Vapor Corrosion Inhibitors for Storage Tanks

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Introduction

This document provides details on using vapor corrosion inhibitors (VCIs) for protection of the soil-side of tank bottoms from corrosion.

VCIs are chemical compounds that are typically available as crystalline powders. They may be available as loose powder or in prepackaged tubes. The crystalline powders may be mixed into a liquid (commonly with potable water) to deliver the VCIs beneath the tank bottom. Whether delivered by either powder or liquid, the VCIs volatize into a gas molecule and use their vapor pressure to permeate through air space until a steady-state concentration is reached. The VCI chemistry allows it to maintain a dynamic steady-state equilibrium, providing ongoing corrosion protection to the tank bottom plates.

Vapor pressures of different VCI compounds will vary. The vapor pressure will determine the carrying distance of the molecule within the enclosure and will also affect the concentration of the vapor molecules within that space. VCIs are compounds that vaporize or sublimate and condense on the tank bottom surface, forming a molecular layer that mitigates the naturally occurring active corrosion mechanisms. The molecular size is such that the VCI propagates through the voids between the sand particles in a sand pad or airspaces between the steel plate and a foundation pad.

VCIs prevents corrosion by the following actions:

— Vapor transport: VCI molecules volatize from a source and diffuse through the airspace as a vapor molecule. This enables the VCI molecules to move to a metallic surface without direct surface contact of the source chemistry.

— Adsorption: Molecules adsorb onto the surface by a physical and chemical process. When a molecule adsorbs on a steel surface, it effectively blocks other molecules from interacting with the surface of the steel. Under a tank bottom, VCI molecules take precedence on the surface and block oxygen and water molecules, thus reducing the corrosion potential at the interface.

— pH balancing: Some VCI formulations are designed with components that can modify the pH of an environment, typically resulting in a more alkaline condition. Testing of the soil from beneath the steel bottom will provide information about the pH. A low pH may be an indication of bacteria or other causes of acidic conditions.

— Chemical passivation: Some VCIs act to shift the electrical potential of metal toward a more electro-positive state. The interaction can be direct, whereby VCI reacts with the metal surface and becomes part of the passive film, or it can be indirect, whereby VCI improves the adsorption of oxygen on the metal surface to passivate the metal surface.

— Contaminant neutralization: Acidic species are known to cause corrosion of ferrous metals. Some VCI molecules can neutralize the acidic species.

Vapor Corrosion Inhibitors for Storage Tanks

1 Scope

1.1 General

1.1.1 The purpose of this technical report (TR) is to provide information to owner/operators regarding the use of vapor corrosion inhibitors (VCI) and to provide guidance for their use in corrosion protection of aboveground storage tank (AST) bottoms, specifically from soil-side corrosion of carbon steel. The VCI chemistries discussed in this document are from the amine-carboxylate group.

1.1.2 Certain practices recommended herein may also be applicable to metallic tanks in services other than hydrocarbon under special circumstances.

1.1.3 VCI manufacturers should be able to assist in determining the suitability of VCI use for each situation, along with proper concentration and application method for their products. VCI professionals working for the manufacturers or working in conjunction with the owner/operators will need information about the tank to make valid recommendations. Annex A provides a list of relevant information that may be required to make an informed decision.

1.1.4 The potential for corrosion can occur in void spaces where cathodic protection (CP) will not be effective because of oxygen concentration cells, from contaminants in the foundation pad, or contaminants that may ingress, such as water and oxygen. VCIs may be beneficial in these situations.

1.1.5 VCI molecules disperse through the foundation materials from their source based on their vapor pressure. Because these molecules are lighter than air, they will adsorb to the surface of materials in the foundation. Also, they have a higher attraction to steel than to the sand, gravel, concrete, or asphalt and other surfaces. Uniform distribution of the VCI source material is not required since the vapor pressure of the VCI molecules will eventually complete the distribution under the tank bottom.

1.2 Limitations

1.2.1 For VCIs to protect the tank bottom from soil-side corrosion, the tank foundation design shall provide a means to contain the VCI beneath the bottom.

1.2.2 While most manufacturers' VCI chemistries for use in tank bottom applications have similarities, each has unique characteristics and chemistries. Owner/operators should review the characteristics of the chemistries to determine which product best suits their needs.

