Redesign of Centrifugal Pump with Capacity 286.8 M³/hrs and Head 32 Metre at Karawang International Industrial City

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ABSTRACT
Mechanical equipment has an important role to support the needs of a process. There is mechanical equipment, namely a pump that functions to move liquid fluid from one place to another through the piping medium. Based on report from customer, Centrifugal pump ETA-N 150 x 125 - 315 which functions as supply distribution of clean water from Water Treatment Plant (WTP) to the Karawang area International Industrial City (KIIC) experienced a decrease in capacity and Head and happened unbalance on the pump drive motor rotor. After an investigation by the team engineering PT. TG Engineering, found problems such as heavy corrosion and corrosion erosion on surface impeller, spoons impeller and volute chamber, deep scratch and light corrosion on shaft / shaft, as well as malfunction bearing on bearing pump and bearing pump drive motor unbalance. Referring to the results of the investigation, the authors design and select centrifugal pump components based on the results of the investigation. So that after calculating the dimensions of impeller, shaft, key and component selection such as type bearing, lubrication bearing, as well as coupling.

Keywords: Redesign of Centrifugal Pump, Decreasing Head and Capacity, API 610

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1. Introduction
In an industry, mechanical equipment has an important role in the process of industrial activities. Energy conversion mechanical equipment is needed to convert potential energy into mechanical energy that can be utilized in industrial processes. On January 12, 2021, PT. TG Engineering accepts requests major overhoul centrifugal pump from KIIC Region (Karawang International Industrial City).

One of the pumps in the KIIC area is the ETA-N 150x125-315 centrifugal pump which functions as a supply distribution of clean water from reservoir to the KIIC area. Based on reports from customer, the centrifugal pump has decreased head and capacity. The pump is requested major overhoul at PT. TG Engineering. After investigation, it was found some defects and failures on its components.

Heavy corrosion and corrosion erosion on surface impeller, spoons impeller and volute chamber casing, deep scratch and light corrosion on shaft / shaft and malfunction bearing on bearing pump and bearing pump drive motor unbalance. Therefore, parameter data from the Centrifugal Pump ETA-N 150x125-315 is used as the basis for calculating the redesign of the centrifugal pump with the aim of writing this journal article is to determine the procedure for
calculating the dimensions of the components that make up the centrifugal pump, the factors considered in redesigning the pump, centrifugal and to determine the dimensions of the centrifugal pump according to the needs of the operation.

![Figure 1. Centrifugal Pump Condition ETA-N 150x125-315](image)

Based on the findings of the investigation, the authors would like to redesign some of the centrifugal components. The aim is to determining the appropriate centrifugal pump with the capacity and head optimally and economically and more resistant to corrosion attack.

2. Materials and Methods

The research methods used in this study as follows: (1) Field Study Methods Collection of fluid specification data such as fluid type, specific gravity, head and capacity. Meanwhile's data collection methods were library study, observation and interview. The methodology redesign of this centrifugal pump is shown in Figure 1 as follows:
ETA-N Centrifugal Pump 150 x 125 - 315 reported decreased head and capacity. After conducting an investigation in Workshop PT. TG Engineering, found erosion corrosion on impeller, heavy corrosion on volume chamber, deep scratch and light corrosion on the shaft and failure bearing caused unbalance on the pump motor. This pump is designed with a capacity of 286.8 m³/h and head 32 meters. redesign data of the centrifugal pump show at table 1 as follow:

| Parameter         | Pump Specification |
|-------------------|--------------------|
| Total Head [m]    | 32                 |
| Rate flow [m³]    | 1750 cm            |
| Speed [RPM]       | 875 mm             |
| NPSHr [m]         | 3500 mm            |
| Liquid            | Fresh water        |
| Temperature       | Ambient            |
| Liquid density [kg/m³] | 995.7              |
A. Determination pump type

The following is a typical graph being used to select the pump type. Based on the graph, the selected is single stage (single suction) type centrifugal pump.

