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CORROSION PROTECTION OF PROCESS VESSELS BY GALVANIC ANODE CP SYSTEM

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ABSTRACT

In petroleum industries, the extraction of crude oils goes through various processes in order to separate the residual impurities (gasses, water, and sludge) and then further processes to establish the different grades of extracted oil. During these processes different types of vessels are being used which need to be protected against corrosion as their internal surfaces are exposed to extreme corrosive environments.

Although these vessels are protected through internal linings, which are considered as a first line of defense from corrosion protection, the application of cathodic protection is still necessary as secondary protection because these linings cannot be 100% effective and the possibility of degradation with the passage of time always exists.

This paper is an effort towards;

- ⇨ Providing information about the types and structure of the process vessels used in petroleum industries.
- ⇨ Concepts for the use of cathodic protection.
- ⇨ Various factors involved in designing galvanic anode protection systems.

INTRODUCTION

A process vessel is a pressure container used to complete the production process, such as separating, combining, or breaking of a product or a substance. It is a container with an internal differential pressure or temperature compared to the outside, or designed to contain products/substances that cannot be stored in open atmosphere due to their highly reactive, toxic, and flammable nature.

There are two types of process vessels - those with and without internal components. The first category referred to as vessels, are provided with substantial internal components for processing like separators, dehydrators, desalters, and hydrocyclones. The second category referred to as drums, have no internal components and are used as intermediate storage or surge containment of a process stream like knockout drums, seal drums, surge drums, flash drums, feed drums, and drain drums.

The well fluid stream generally constitutes the mixtures of crude oil, natural gas, and salt water. These mixtures are very difficult to handle, transport, and store. Therefore, the first step in processing is the well fluid stream separation in separate streams (oil, gas, and water). This process takes place in separator vessels, also called as High-Pressure Production Trap (HPPT), Intermediate Pressure Production Trap (IPPT) and Low Pressure Production Trap (LPPT) or somewhere as HP production separator and LP production separator.

The salt water in oil creates serious corrosion and scaling problems in transportation and refining operations. Therefore, it is necessary to remove water up to the acceptable limits i.e. 1% or sometimes less than 0.5% of the total volume. The oil leaving the separator may still contain water between 10% and 15% as emulsified water, which requires further treatments like Dehydration.

The presence of salt content in remnant water makes the fluid more corrosive, hence need to be minimized to acceptable limits, which is 28.5 to 42.5 ppm. The treatment required for this purpose is desalting, which is similar to dehydration except the addition of wash water to lower the salt concentration.

Some crude oils contain hydrogen sulfide (H_2S) and other sulfur products. When it contains more than 400 ppm of H_2S, it is classified as Sour Crude. Sour crude oil presents serious safety and corrosion problems. The treatment to remove the H_2S or reduce the sulfur to acceptable limit is a dual process of Stabilization and Sweetening.

The separated natural gas generally contains undesirable components such as H_2S, CO_2, N_2, and water vapors. Field processing of natural gas requires removing or reducing to acceptable limit of these components through gas sweetening process.

Water vapor is also the main impurity in natural gas. It is not objectionable in vapor phase, however get critical in liquid or solid phases when gas is compressed or cooled called condensate. This liquid phase of water cause problems in pipelines like accelerate corrosion and reduce capacity by accumulating in low level regions, therefore glycol dehydration is the pretreatment to remove the water vapors prior to compressing, storing or transporting.

The produced water collected from separation, dehydration, and desalting processes still contain hydrocarbons in the form of droplets, it cannot be utilized, or disposed directly. The primary treatment of produced water is to remove oil droplets through deoiling units and skimmers.

This produced water is further treated to remove dissolved solids, sulfates, nitrates, contaminants and scaling agents. This water is contained in different water drums used as multiple utility purposes like wash, cleaning and other maintenance purposes.

Sometimes sand and solid particles are also produced with well stream fluid. This causes many serious problems in production, processing, and transportation of crude oil, like erosion, corrosion, accumulation, and equipment reliability and instrumentation errors. Therefore, the effective control, safe removal, and environmental friendly disposal of these solids are very important. The separation of solids from liquids can be accomplished in desanders, which can be situated in multiphase oil, produced water, and sand jetting streams.

All drained hydrocarbon liquids from pressurized vessel are collected into the Closed Drain Drums. The liquid in this vessel contained dissolved gasses that can flash and become hazard if not handled properly. After removing all hazard gasses safely from drained liquids, it is collected into the Slop Oil Drum for recovery and safe disposal.

Similarly all separated liquids and solids from different processes as well as from the fluid transportation system are gathered into one central unit called Slug Catcher. These collected materials then cleaned to remove absorbed contaminants, chemicals in order to comply environmental, and disposal regulations.

