2H
Anchor Bolt	SA-307 B
Support Pad	SA-36

6) Mechanical Properties and Chemical Composition of Materials

The mechanical properties of the material in the form of yield strength (σ_y) and tensile strength (σ_u) in the material can be seen in ASME Sec. II-D (Metric), yield strength and tensile strength determine the maximum allowable stress (S) on a material.

The chemical composition of a material determines the chemical properties of the material. The chemical composition can be found in ASME Sec. II-A.

The mechanical properties of the material used in this Slug Catcher can be seen in the following table, the maximum allowable stress is determined at the design temperature (73.89 ° C).

Table 5. Mechanical Properties of Materials

Material	Strength		Max. Allow. Stress (kg/cm ²)
	Tensile (kg/cm ²)	Yield (kg/cm ²)	
SA-36	4078,88	2549,30	1162,48
SA-105	4945,64	2549,30	1407,21
SA-106 gr.B	4231,84	2447,33	1203,27
SA-516 gr.70	4945,64	2651,27	1407,21
SA-193 gr. B7	8106,77	6679,17	1621,35
SA-307 gr. B	4231,84	2549,30	492,52
SA-234 WPB	4231,84	2447,33	1498,99

C. General Design

The general design of the Slug Catcher includes:

1) Thickness Calculation

There are several types of wall thickness that are calculated in the design of this pressure vessel, including *Required thickness*, which is the minimum thickness needed to withstand internal or external pressure on the vessel before the corrosion allowance is added, *Design thickness* is the amount of required thickness plus the corrosion allowance (UG-25), *Nominal thickness*, the thickness of the plate ordered, must not be thinner than the design thickness. The thickness is selected based on market availability.

a. Shell

Calculated with UG-27, the effect of the greatest stress, namely the circumferential stress uses the formula as below:

$$t = \frac{P R}{SE-0,6P} \dots\dots\dots (1)$$

b. Head

Calculated with UG-32, the type of head used is ellipsoidal so it uses the formula as below :

$$t = \frac{P D}{2SE-0,2P} \dots\dots\dots (2)$$

c. Nozzle

The nozzle neck thickness is calculated by the UG-45. For access openings and openings used for inspection only

$$t_{UG-45} = t_a \dots\dots\dots (3)$$

For other nozzles :

$$t_b = \min [t_{b1}, \max(t_{b1}, t_{b2})] \cdot (4)$$

$$t_{UG-45} = \max(t_a, t_b) \dots\dots\dots (5)$$

Table 6. Nozzle Min. Thickness Req.

Nozzle Minimum Thickness Requirements		
Nominal Size	Minimum Wall Thickness	
	in.	mm
NPS 1/8 (DN 6)	0.060	1.51
NPS 1/4 (DN 8)	0.077	1.96
NPS 3/8 (DN 10)	0.080	2.02
NPS 1/2 (DN 15)	0.095	2.42
NPS 3/4 (DN 20)	0.099	2.51
NPS 1 (DN 25)	0.116	2.96
NPS 1 1/4 (DN 32)	0.123	3.12
NPS 1 1/2 (DN 40)	0.127	3.22
NPS 2 (DN 50)	0.135	3.42
NPS 2 1/2 (DN 65)	0.178	4.52
NPS 3 (DN 80)	0.189	4.80
NPS 3 1/2 (DN 90)	0.198	5.02
NPS 4 (DN 100)	0.207	5.27
NPS 5 (DN 125)	0.226	5.73
NPS 6 (DN 150)	0.245	6.22
NPS 8 (DN 200)	0.282	7.16
NPS 10 (DN 250)	0.319	8.11
≥ NPS 12 (DN 300)	0.328	8.34

The nozzle requirement data from the client data sheet proposal are:

Table 7. Nozzle Required

Nozzle	Size (In)	Rating	Face & Type	Service
N1	16	600#	RFV3	Inlet
N2	16	600#	RFV3	Outlet
N3	2	600#	RFWN	Drain
N4	4	600#	RFWN	Drain
N5	2	600#	RFWN	PSV
K1	2	600#	RFWN	PT
K2	2	600#	RFWN	PG
K3	2	600#	RFWN	TT
K4	2	600#	RFWN	TG
K5A/K5B	2	600#	RFWN	Bridle (LG/LT)
K6A/K6B	2	600#	RFWN	Chamber LT
MH	20	600#	RFV3	Manway c/w Blind Flange

For RFWN nozzles, it can use a flange (ASME B16.5) connected to a pipe (ASME B36.10), while RFV3 uses an integral nozzle (forging nozzle catalog). The results of the thickness calculation are in the following table :

Table 8. Nozzle Thickness Calculation Results

Thickness	Required, t_r (mm)	Design, t_{min} (mm)	Nominal, t_n (mm)
Shell	54,42	57,42	60
Head	52,77	55,77	58
Nozzle N1& N2	15,64	15,64	68,33
Nozzle N2, N3, N5, K1, K2, K3, K4, K5A/B, K6A/B	15,64	15,64	68,33
Nozzle N4	8,27	11,27	14,98
Nozzle MH	18,8	18,8	75,44

2) Reinforcement

The basis of the code reinforcement rule ensures that at any section crossing through an opening, the area of the shell lost due to the opening is replaced by a material which has sufficient strength and an area equivalent to

that of the opening. Paragraph UG-36 (c) (3) provides exemption from the need of reinforcement if the opening is not greater than 3 1/2 in. (89 mm) diameter - in a shell or vessel head having a minimum thickness of 3/8 in (10 mm) or less, or 2 3/8 in. (60 mm) diameter - on a shell or vessel head that has a minimum thickness of more than 3/8 in. (10 mm). The calculation of reinforcement requirements is given in Figure UG-37.1 (Figure 2). If the available area is greater than or equal to the required area, the use of reinforcement is not necessary.

However, if the available area is less than the required area, it can be done in several ways, such as increasing the nozzle neck wall thickness (increasing pipe schedule), using a reinforcing pad, or using a forging nozzle (integral flange). Of the several options, considerations were made to choose the most effective method in terms of cost, difficulty level and processing time.

Figure 2. Nomenclature and reinforced opening formula

Table 9. Reinforcement Requirements Calculation Result

Aavail.	Areq.	Pad	
		width	t _{pad}
cm ²		mm	
309,46	224,43	N/A	N/A
309,46	224,43	N/A	N/A
exempted		N/A	N/A
92,69	55,59	200	60
exempted		N/A	N/A
exempted		N/A	N/A
exempted		N/A	N/A
exempted		N/A	N/A
exempted		N/A	N/A
exempted		N/A	N/A
exempted		N/A	N/A
exempted		N/A	N/A
366,77	279,72	N/A	N/A

3) MAWP

The Maximum Allowable Working Pressure (MAWP) is the maximum pressure allowed in the normal operating position at a certain temperature under "hot and corroded" conditions, usually the design temperature (UG-98). Each vessel element has a different MAWP, the lowest MAWP of all the elements is chosen as the MAWP of the vessel.

Shell

$$P_w = \frac{S_{DT} E t_{sc}}{Rc + 0,6t_{sc}} \dots\dots\dots (6)$$

Ellipsoidal Head

$$P_w = \frac{2S_{DT} E t_{hc}}{Dc + 0,2t_{hc}} \dots\dots\dots (7)$$

From the calculation, the lowest MAWP is at the ellipsoidal head with 87.60 kg/cm².

4) Test Pressure

A requirement to determine the test pressure based on calculations, carried out to find out if there is a leak in the vessel:

Hydrostatic Test UG-99(c)

$$P_{hydro} = 1,3MAWP \times \frac{S_{test temp.}}{S_{design temp.}} \dots\dots\dots (8)$$

The pressure obtained for the hydrostatic test is 113 kg/cm², if the hydrostatic test is not possible to perform, then a pneumatic test can be a substitute for testing vessels with the formula

$$P_{pneu} = 1,1MAWP \times \frac{S_{test temp.}}{S_{design temp.}} \dots\dots\dots (9)$$

then the pressure for the pneumatic test = 96.36 kg/cm².