1.2.3 In cases where API 651 identifies several foundation designs or details where CP may not be effective or may offer limited protection, VCIs may be an effective alternative or may work in conjunction with CP to improve protection.

1.2.4 VCIs volatize into vapors that may be inhaled. VCIs, in powder form, may create dust when handled. If engineering or administrative controls are not effective in reducing exposures, proper PPE should be worn when handling the VCI during installation. At very large concentrations, the dust may be combustible. Concentrations in air from mixing or applying VCI powder are considerably below the concentrations susceptible to combustion. Consult the Safety Data Sheet for additional information.

1.2.5 Since VCIs may be discharged to the ground at any time during installation and service, it is imperative that all federal, state, and local discharge permit requirements be followed. This may preclude the use of VCIs, depending on the jurisdiction's discharge permit requirements.

1.2.6 When using VCI powder near welding operations, VCI powder shall not be in the weld zone. The powder is not combustible, but may affect the quality of the weld, as would other contaminants.

2 Normative References

There are no normative references in this document.

3 Definitions

3.1
aboveground storage tank (AST)
An on-grade, stationary, uniformly supported container, usually cylindrical in shape, consisting of a fixed or floating roof, shell, bottom, and support structure where more than 90 % of the tank volume is above surface grade.

3.2
adsorb
adsorption
The process in which atoms, ions, or molecules from a gas, liquid, or dissolved solid adhere to a surface of the adsorbent (in this case, the steel surface)..

3.3
cathodic protection
A technique to reduce the corrosion of a metal surface by making the entire surface the cathode of an electrochemical cell.

3.4
cathodic inhibitors
Chemical components that either slow the cathodic reaction itself or selectively precipitate on cathodic areas to increase the surface impedance and limit the diffusion of reducible species to these areas.

3.5
contact inhibitors
A mechanism for inhibiting corrosion that involves formation of a coating, often called a passivation layer, that prevents access of the corrosive substance to the metal.

3.6
coupon
A weighed sample of metal that is placed in similar environmental conditions as the subject metal, which is later evaluated for loss to establish a corrosion rate.

NOTE Also called corrosion metal loss or weighted loss coupon.

3.7
drain pipes
Pipes in the foundation area of the tank that act as monitoring ports, leak detection ports, or tell-tale ports.

3.8
electrical resistance probe
An instrument that measures the change in electrical resistance of a metallic element embedded in the tank pad relative to a reference element sealed within the probe body.

3.9
inhibitor solution
VCI powder dissolved in potable water in a specific concentration.

3.10
microbial-induced corrosion (MIC)
Corrosion resulting from biological activities of bacteria and other microorganisms.

3.11
oxygen concentration cell
An electrochemical cell, the electromotive force of which is due to a difference in air (oxygen) concentration at one electrode as compared with that at another electrode of the same material.

3.12
passivation
The process of treating or coating a metal to reduce the chemical reactivity of its surface. Steel will initially create its own passivation (flash rust) layer when initially exposed to moisture and oxygen.

3.13
pH balancing
Managing the acidity or alkalinity of an environment to reduce the rate of corrosion on carbon steel.

3.14
release prevention barrier (RPB)
Includes steel bottoms, synthetic materials (also called flexible membrane liners), clay, geotextiles, concrete pads, and other impermeable layers placed under a tank bottom, that have the function of:

1) preventing the escape of released material; and

2) containing or channeling released material for leak detection.

3.15
shovel bottom
A tank bottom that is sloped from one side of the tank bottom to the other, rather than being sloped to or from the center.

3.16
stretched steel
Steel grating, grillage, or structural shapes that provide separation between the secondary and primary bottoms in a double bottom tank. See API 650, Annex I, section I.4.2.

3.17
tank bottom flexing
The physical movement of the tank bottom during filling and emptying of the tank that causes VCI, air, oxygen, and water moisture to freely flow out from under the tank, and air, oxygen, and water moisture to flow back under the tank

3.18
foundation
The foundation pad and structural support of the tank, including ring wall construction and penetrations through the ring wall, and any impermeable layers of flexible membrane, clay, geotextiles, or other equivalent layer.

3.19
tank pad
The layer directly beneath the tank bottom that may be sand, gravel, concrete, asphalt, limestone, soil, or similar material.