A flare or vent disposal systems collect and discharge gases from pressurized process components to atmosphere or to safe location for final release during normal operations and abnormal conditions (emergency relief). In vent system, the gas exiting the system is dispersed in atmosphere, however in flare system, the gas exiting the system by burning due to toxicity or flammable nature. The gases fed to the flare system are from Knockout Drums. A Water Seal Drum is provided at flare header to provide a positive seal to isolate flare, which itself an ignition source from header to process unit.

There are some chemicals used in closed loop system during processing of crude oil and natural gas, which contaminates gradually. Continuous recovery of these chemicals is required for smooth and cost effective operations. Glycol recovery and amine recovery are the example of these processes.

Further to above petroleum process vessels, some storage drums are used between units to dampen fluctuations in flow rate, composition, or temperature. They can allow one unit to be shut down for maintenance without shutting down the entire plant.

Flash evaporation is the partial vapor that occurs when a saturated liquid stream undergoes a reduction in pressure by passing through a throttling device. This process takes place in the vessel which is known as flash drums.

Accumulators are used to store water under pressure and to take up expansion or contraction within the hot water system. These vessels are charged with water from either main or a pump system and are capable of delivering extremely high flow rate until empty.

CATHODIC PROTECTION CONCEPT AND DESIGN

Structural Details

Generally, the process vessels are composed of three main parts i.e. shell, heads, and nozzles.

The shell is primary component that contains pressure. Pressure vessel shells are welded together to form a structure that has a common rotational axis. Most pressure vessel shells are cylindrical, spherical, or conical in shape.

All pressure vessel sheets must be closed at the ends by heads. Heads are typically curved rather than flat. Curved configurations are stronger and allow the heads to be thinner, lighter, and less expensive than flat heads.

A nozzle is cylindrical component that penetrates the shell or heads of a pressure vessel. The nozzle ends are usually flanged to allow for the necessary connections and to permit easy disassembly for maintenance or access. Nozzles are used for the following applications:

1) Attach piping for flow into or out of the vessel.
2) Attach instrument connections, (e.g. level gauges, thermowells, or pressure gauges).
3) Provide access to the vessel interior at manways.
4) Provide for direct attachment of other equipment items (e.g. heat exchanger or mixer).

Nozzles are also sometimes extended into the vessel interior for some applications, such as for inlet flow distribution or to permit the entry of thermowells.

The main factors influence in material selection of vessels are; strength, corrosion resistance, hydrogen attack resistance, fracture toughness and fabricability. Generally, process vessels and its attachments are constructed with following materials grades:

Shell and Heads (Carbon Steel Grades)	Nozzles (Carbon Steel Grades)	Internal Pipes (Stainless Steel Grades)
SA 516 Gr 70	SA 106 Gr B	SA 312 TP316L
SA 516 Gr 70N	SA 106M Gr 8	
SA 516 Gr 70N+HIC	SA 333 Gr 3	
SA 516M Gr 485	SA 333 Gr 6	
SA 387 Gr 12	SA 335 Gr P12	
SA 203 Gr D		

Table-1: Process Vessels Construction Material Grades

Design Overview

The process vessels are typically designed in accordance with American Society of Mechanical Engineers (ASME) Code Section VIII. This section is further divided into three divisions, i.e.

Division-1: Applies for pressures greater than 15 psig and lower than 3,000 psig.
Division-2: Identical to Division-1, accept few conditions related to stress, design, quality, fabrication and inspection.
Division-3: Applies for pressures greater than 10,000 psig.

Division-1 is used most often since it contains sufficient requirements for the majority of pressure vessel applications.

The mechanical design of a pressure vessel begins with specification of design pressure and temperature. Pressure imposes loads that must be withstood by the individual components. Temperature effects material strength and its allowable stress. The design conditions are the most severe conditions of coincident pressure and temperature that expected during normal service.

The operating conditions are associated with the normal operation of process vessels. The operating pressure and temperature is based on the maximum internal or external pressure and temperature that the vessel may encounter.

The first line of defense for any structure protection from corrosion is the coatings. Similarly, the vessel internal surfaces and all internal components electrically continuous with vessel body should be coated with effective coating system.

The selection of coating type is dependent on the following factors:

1) Compatible with extreme temperature requirements.
2) Compatible with extreme pH levels.
3) Compatible with immersion, wet/dry cycles.
4) Resistant to service environment.
5) Meets applicable regulatory requirements.
6) Effective protection for required duration.
7) Compatible with substrate.

Internal Components

Generally, vessels have internals to help them effectively process the fluids go through it. Depending on the purpose of the vessel, the amount and configuration of the internals will vary. Following are some of the more common vessel internals.

1) Wave breaker or stilling baffles; are installed in long horizontal vessels, which spanning the gas-liquid interface and perpendicular to the flow. These plates are the part of vessel body and made of same vessel material.