5) Overpressure Protection

All pressure vessels must be equipped with overpressure protection. If a pressure relief device is used, the pressure inside the vessel should not be more than 10% or 3 psi (20 kPa) of the MAWP (whichever is greater). Meanwhile, if a dual (more than one) pressure relief device is used, the pressure in the vessel should not be more than 16% or 4 psi (30 kPa) of MAWP (UG-125) (c). The pressure tolerance, more or less, of the pressure relief valve should not be more than 2 psi (15 kPa) for pressures less than or equal to 70 psi (50 kPa) and 3% for pressures above 70 psi (500 kPa).

From the results of the above calculations, it can be seen that the PSV set pressure on the Slug Catcher is 96.36 kg/cm² with an over / under pressure tolerance of 2.63 kg/cm².

D. Loads Calculation

loads that generally need to be considered on the vessel are:

1) Pressure Load

Derived from internal or external pressure, in this case the largest Slug Catcher pressure load during the hydrostatic test.

2) Moment Load

Due to wind, earthquake, erection, or transportation, in this case the load by wind and earthquake is calculated using the ASCE 7-16 standard, a design wind force of 61.26 kgf is obtained and a design seismic force is 474.4 kgf.

3) Weight Load

The type of weight calculated is the empty weight (the total weight of the vessel sitting on the foundation), the operating weight (the empty weight plus the weight of the operating fluid) and the test weight (the vessel full of water). The weight of a component can be calculated by the surface area times the thickness times the density. For the specific gravity of carbon steel (carbon steel) which is generally used in vessels 7.85 g/cm³ or 0.284 lb/in³. A practical calculation formula for determining the weight of a vessel made from carbon steel can be seen in the following table.

Table 10. Vessel Weight Formula

Identification	Formula
Shell	$\pi D m L t \rho$
Spherical Head	$\pi D m^2 t \rho$
Hemispherical Head	$1,57 D m^2 t \rho$
2:1 Ellipsoidal Head	$1,084 D m^2 t \rho$
Cone	$A c t \rho$

After the weight of all components has been added to the total weight, a typical percentage is added to allocate the weight of the other components and the weight of the weld.

Table 11. Typical Percentage of Weight

Total Weight	Added by
<50.000 lb	10%
50.000 - 75.000 lb	8%
75.000 - 100.000 lb	6%
>100.000 lb	5%

For vessel components: Flange-Flange weight see ASME B16.5 Pipe Flanges and Flanged Fittings or in the product catalog. Pipe - Pipe weights can be found in ASME B36.10. Manway - Manway weight can be seen in ASME 16.47. There are two types of fluid weight calculated, the weight of the operating fluid and the weight of the test fluid. This weight can be calculated by multiplying the volume of a component by the density.

The formula for calculating the volume of each vessel component can be seen in the following.

Table 12. Vessel Volume Formula

Section	Volume
Cylinder	$\pi D^2 h / 4$
Sphere	$\pi D^3 / 6$
Ellipsoidal Head	$\pi D^2 h / 6$
2:1 S.E. Head	$\pi D^3 / 24$
Ellipsoidal Head	$\pi D^2 h / 6$
F&D Head	$\pi D^3 K / 12$
Cone	$\pi D^2 h / 12$
Hemispherical Head	$\pi D^3 / 12$

The results of weight calculations are in the following table.

Table 13. Slug Catcher Weight

<i>Vessel Total</i>	
<i>Operating weight</i>	17376 kg
<i>Empty weight</i>	16872 kg
<i>Test weight</i>	26667 kg
<i>Capacity</i>	9824 liter

E. Design of Vessel Support

This slug catcher has a horizontal orientation so that it uses a support saddle type, the design method uses analysis by L.P. Zick. The distance between the head tangent line and saddle must not be more than 0.2 times the length of the vessel. The minimum contact angle suggested by the ASME Code is 120 °, except for a very small vessels.