3.20
ultrasonic thickness probe
A device that precisely measures the time required for a sound pulse that has been generated by a small probe, called an ultrasonic transducer, to travel through a test piece and reflect back from the inside surface or far wall.

3.21
vapor corrosion inhibitors (VCIs)
Chemical substances that slowly release a corrosion-preventative compound into an enclosed airspace, effectively protecting exposed metal surfaces.

NOTE Also known as volatile corrosion inhibitors.

3.22
VCI professional
An individual who is recognized as experienced or trained to design a VCI system for use under tank bottoms or pipeline and casing applications.

NOTE There is currently no nationally recognized organization that provides certification, education, or training for VCI systems, so this reference generally refers to individuals trained by the VCI manufacturers.

4 VCI Application Method Options

4.1 Foundation Design and Application Methods

4.1.1 Differences in tank construction designs will affect the design of a CP system and the design of a VCI system. Figure 1 illustrates a generic foundation design with potential VCI installation features. VCI installation locations include but are not limited to 1) drain pipes, 2) through the bottom plate, or 3) between the bottom edge projection and the foundation.

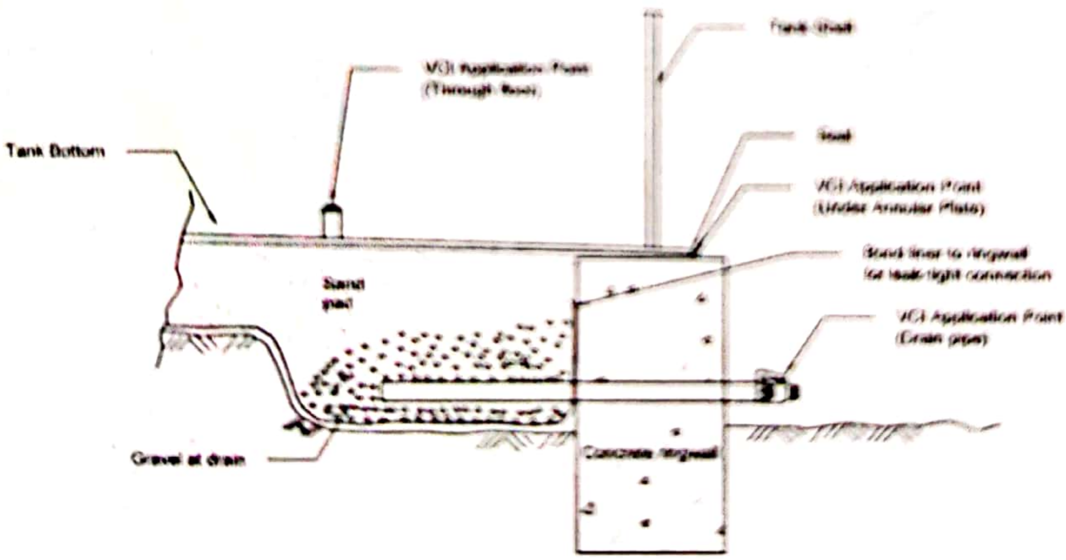

Figure 1—VCI Application Points

VCIs typically are sold in powder form. They can be applied or installed as a dry powder or mixed with potable water and applied or installed as a liquid. Delivery methods are limited for applying the VCI in powder form while the tank is in service; however, the powder form may be considered if design provisions are made during tank construction or bottom replacement. For new tank construction or bottom replacement, application of loose VCI powder on top of the tank pad is not recommended. If the tank bottom is in place, the powder can be dissolved in potable water, which can be injected to distribute the VCI across the tank foundation. The use of water necessitates the presence of an impervious liner that provides containment under the bottom. Drain pipes are useful for both injection of inhibitor solutions and leak detection systems. Documenting the number of ports, location, and diameters will be useful in the VCI delivery design. Sealing the bottom edge projection to the foundation is required to contain the VCI and limit ingress of moisture and contaminants. API 654 offers guidance on this topic.

NOTE Consult a VCI professional with details of each foundation design when designing the VCI delivery system. These details include tank pad materials, ring wall design, cone-up, cone-down, shovel bottom, liner configuration, drain pipes, etc.