2) Overflow weir; is used to separate the two liquids based on their gravitational separation process. This box is also the part of vessel body and made of same vessel material.
3) Splash plate; inlet diverter, or inlet deflector takes the inlet flow and causes it to change direction suddenly. The rapid change in direction and change of velocity causes the gas to break out of the liquid.
4) Vortex breaker; is normally installed on the liquid outlet to prevent formation of a vortex when the liquid outlet valve is open. This part is also made of same vessel material.
5) Sand jetting system; is commonly used in the upstream separator to remove solids that settles in gravity separators. The solids are then discharged through sand drains located down the length of the vessel.
6) Mesh Pad Demister; this contains a knitted wire mesh, supported by an open grid. The gas flows unimpeded through the wire mesh and the inertia of the droplets causes them to impact the wire surface. The droplets then coalesce on the wire surface. When the droplets reach a certain size, they fall down due to gravity.
7) Cyclone devices; with optimized blade geometry brings the combined phase into rotation. The resulting centrifugal force moves the liquid and solid particles towards the vessel wall, where they form a liquid film flowing downwards to the bottom of the vessel. This device is used in hydrocyclone vessels.
8) Coalescer plate; pack coalescer is used in the liquid section of a separator or scrubber to optimize the degree of liquid-liquid separation. These are either corrugated or perforated plates and can be made of same material of vessel.
9) Electrostatic grids; are used in dehydration and desalting process of crude oil. These grids are powered by either AC or DC from an external power sources for the process of coalescing of oil-water emulsions. These grid plates kept isolated from the vessel body through insulators.
10) Submersible pump casings; In some vessels like slope drums and drain drums the submersible pumps are provided with the casing pipe, which is continuous with the vessel body and made of same vessel material.

Refer figure 1, showing the internal components arrangement of a three phase crude oil separator as an example.

Surface Area Consideration

The cathodic protection for the process vessels is required only in those areas where water is expected to be accumulated in liquid phase. Hydrocarbon fluids not only contain free water, but also contain emulsified water in the form of water droplets. These droplets also cause the corrosion when they hit the vessel walls and break. Therefore, for protection it is safe to consider the surface area up to the highest liquid level.

In natural gas processing, the wet gasses contains water in the vapor phase, which condenses and settles in the bottom of the vessels. Therefore, the cathodic protection requirement is limited to those portions where water accumulates.

In produced water treatment process and other vessels, that contain water as a utility for main crude and gas treatments, the cathodic protection system requirement consideration should be for the entire surface area of the vessels.

Since all the vessels contain internal components there should be a consideration of additional surface area to be protected. This is generally considered by taking a safe percentage over the calculated surface area of the vessel body. This can be assessed by knowing the vessel type and function.

The most common practice followed by the CP design engineers in consideration of additional surface area is 5 to 10% for drums and 10 to 30% for vessels.

Coating Breakdown Factors

Usually there are three different assumptions about the coating breakdown factors i.e.

1) Coating breakdown due to ineffective coating application.
2) Coating breakdown during the installation phase due to mishandling.
3) Coating breakdown due to coating degradation over time.

The first two assumptions can be minimized or almost eliminated by taking actions like proper coating application, inspections, and effective coating repairs after all mechanical works completion.

The third assumption is the potential factor that cannot be controlled. Hence, some possibilities to be considered include the percentage as bare surface area or by adding some allowances in design current density.

There are no specific values determined by any industry standards or specifications, therefore considerations are made based on observation and studies during testing and inspection (T&I) by the users/owners or based on the experiences of CP design engineers. An effective method to estimate this value has been specified in Det Norseky Veritas (DNV) standard RP-B-401.

Current Density Consideration

This is the most important factor through which the structure current demand is calculated and which determines the required anode quantities; therefore, the approach should be as realistic as possible in determining the values. Many standards and specifications exist which specify the current density values depending on their tests, research, and past experiences.

The current density required to protect the structure is very much dependent on the following factors;

1) Type of coating and its condition.
2) The operating temperature of the vessel.
3) The internal fluid movement based on vessel function.
4) Oxygen concentration inside the vessel.
5) Acidity of internal fluid (presence of H_2S).
6) Internal fittings & coalescing packing materials.
7) Variety of metallic structures.