Figure 3. Design Saddle Dimension

Total force reaction at saddle : Q = terbesar diantara Q_1 (*Longitudinal*) dan Q_2 (*transversal*).

$$Q_1 = \frac{W_o}{2} + \frac{F_L B}{L_s} \dots\dots\dots (10)$$

$$Q_2 = \frac{W_o}{2} + \frac{3 F_T B}{E} \dots\dots\dots (11)$$

the calculation results show that the largest total reaction force received by the vessel is based on the transverse seismic load of 10421.5 kgf.

Stress due to internal pressure :

$$\sigma_x = \frac{PR}{2t_s} \dots\dots\dots (12)$$

Obtained $\sigma_x = 657,97 \text{ kg/cm}^2$

Vessels using a saddle experience:

- 1) Longitudinal bending stress
At saddle

$$S_1 = \pm \frac{QA \left(1 - \frac{1 - \frac{A}{L} + \frac{R^2 - H^2}{2AL}}{1 + \frac{4H}{3L}} \right)}{K_1 R^2 t_s} \dots\dots\dots (13)$$

Between two saddles (*midspan*)

$$S_1 = \pm \frac{\frac{QL}{4} \left(\frac{1 + 2 \frac{R^2 - H^2}{L^2}}{1 + \frac{4H}{3L}} - \frac{4A}{L} \right)}{\pi R^2 t_s} \dots\dots\dots (14)$$

Where $K_1 = 0.335$, the largest longitudinal stress (S_1) is found in the saddle, which is 7.6 kg/cm^2 . Maximum allowable stress: Tension: $S_1 + \sigma_x \leq SE = 665.57 \text{ kg/cm}^2 \leq 1406 \text{ kg/cm}^2$, the tension stress is acceptable; Compressive: $t / R \geq 0.005 = 0.0641 \geq 0.005$ so that compressive stress is not considered.

- 2) Tangential shear stress

Because $A > R / 2$ ($700 \text{ mm} > 467.5 \text{ mm}$), the following equation is used.

$$S_2 = \frac{K_2 Q}{R t_s} \left(\frac{L - 2A}{L + \frac{4}{3}H} \right) \dots\dots\dots (15)$$

Where $K_2 = 1.171$, obtained $S_2 = 10.99 \text{ kg/cm}^2$. Max. allowable stress: $S_2 \leq 0.8 S_s = 10.99 \text{ kg/cm}^2 \leq 929.98 \text{ kg/cm}^2$, tangential shear stress is acceptable.

- 3) Circumferential stress

Because $L \geq 8R$ ($3500 \text{ mm} \geq 7480 \text{ mm}$), used the following equation.

$$S_4 = \frac{Q}{4ts(b+1,56\sqrt{Rts})} - \frac{12K_6 QR}{L ts^2} \dots\dots (16)$$

Where $K_6 = 0.03$, obtained $S_4 = -35.12 \text{ kg/cm}^2$. Max. allowable stress: $S_4 \leq 1.5 \times S_s = -35.12 \text{ kg/cm}^2 \leq 1743.72 \text{ kg/cm}^2$, the circumferential stress is acceptable.

F. Lifting Lug

The design of the lifting lug dimensions is based on the calculation of the Slug Catcher weight in erected conditions, namely using an empty weight. The design of the lifting lug dimensions based on the vessel weight can use the image below.

LIFTING LUG						
VESSEL WEIGHT (Lbs)	D (In)	T (In)	R (In)	H (In)	L (In)	WELD (Min)
12,000	1	½	1½	5	10	Double-bevel groove weld with T/4 (max. ½ in.) fillet weld all around.
20,000	1¼	¾	2	6	10	
30,000	1¾	1	2¼	6	10	
50,000	1¾	1¼	2½	7	12	
70,000	2¼	1¼	3½	8	12	
100,000	2½	1½	4½	9	16	
150,000	3	1¾	5	10	16	
200,000	4	2	6	12	18	
250,000	4¼	2	6½	13	18	Double-bevel groove weld with T/4 (max. ½ in.) fillet weld all around.
300,000	4½	2½	7	14	20	
Notes: 1. All dimensions are in inches. 2. The design is based on conditions: a. $\alpha = 45^\circ$ maximum b. Minimum tensile strength of lug material 70,000 psi. c. Direction of force is in the plane of lugs. 3. Use wear plate if necessary to eliminate buckling due to normal or sudden loading.						