4.2 Single Bottom with Release Prevention Barrier

4.2.1 Two common designs for tank bottoms with an RPB are 1) a flexible membrane liner (HDPE or equivalent) that is compatible with the contents of the tank and is sealed to the foundation or, 2) a clay layer (including natural clay and geotextile.) Typically, a permeable tank pad layer (usually sand) is installed on top of the impervious liner and the bottom plate is installed on top of this layer. Impervious liners are also often used under concrete or asphalt pads. A functioning impervious liner should contain the inhibitor solution and prevent it from percolating or entering the ground beneath the tank. Figure 2 shows a granular ring wall design and options for VCI application points. The flexible membrane liner can be sealed using different methods based on the foundation design.

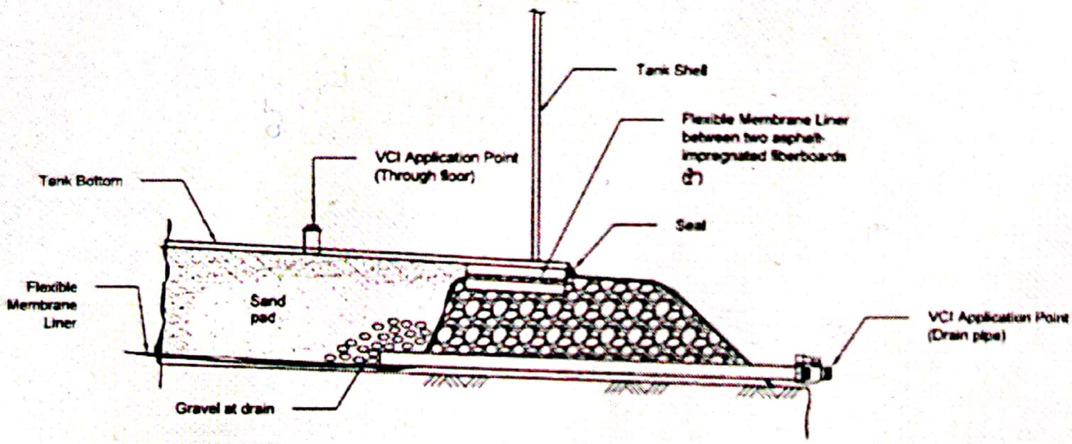

Figure 2—Single Tank Bottom with Release Prevention Barrier

4.2.2 An RPB is designed to contain any product that may leak from the tank bottom. Dike liners are often installed to protect the ground outside the tank in the event of an overfill. A dike liner may not necessarily provide continuous lining beneath the tank bottom, and may or may not be considered part of the RPB system. Often, the dike liners are terminated and connected to the foundation concrete ring walls and offer no protection beneath the tank bottom. Having a dike liner does not necessarily mean that the liner can contain VCI. It is essential to study the design and details of both the RBP and any dike lining in detail to determine if the RPB can contain VCI. If VCI liquid cannot be contained, it should not be used in a liquid form. It may be possible to design a dry VCI system for these situations.

4.3 Single Bottom Without a Release Prevention Barrier

4.3.1 Single bottoms may be installed directly on native or non-native soil material with no containment. If no containment exists, or if the containment is not sealed under the tank bottom, any liquids introduced under the bottom will drain into the ground under the tank, so a VCI liquid in the form of an inhibitor solution should not be considered as it may quickly wash away. Partial bottom protection using dry VCI powder may be possible when the tank is in service, but this will be limited to the perimeter areas and may also wash away.

4.4 Double Bottom with Sand Pad

4.4.1 A double bottom design may be installed during initial construction, but more frequently, a new bottom is installed over an existing bottom rather than replacing or repairing the original bottom. The new bottom is slotted into the existing shell, and the remaining shell beneath the new bottom that is still welded to the old bottom may become part of the RPB system shell wall, thus creating the false shell component to the existing foundation tank pad. The distance between the new bottom and the old bottom will vary by tank, and this will affect the amount of VCI required for the interstice. A flexible membrane that acts as an impervious layer is used over the existing bottom. VCI is incorporated into the sand layer that provides support for the new bottom. The slope of the bottom and the slope of the impervious layer may affect the installation method, as well as the amount of VCI required.

4.4.2 Drain ports installed as part of the design may be used for VCI injection. The drain ports, by design, shall be fully sealed. The gap created in the shell needs to be sealed. This can be accomplished by welding and/or caulking. Sealing this gap is necessary to inject an inhibitor solution.