An increase of these factors causes depolarization of the structure (cathode), which increases the current density requirement for protection, hence these factor should be accounted for during the design stage for current requirement calculations, e.g.;

1) The coating condition in new vessels compared to old vessels is better, hence the low current density consideration with provision of expected coating degradation up to the design life.
2) The operating temperature of the vessels is sometimes high. Since most of the represented data about current densities is based on ambient conditions, the current density should be either considered or calculated with temperature rise effects.
3) The hydrocyclone vessels are continuously subjected to internal fluid cyclic movements; therefore, some provision should be added in current density values.
4) The oxygen concentration inside the vessels is increased due to the water flow or turbulence; therefore, all those vessels which handle water in large amounts require consideration of this factor as well.
5) Low pH value fluids will require additional consideration in current density values. Sour crude and gas requires the removal of acid gas (H_2S) for which amine solutions are used. The amine solutions themselves are alkaline, but become contaminated with acid during the sweetening process. Therefore vessels handling or processing sour fluids and amine recovery units will require consideration for the extra safe value.

The acidic conditions in process vessels will also have an adverse effect on galvanic anodes by increasing their consumption rates, which is further discussed below in Anode Selection Criteria.

National Association of Corrosion Engineers (NACE) has specified in standard SP0575-2007, the current density consideration range i.e. from 50 to 400mA/m^2. These values contain considerations for depolarized state due to factors like H_2S, oxygen, high operating temperatures and high flow rates.

Electrolyte Resistivity

The electrolyte resistivity for the consideration of cathodic protection system designing is related to the accumulated water resistivity, since the corrosion characteristics are mostly associated with water. This relation is inversely proportional i.e. water of low electrical resistivity tends to be more corrosive, while water with high resistivity tend to be less corrosive.

Several factors influence water resistivity, but most important are: concentration of ions in the water, mobility of the ions in the water, acid forming components (H_2S and CO_2) and temperature of the water.

Since all the above-discussed processes are associated with either removal of water, lowering the salt concentration, treating the water, and using it as a utility during different process, the resistivity is therefore expected to be different in each phase. This needs to be determined properly and used for the design calculations.

Based on personal experience of last 10 years, working on vessel internal CP designs in GCC countries, following are observations related to accumulated water resistivity values;

1) The unprocessed well stream fluid contains water with resistivity less than 100 ohm-cm.
2) The processed crude oil contains water with resistivity greater than 1,000 ohm-cm.
3) The unprocessed natural gas contains water with resistivity greater than 1,000 ohm-cm.

Anode Selection Criteria

The galvanic anodes (magnesium, zinc, and aluminum) have been developed in alloys to remain active and to extend life, since the pure form always has the problem to undergo self-corrosion and cannot stay active. The efficiency and consumption rate of anodes depend on alloys of anodes and the environment to which it is exposed. Therefore, for the application of vessel internal special type of anode alloys are used, i.e.:

1) Aluminum Alloy-III: This anode is alloyed with the addition of indium, most suitable for seawater, brackish water, and mud saline. Since in crude separation process the vessel contained similar environment, therefore these anodes are most suitable for this application. The efficiency and consumption rate of this anode is very much effective with rise in temperature. Its standard potential and consumption rate is based on 25^0C temperature. As the temperature increases, the consumption rate of the anode also increase.
2) Zinc ASTM B-418-73 Type-1 and Mil Spec A-18001K: These anodes are also suitable for seawater and brackish water. All zinc anodes have the limitation to undergo inter-granular corrosion at temperature above than 50^0C. Therefore, these anodes can be used only in those vessels, which operate less than the specified temperature.
3) High Temperature Zinc Anode: This is the special zinc alloy anode to work at elevated temperature without subjecting to inter-granular corrosion problems. Therefore, for vessels operating temperature in excess of temperature above 50^0C to 80^0C, this anode shall be used.

The acidic environments accelerate the anode consumption rates by depolarizing the anode potentials. Therefore, the fast consumption of anodes lead to shorten the required design life of anodes.

Design Life Consideration

The required design life of the anodes generally referenced from the clients requirements and specification, which are based on their testing and inspection (T&I) and maintenance programs.

The anode design life calculation is mainly dependent on anode current outputs. The size and dimensions of the anodes control the anode current output in the given environments. Sometimes if the anode size with reference to its weight requirements for design life do not match under such circumstances the anode current output shall be controlled by applying coating over some part of the anode.

ANODES INSTALLATION METHOD

Anode Arrangement & Installation

The most typical method for the installation of anodes inside the vessels is to fix anodes over the welded supports on vessel internal walls. These supports are either brackets, flat headed bolts or internally threaded small pipe (boss). The anodes with mounting straps installed over the brackets or bolts, and anodes with core pipe installed over the boss. Both installation details have shown in figure 2 and 3 in last.

The anode positioning and location is very important for uniform current distribution inside over the vessel internal surface that needs protection. Hence following points need to be considered while designing;

1) The total designed or proposed quantity of anodes shall be distributed evenly over the surface required for protection.
2) The vessels with the compartments must have at least one anode installed in every compartment.
3) The anode should be located as near to the center of compartment as practical.
4) Ensure that anodes remain submerged in the electrolyte.