Figure 4. Lifting Lug Dimension

A vessel weight of 50,000 lb was chosen so that the dimensions are $D = 1 \frac{5}{8} \text{ in.} = 41.28 \text{ mm}$, $T = 1 \frac{1}{4} \text{ in.} = 31.75 \text{ mm}$, $R = 2 \frac{1}{2} \text{ in.} = 63.5 \text{ mm}$, $H = 7 \text{ in.} = 177.8 \text{ mm}$, $W = 12 \text{ in.} = 304.8 \text{ mm}$, Fillet weld = $\frac{3}{8} \text{ in} = 9.5 \text{ mm} \approx 10 \text{ mm}$.

G. Welding

The type of welding process used is Shielded Metal Arc Welding (SMAW). The parts of the vessel that will be weld are:

1) Shell

Shell, which is composed of three steel plates, is welded with a double v-groove type joint. In the following picture. Reviewed from the UW-3, it is included in the joint category A in the form of a longitudinal joint in the shell and joint category B in the form of a circumferential joint in the shell that connects between the steel plates making up the shell.

Figure 5. Joint at Shell

2) Head

The head is welded in the form of a circumferential joint to the shell, which is included in the joint category A, per UW-3, a double v-groove type joint.

Figure 6. Joint at Head

3) Nozzle

Welding performed to connect the nozzle to the shell is included in category D joints, per UW-3. Double v-groove joint type.

Figure 7. Welding of Nozzle to Shell

4) Neck to Flange

The welds performed to connect the nozzle neck to the flange are included in category B joints, per UW-3.

5) Saddle Support

Joint type on saddle support uses fillet weld.

6) Reinforcement Pad

The type of joint in the reinforcement pad uses fillet weld.

Figure 8. Welding of Neck to Flange

H. Examination

The type of examination performed in this Slug Catcher is Full Radiography Examination in terms of UW-11 (2), which is intended to determine the quality of the welds that have been carried out at full length on all butt joints in the shell and head of vessels that have a nominal thickness in the weld joints of more than 38. mm.

I. Heat Treatment

Postweld heat treatment (PWHT) performed to heating a vessel at a certain temperature which is intended to release residual stress resulting from mechanical treatment and welding. Based on the thickness calculations that have been done, it is known that the nominal thickness on the shell is 60 mm and the nominal thickness on the head is 58 mm, thus this Slug Catcher requires PWHT per UW-11 (a) (2) which states that all butt welds are shells and head vessels with a nominal thickness greater than 1 ½ in. (38 mm) must be performed PWHT. The WPS used in welding at Slug Catcher includes PWHT, so that the holding temperature and holding time based on WPS is 595 ° C for 2 hours 24 minutes.

J. Low Temperature Operation

It is the lowest temperature that can operate in a vessel, it is known that the operating temperature of the fluid in this Slug Catcher is 20.34 ° C. This is related to the Minimum Design Metal Temperature (MDMT), which is the lowest temperature allowed in a metal material whether it requires a charpy impact test or not. The MDMT set on the vessel is related to the MAWP set on the vessel (UG-20 (b)). It has been previously known that the MAWP vessel is 87.60 kg / cm² which is located on the head, so that MDMT based on the head data can be calculated as follows: Governing thickness = $t_n = 58$ mm, Curve = For SA-516 plates with a thickness of more than 40 mm, done normalizing. (ASME Sec. II-A). So for SA-516 gr. 70 with a governing thickness of 60 mm using a D curve, MDMT vessel = 20.34 ° C in terms of UCS-66 using the impact test exemption curve, the combined line of MDMT temperature and governing thickness is above the D curve so that it is free from impact tests, per UCS- 66 (a).