4.4.3 If the tank is out of service and floor plates are being removed and replaced, dry VCI may be installed into the tank pad between the bottoms. If the tank has already been placed in service, it is still possible to install VCI in the interstice using an inhibitor solution. Consult a VCI professional for installation options under these circumstances.

4.4.4 Figure 3 illustrates a typical double bottom with a sand pad. An impervious flexible membrane is recommended on top of the original bottom to provide containment.

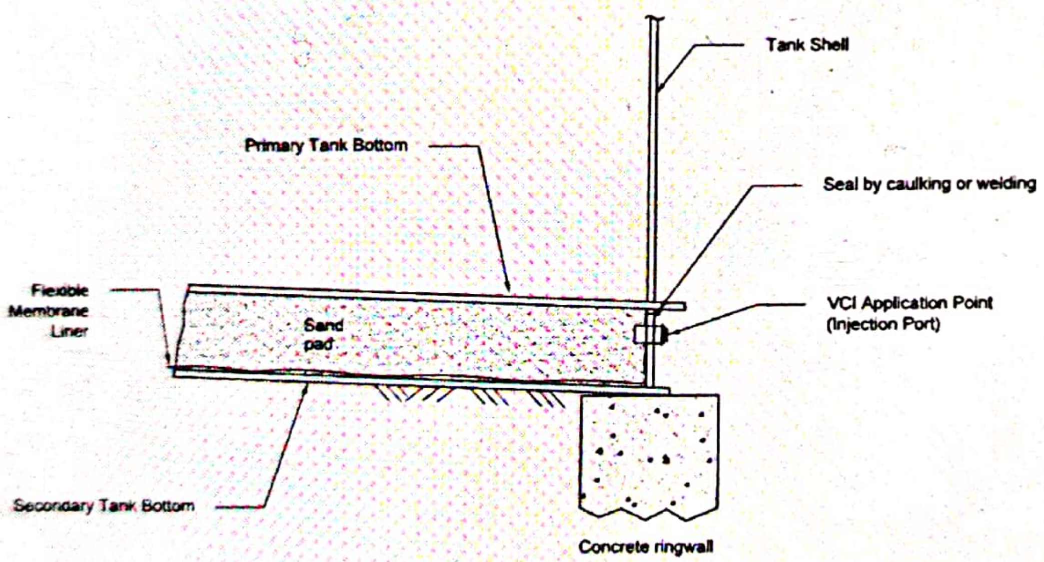

Figure 3—Double Bottom with Sand Pad

4.5 Double Bottom with Concrete (Solid) Pad

4.5.1 When using a solid tank pad, channels are formed into the top of the tank pad to allow fluids to easily flow to the drain pipes. A hollow or well in the concrete at the monitoring port will allow for liquid to collect at the port. These wells may allow a probe or coupon to be used as a corrosion monitoring device. See API 650, Annex I, and Figure 4 of this document.

4.5.2 An impervious flexible membrane is installed on top of the existing bottom and sealed to the foundation. The concrete is installed over the impervious liner and channels are formed in the top of the concrete. The channels in the concrete can be used to insert dry VCI. In the alternative, inhibitor solution may also be considered. The slope of the bottom and type of solid pad material can affect the installation design and the amount of VCI required. Consult a VCI professional for assistance in designing the size, number, location, and orientation of the channels in the concrete for dry VCI installation.