The vertical water vessels containing no internal components and compartments can provided with anode strings suspended from top head. This arrangement provides better current distribution because anodes are parallel to the walls and deteriorated anodes can be replaced without lowering the water level or draining the vessel. Refer figure 4 for installation details.

Anode Monitoring System

The anode monitoring system is a very effective method to monitor the anode current outputs inside the vessel, through this the anode performance with respect to the exposed environment can be monitored, and the anode life can be estimated.

For this purpose, dedicated nozzles are provided in the vessel, and a test station is installed with current measuring shunt outside the vessel. The position of anode monitoring facility is critical and normally at the end of vessel, but in some cases additional monitoring facilities are required. Refer figure 5 for installation details.

For monitoring the anode should be electrically isolated from vessel. Therefore the dedicated nozzle plate should be provided with proper insulation gasket and confirmed through the testing.

CONCLUSION

The CP designing of process vessels is difficult and critical due to enclosed and extreme electrolyte conditions of non-ambient temperature, pressure, velocity, chemical compositions and immune to environment. Since these conditions causes adverse effects like high corrosion activity, CP depolarization and higher anode consumptions. It is important to take special care while designing. Another limitation is the CP system effectiveness cannot be monitored except for anode consumption rate, therefore difficult to evaluate the CP performance and life.

This paper discussed all possible aspects which can contribute in vessel internal CP system designing. Every discussed factor should be well evaluated during design stage, so that the estimation can be effective for every possible worst condition and match the life requirements.

The periodic testing and inspection (T&I) of process vessel is an effective method of observing the designed CP system effectiveness and deficiencies. This gives the complete track record and feedback about the corrosion, erosion, metal loss and anode consumptions. This database can be an effective tool for the CP system designing of those new vessels which handle electrolyte similar to other old vessels as well as redesigning of the old ones.