K. Bill of Materials

A bill of materials (BOM) is a list of raw materials and components with the respective quantities required to manufacture the final product. BOM can be used for communication between the designer and the production.

WELDING PROCEDURE SPECIFICATION (WPS)																																	
ASME SECTION IX																																	
Company Name	PEM AKAMIGAS	By	Arsyad																														
WPS No.	001-S 01-PW	Date	9-Jun-2020																														
Revision no.	0	Support PQR No. (s)	001-S 01-PW																														
Welding Process(es)	SMAW	Type (s)	Manual																														
JOINTS (QW-402) Joint Design : Groove and Fillet Backing : Yes - No - Backing Material (Type) : None ☐ Metal ☐ Nonfusing Metal ☐ Nonmetal ☐ Other *Or follow applicable map																																	
BASE METALS (QW-403) P No. 1 Group No. 2 to P No. 1 Group No. 2 OR Specification and type/grade or UNS Number : to Specification and type/grade or UNS Number : OR Chem. Analysis and Mech. Prop. : N/A to Chem. Analysis and Mech. Prop. : N/A Thickness Range : Base Metal : Without Impact Groove 5 ~ 200 mm Fillet All With Impact Groove Fillet All Maximum Pass Thickness ≤ 1/2 in (13 mm) (Yes) (No) Others :																																	
FILLER METALS (QW-404) <table border="1"> <thead> <tr> <th></th> <th>SMAW</th> </tr> </thead> <tbody> <tr> <td>Spec. No (SFA)</td> <td>5.1</td> </tr> <tr> <td>AWS No. (Class)</td> <td>E 7018-1</td> </tr> <tr> <td>F-No.</td> <td>4</td> </tr> <tr> <td>A-No.</td> <td>1</td> </tr> <tr> <td>Size of Filler Metal</td> <td>3.2 mm Ø</td> </tr> <tr> <td>Weld Metal</td> <td></td> </tr> <tr> <td>Deposited Thickness</td> <td></td> </tr> <tr> <td> Groove</td> <td>40 mm</td> </tr> <tr> <td> Fillet</td> <td>All</td> </tr> <tr> <td>Electrode-Flux (Class)</td> <td>N/A</td> </tr> <tr> <td>Flux Type</td> <td>N/A</td> </tr> <tr> <td>Flux Trade Name</td> <td>N/A</td> </tr> <tr> <td>Consumable Insert</td> <td>None</td> </tr> <tr> <td>Other</td> <td>-</td> </tr> </tbody> </table> Approved by : MIGAS Company : PEM AKAMIGAS ARSYAD					SMAW	Spec. No (SFA)	5.1	AWS No. (Class)	E 7018-1	F-No.	4	A-No.	1	Size of Filler Metal	3.2 mm Ø	Weld Metal		Deposited Thickness		Groove	40 mm	Fillet	All	Electrode-Flux (Class)	N/A	Flux Type	N/A	Flux Trade Name	N/A	Consumable Insert	None	Other	-
	SMAW																																
Spec. No (SFA)	5.1																																
AWS No. (Class)	E 7018-1																																
F-No.	4																																
A-No.	1																																
Size of Filler Metal	3.2 mm Ø																																
Weld Metal																																	
Deposited Thickness																																	
Groove	40 mm																																
Fillet	All																																
Electrode-Flux (Class)	N/A																																
Flux Type	N/A																																
Flux Trade Name	N/A																																
Consumable Insert	None																																
Other	-																																