Figure 3. Centrifugal pump selection guide

B. Calculation of Specific Index

Specific speed is an index number that shows the relationship between capacity, head and rotational speed at the best efficiency conditions. The specific speed will later be used to determine the type impeller, power value, efficiency value approach, radial force value approach. The value of the specific kinematic velocity can be calculated using the following equation:

\[ n_s Q = \frac{n_s}{h_a^{\frac{1}{2}}} \] \hspace{1cm} [1]

The dynamic specific velocity value can be calculated using the following equation:

\[ n_s P = \sqrt{\frac{V}{75}} . n_s Q \] \hspace{1cm} [2]

Dimensionless Shape Number value can be calculated using the following equation:

\[ n_{sf} = 3 n_s Q \] \hspace{1cm} [3]

C. Efficiency Overall

Efficiency Overall can be determined by relating the specific speed value to the efficiency approximation graph. So that the value of efficiency is obtained overall.
D. Pump power

Power is work done per unit time by relating the specific speed value to the efficiency approximation graph. Fluid power is the power the fluid receives or the power it exerts impeller in liquids, can be calculated by:

\[ P_w = \frac{Q H}{75} \]  \hspace{1cm} \text{[4]}

Pump power or shaft power is the power applied to the impeller to rotate to produce the desired pumping condition, the shaft power can be calculated using the following equation:

\[ P_F = \frac{P_w}{\eta_{sp}} \]  \hspace{1cm} \text{[5]}

The driving force is the drive shaft power exerted on the pump shaft. The driving force can be calculated using the following equation:

\[ P_m = \frac{P_F (1+\alpha)}{\eta_{d.w.-}} \]  \hspace{1cm} \text{[6]}

The amount of NPSHr can be calculated using the following equation:

\[ NPSHr = \left( \frac{\Delta H}{S} \right)^{\frac{1}{2}} \]  \hspace{1cm} \text{[7]}

Due to the calculation of NPSHa there is no supporting data in the field, so the author only calculates the value of NPSHr. Thus, the calculation of NPSHr is carried out in order to make a comparison between the NPSHr value of the design results with the NPSHr value in the field (existing).

Based on the value of NPSHr in the field (existing) obtained the NPSHr value of 3.8 m and the design value of NPSHr of 3.65 m. Thus, it was concluded that there was a decrease in the value of NPSHr before and after the redesign. The main advantages obtained when the NPSHr value is getting smaller are: range the value of the possibility of cavitation will be greater, so that the risk of the possibility of cavitation will be smaller.

E. Design Impeller

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:

| Component | Mole Fraction (%) | Concentration (ppm) |
|-----------|------------------|---------------------|
| Methane   | 0.83             | 8300                |
| Ethane    | 0.044            | 440                 |
| Propane   | 0.036            | 360                 |
| i-Butane  | 0.11             | 110                 |
| n-Butane  | 0.005            | 50                  |
| i-Pentane | 0.003            | 30                  |
| n-Pentane | 0.005            | 50                  |
| Hexane+   | 0.00             | 0                   |
| Helium    | 0.08             | 80                  |
| Argon     | 0.00             | 0                   |
| Oxygen    | 0.00             | 0                   |
| CO₂       | 0.046            | 460                 |
| Nitrogen  | 0.002            | 20                  |
| H₂S       | 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.

| 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 (σy) and tensile strength (σu) 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 |
|-----------|------------------|-------------------|
|           | Tensile (kg/cm²) | Yield (kg/cm²)    | (kg/cm²) |
| 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  |

F. 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, \textit{Design thickness} is the amount of required thickness plus the corrosion allowance (UG-25), \textit{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:

\[ t = \frac{P R}{2S - 0.6P} \]  

(1)

b. Head

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

\[ t = \frac{PD}{2S - 0.2P} \]  

(2)

c. Nozzle

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

\[ t_{UG-45} = t_{b} \]  

(3)

For other nozzles:

\[ t_{b} = \min [t_{b1}, \max(t_{b1}, t_{b2})] \]  

(4)

\[ t_{UG-45} = \max(t_{a}, t_{b}) \]  

(5)

| 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 11/4 (DN 32) | 0.123  | 3.12  |
| NPS 11/2 (DN 40) | 0.127  | 3.22  |
| NPS 2 (DN 50) | 0.135  | 3.42  |
| NPS 21/2 (DN 65) | 0.178  | 4.52  |
| NPS 3 (DN 80) | 0.189  | 4.80  |
| NPS 31/4 (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        | Briddle (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, $t_{\text{min}}$ (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 ½ 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.