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FIGURES

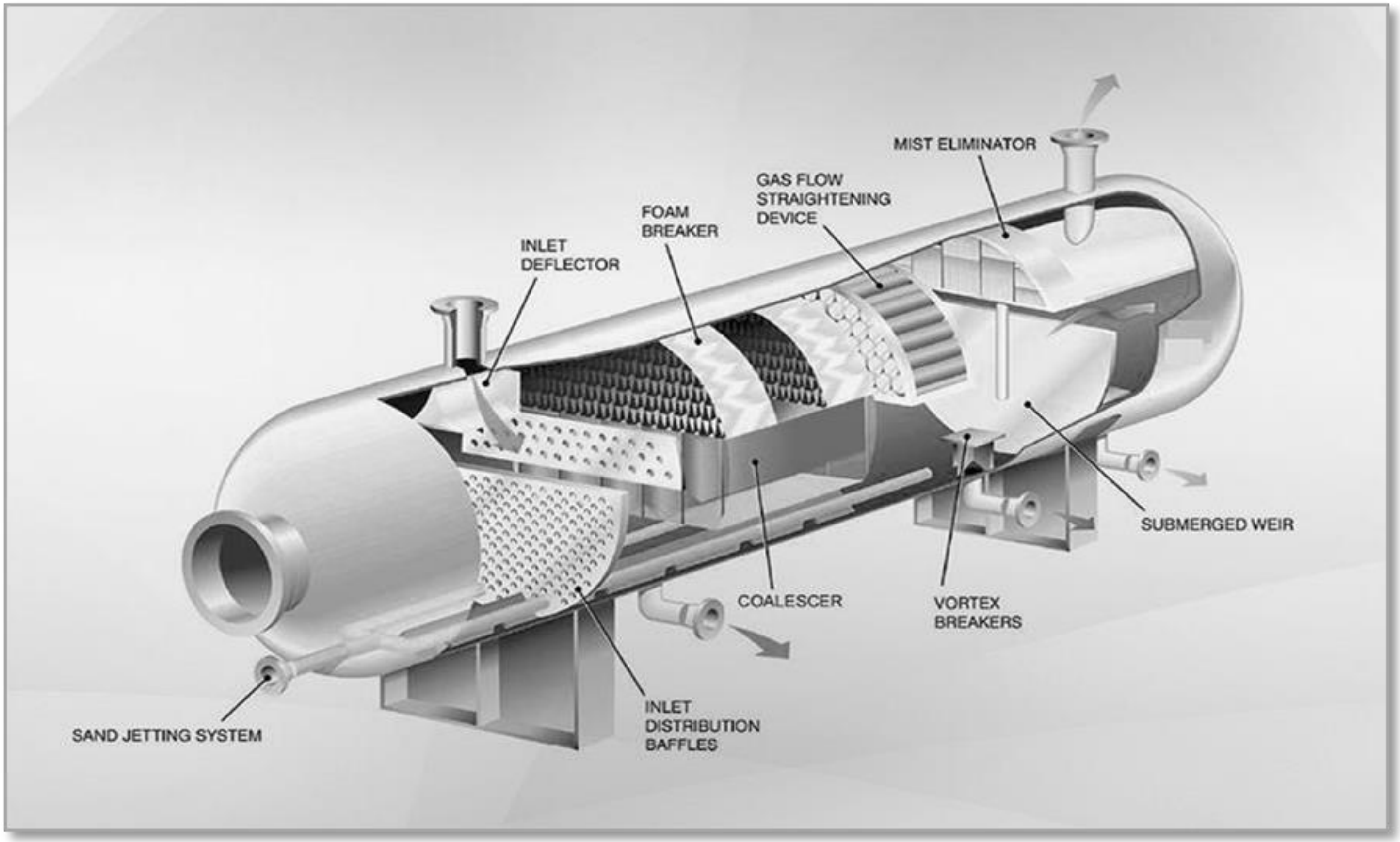

Figure-1: Internal Arrangement of Three Phase Crude Oil Separator

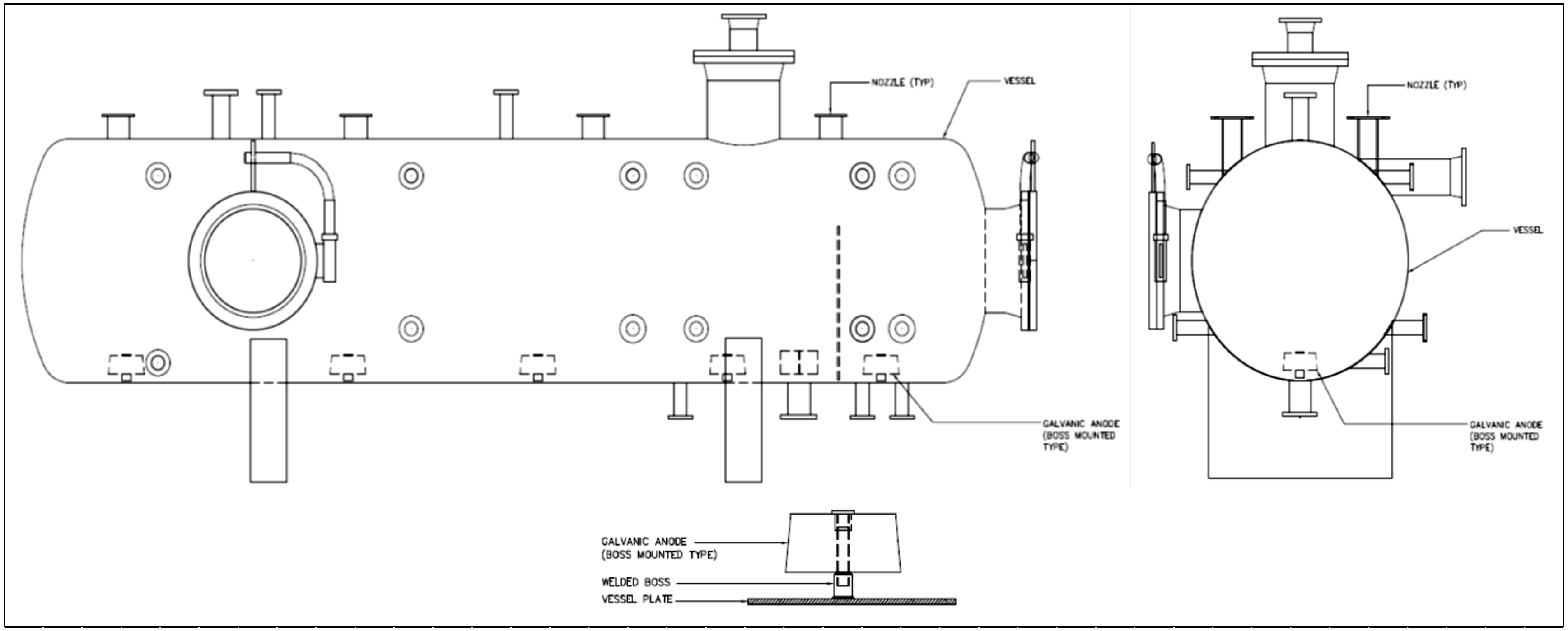