WELDING PROCEDURE SPECIFICATION (WPS)																																																								
ASME SECTION IX																																																								
		WPS No. 001-S 01-PW																																																						
POSITION (QW-405) Position(s) of Groove All Welding Progression Up Yes Down Position(s) of Fillet All Other -		POSTWELD HEAT TREATMENT (QW-407) Temperature Range 595 °C Time Range 1 hr/in or 15 min (min) Other -																																																						
PREHEAT (QW-406) Preheat Temp. Min. 95 °C Interpass Temp. Max. Preheat Maintenance Other		GAS (QW-408) <table border="1"> <thead> <tr> <th></th> <th colspan="3">Percent Composition (Mixture%) Flow Rate</th> </tr> <tr> <th></th> <th>Gas(es)</th> <th></th> <th></th> </tr> </thead> <tbody> <tr> <td>Shielding</td> <td>N/A</td> <td>N/A</td> <td>N/A</td> </tr> <tr> <td>Trailing</td> <td>N/A</td> <td>N/A</td> <td>N/A</td> </tr> <tr> <td>Backing</td> <td>N/A</td> <td>N/A</td> <td>N/A</td> </tr> <tr> <td>Other</td> <td>-</td> <td>-</td> <td>-</td> </tr> </tbody> </table>			Percent Composition (Mixture%) Flow Rate				Gas(es)			Shielding	N/A	N/A	N/A	Trailing	N/A	N/A	N/A	Backing	N/A	N/A	N/A	Other	-	-	-																													
	Percent Composition (Mixture%) Flow Rate																																																							
	Gas(es)																																																							
Shielding	N/A	N/A	N/A																																																					
Trailing	N/A	N/A	N/A																																																					
Backing	N/A	N/A	N/A																																																					
Other	-	-	-																																																					
ELECTRICAL CHARACTERISTICS (QW-409) <table border="1"> <thead> <tr> <th rowspan="2">Weld Pass(es)</th> <th rowspan="2">Process</th> <th colspan="2">Filler Metal</th> <th rowspan="2">Current Type and Polarity</th> <th rowspan="2">Amps (Range)</th> <th rowspan="2">Volt (Range)</th> <th rowspan="2">Travel Speed (Range)</th> <th rowspan="2">Other</th> </tr> <tr> <th>Class</th> <th>Diam.</th> </tr> </thead> <tbody> <tr> <td rowspan="3">Face</td> <td>Root</td> <td>SMAW</td> <td>E 7018-1</td> <td>3.2</td> <td>DC-RP</td> <td>80 ~ 145</td> <td>22 ~ 28</td> <td>90 ~ 130</td> </tr> <tr> <td>Filler</td> <td>SMAW</td> <td>E 7018-1</td> <td>3.2</td> <td>DC-RP</td> <td>80 ~ 145</td> <td>22 ~ 28</td> <td>90 ~ 130</td> </tr> <tr> <td>Cap</td> <td>SMAW</td> <td>E 7018-1</td> <td>3.2</td> <td>DC-RP</td> <td>80 ~ 145</td> <td>22 ~ 28</td> <td>90 ~ 130</td> </tr> <tr> <td rowspan="2">Back</td> <td>Filler</td> <td>SMAW</td> <td>E 7018-1</td> <td>3.2</td> <td>DC-RP</td> <td>80 ~ 145</td> <td>22 ~ 28</td> <td>90 ~ 130</td> </tr> <tr> <td>Cap</td> <td>SMAW</td> <td>E 7018-1</td> <td>3.2</td> <td>DC-RP</td> <td>80 ~ 145</td> <td>22 ~ 28</td> <td>90 ~ 130</td> </tr> </tbody> </table>				Weld Pass(es)	Process	Filler Metal		Current Type and Polarity	Amps (Range)	Volt (Range)	Travel Speed (Range)	Other	Class	Diam.	Face	Root	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130	Filler	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130	Cap	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130	Back	Filler	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130	Cap	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130
Weld Pass(es)	Process	Filler Metal				Current Type and Polarity	Amps (Range)						Volt (Range)	Travel Speed (Range)		Other																																								
		Class	Diam.																																																					
Face	Root	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130																																																
	Filler	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130																																																
	Cap	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130																																																
Back	Filler	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130																																																
	Cap	SMAW	E 7018-1	3.2	DC-RP	80 ~ 145	22 ~ 28	90 ~ 130																																																
Pulsing Current _____ Heat Input (max.) _____ Tungsten Electrode Size and Type _____ N/A (Pure Tungsten, 2% Thoriated, etc) Mode of Metal Transfer for GMAW (FCAW) _____ N/A (Spray Arc, Short Circuiting Arc, etc) Other _____																																																								
TECHNIQUE (QW-410) String or Weave Bead _____ String and Weave Orifice, Nozzle, or Gas Cup Size _____ N/A Initial and Interpass Cleaning (Brushing, Grinding, etc) _____ Grinding and Wire Brushing Method of Back Gouging _____ Oscillation _____ N/A Contact Tube to Work Distance _____ N/A Multiple or Single Pass (Per Side) _____ Multiple Multiple or Single Electrodes _____ Single Electrode Spacing _____ Peening _____ N/A Other _____																																																								