![Diagram](image)

**Figure 2. Nomenclature and reinforced opening formula**

**Table 9. Reinforcement Requirements Calculation Result**

| \( A_{\text{avail}} \) | \( A_{\text{req}} \) | Pad width | \( t_{\text{pad}} \) |
|------------------------|---------------------|----------|-----------------|
| cm\(^2\)               | mm                  |          |                 |
| 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

\[ P_{W} = \frac{SDT E_{Sc}}{Rc + 0.65 \Delta Sc} \] ...........................................(6)

Ellipsoidal Head

\[ P_{W} = \frac{SDT E_{The}}{Dc + 0.2 \Delta the} \] ...........................................(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)

\[ P_{hydro} = 1.3 MAWP \times \frac{S_{test temp}}{S_{design temp}} \] ...........................................(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

\[ P_{pneu} = 1.1 MAWP \times \frac{S_{test temp}}{S_{design temp}} \] ...........................................(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.

G. 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.

| Identification      | Formula          |
|---------------------|------------------|
| Shell               | $\pi Dm L t \rho$ |
| Spherical Head      | $\pi Dm^2 t \rho$ |
| Hemispherical Head  | $1,57 Dm^2 t \rho$ |
| 2:1 Ellipsoidal Head| $1,084 Dm^2 t \rho$ |
| Cone                | $Ac t \rho$      |

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.

| 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

| Vessel Total          |                        |
|-----------------------|-------------------------|
| Operating weight      | 17376 kg                |
| Empty weight          | 16872 kg                |
| Test weight           | 26667 kg                |
| Capacity              | 9824 liter              |

H. 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 $120^\circ$, except for a very small vessels.

![Design Saddle Dimension](image)

Total force reaction at saddle: $Q = \text{terbesar diantara } Q_1 (\text{Longitudinal}) \text{ dan } Q_2 (\text{transversal})$.

\[
Q_1 = \frac{W_0}{2} + \frac{P}{L} \tag{10}
\]

\[
Q_2 = \frac{W_0}{2} + \frac{3F}{B} \tag{11}
\]

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:
\[
\sigma_x = \frac{PR}{2\pi z} \quad \text{(12)}
\]

Obtained \(\sigma_x = 657.97 \text{ kg/cm}^2\)

Vessels using a saddle experience:

1) Longitudinal bending stress
   
   At saddle
   
   \[
   S_1 = \pm \frac{Qa}{K.R^2 \pi z} \quad \text{(13)}
   \]
   
   Between two saddles (midspan)
   
   \[
   S_2 = \pm \frac{QL}{4} \left( 1 + \frac{R^2 - L^2}{L^2} \frac{4a}{L^2} \right) \quad \text{(14)}
   \]

   Where \(K_1 = 0.335\), the largest longitudinal stress (\(S_1\)) is found in the saddle, which is 7.6 kg/cm². Maximum allowable stress: Tension: \(S_1 + \sigma_x \leq SE = 665.57 \text{ kg/cm}^2\) ≤ 1406 kg/cm², 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 mm > 467.5 mm), the following equation is used.
   
   \[
   S_2 = \frac{K_2 Q}{K.R^2 \pi z} \left( \frac{L - 4a}{L^2} \right) \quad \text{(15)}
   \]

   Where \(K_2 = 1.171\), obtained \(S_2 = 10.99 \text{ kg/cm}^2\). Max. allowable stress: \(S_2 \leq 0.8 \times S_s = 10.99 \text{ kg/cm}^2\) ≤ 929.98 kg/cm², tangential shear stress is acceptable.

3) Circumferential stress
   
   Because \(L \geq 8R\) (3500 mm ≥ 7480 mm), used the following equation.
   
   \[
   S_4 = \frac{Q}{4ts(2+1.56\sqrt{R}z)} - \frac{12 K_6 Q R}{L t^2} \quad \text{(16)}
   \]

   Where \(K_6 = 0.03\), obtained \(S_4 = -35.12 \text{ kg/cm}^2\). Max. allowable stress: \(S_4 \leq 1.5 \times S_s = -35.12 \text{ kg/cm}^2\) ≤ 1743.72 kg/cm², the circumferential stress is acceptable.

   I. 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.

[60]
A vessel weight of 50,000 lb was chosen so that the dimensions are D = 1 5/8 in. = 41.28 mm, T = 11/4 in. = 31.75 mm, R = 21/2 in. = 63.5 mm, H = 7 in. = 177.8 mm, W = 12 in. = 304.8 mm, Fillet weld = 3/8 in = 9.5 mm ≈ 10 mm.

J. 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.

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.
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](image)

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](image)

![Figure 9. Welding Procedure Specification (WPS)](image)

K. 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.

L. 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.

M. 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 = tn = 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).

N. 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.

Figure 10. Impact Test Exemption Curve
0. 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.

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