Figure-2: CP System for Vessel Internal with Boss Mounted Galvanic Anodes

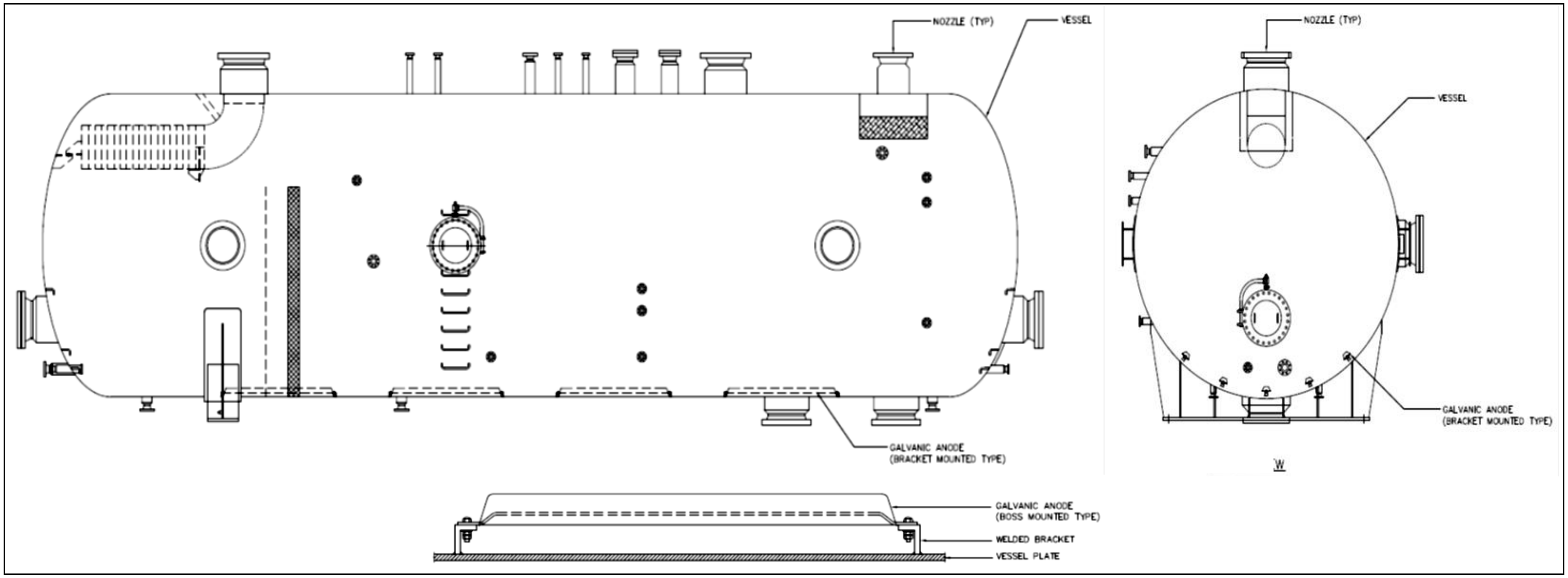

Figure-3: CP System for Vessel Internal with Bracket Mounted Galvanic Anodes