Figure 9. Welding Procedure Specification (WPS)

Figure 10. Impact Test Exemption Curve

L. Construction Drawings

The main purpose of construction drawings is to provide a graphical representation of what to build. Construction drawing in this Slug Catcher design shows the composition of components, construction details, dimensions, weld joints, material specifications, and bill of materials. The construction drawing of the Slug Catcher design is given in the appendix.

3. Conclusion

The main mechanical data on the Slug Catcher are : material shell & head SA 516 Gr 70: low carbon steel; inside diameter: 1750 mm; vessel thickness: 60 mm; maximum allowable working pressure (MAWP): 87.60 kg/cm² ; hydrostatic test pressure: 1619.34 kg/cm²; minimum design metal temperature (MDMT): 20.34 °C; Postweld Heat Treatment (PWHT) : Yes; Radiography Examination: RT-1; Impact test: exempt per UCS-66.1; Joint efficiency: 1; Corrosion allowance: 3 mm; Support type: Saddle. Based on the design calculation result the Slug Catcher comply to requirement of ASME BPVC Section VIII Division 1.

References

- [1] American Society of Civil Engineers. *ASCE/SEI-7 Minimum design loads and associated criteria for buildings and other structures*. Virginia: 2016.
- [2] American Society of Mechanical Engineers. *ASME BPVC Section II Part A Ferrous Material Specifications*. New York: 2019.
- [3] American Society of Mechanical Engineers. *ASME BPVC Section II Part D Properties (Metric)*. New York: 2019.
- [4] American Society of Mechanical Engineers. *ASME BPVC Section IX Welding, Brazing, and Fusing Qualifications*. New York: 2019.
- [5] American Society of Mechanical Engineers. *ASME BPVC Section V Nondestructive Examination*. New York: 2019.
- [6] American Society of Mechanical Engineers. *ASME BPVC Section VIII Div-1 Rules for Construction of Pressure Vessels*. New York: 2019.
- [7] American Welding Society. (2001). *Welding Handbook*. Denvers: 2001.
- [8] Ashby, M. F. *Materials Selection in Mechanical Design 3rd edition*. Burlington: Elsevier Inc. 2005. Bohnart, E. R. *Welding : principles and practices*. New York: McGraw-Hill. 2017
- [9] Jawad, M. H. *Structural Analysis and Design of Process Equipment*. Hoboken: JohnWiley & Sons, Inc. 2019
- [10] Megyesy, E. F. *Pressure Vessel Handbook 12th edition*. Oklahoma: Pressure Vessel Publishing, Inc. 1973.
- [11] Moss, D. R. *Pressure Vessel Design Manual 4th*. Waltham: Elsevier Inc. 2013.
- [12] Peters, M. S., & Timmerhaus, K. D. *Plant Design and Economics for Chemical Engineers (4th ed.)*. McGraw-Hill Chemical Engineering Series. 1991.
- [13] Towler, G., & Sinnott, R. *Chemical Engineering : Principles, Practice, and Economics of Plant and Process Design*. Burlington: Elsevier. 2008.

LAMPIRAN A. Gambar Teknis Slug Catcher