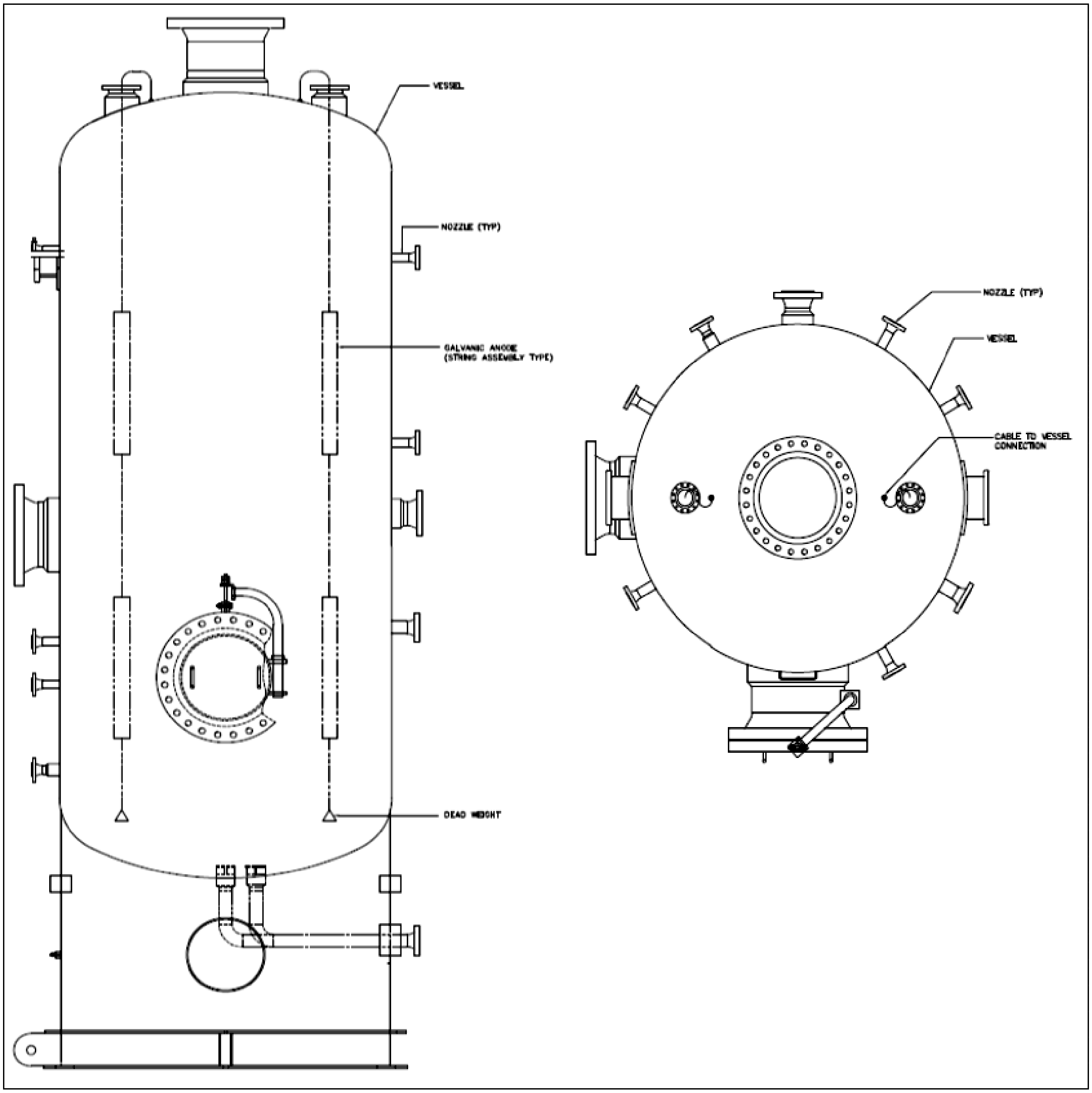

Figure-4: CP System for Vessel Internal with String Assembled Galvanic Anodes

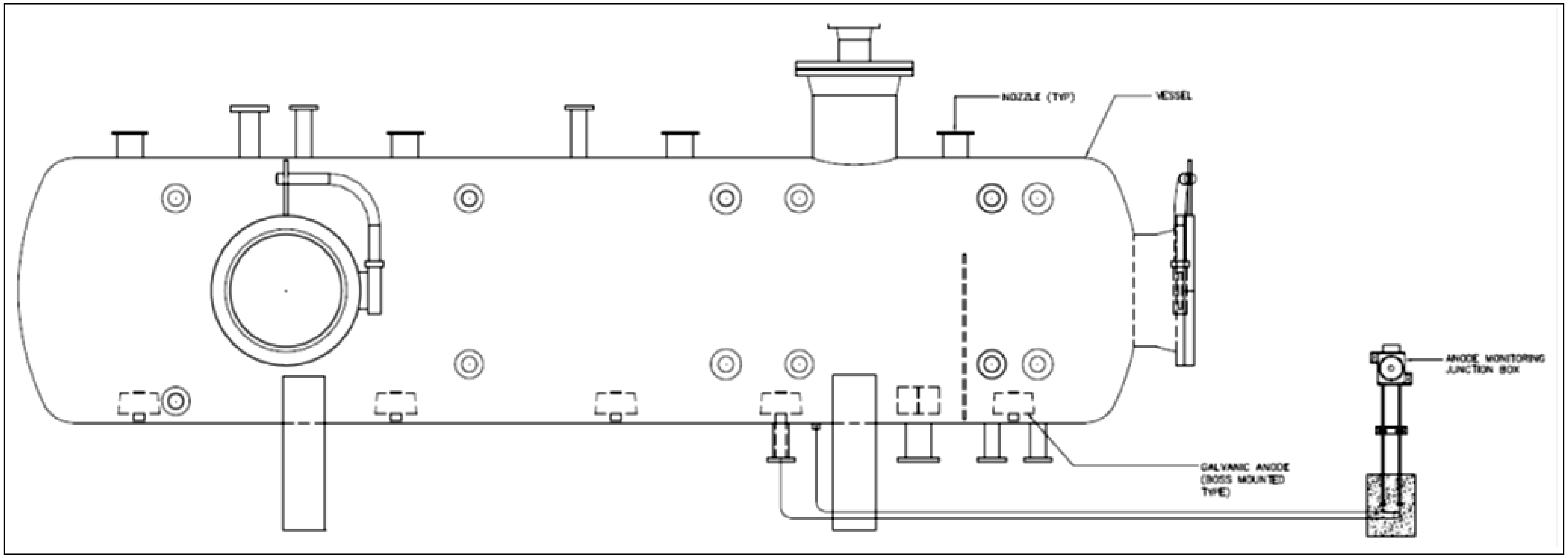

Figure-5: CP System for Vessel Internal with Anode Monitoring System