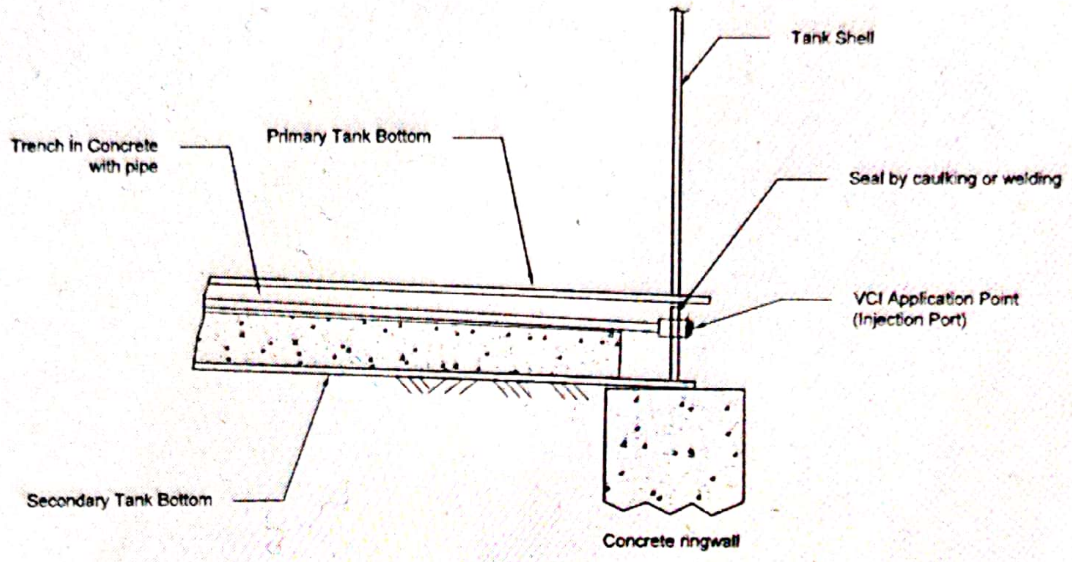

Figure 4—Double Bottom with Solid Concrete Pad

4.6 Double Bottom with Stretched Steel Interstice

4.6.1 API 650, Annex I, section I.4.2 illustrates a double bottom design using stretched steel, wire fabric, grating, or other structural shapes in the interstice. Often, this interstice is filled with nitrogen and maintained for corrosion prevention. VCI may be used in addition to nitrogen, or as an alternative to nitrogen. VCI installation ports will need to be incorporated into this design. Figure 5 illustrates a typical double bottom design of this type using VCI.

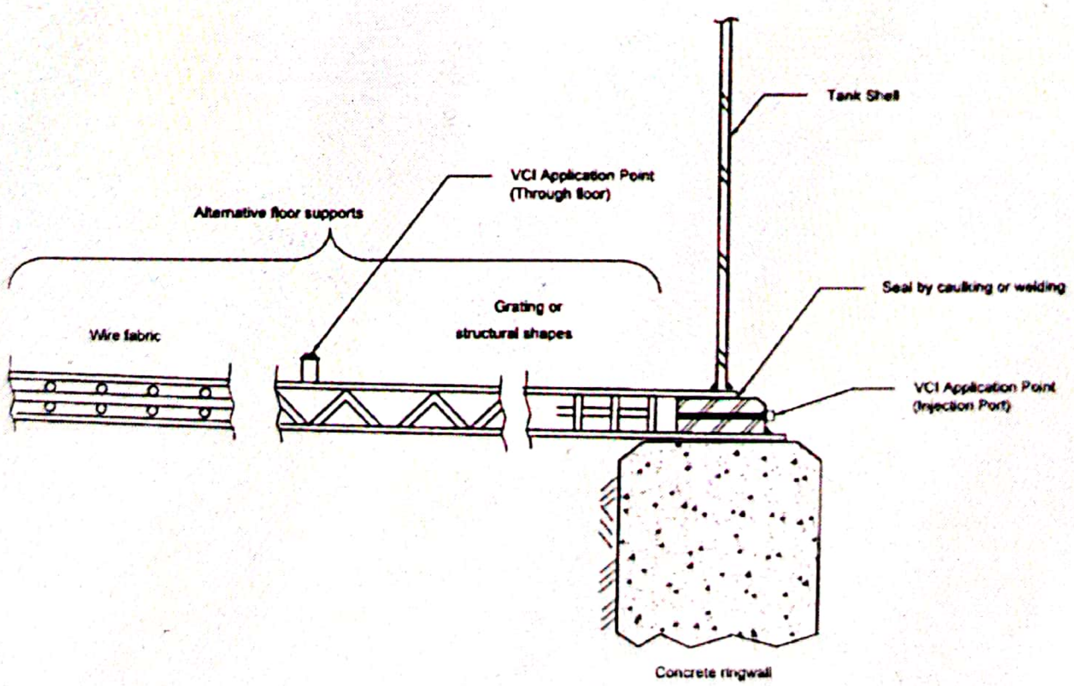

Figure 5—Double Bottom with Stretched Steel

4.7 Single Bottom with Reinforced Concrete Slab and Sand Pad

4.7.1 API 650, Annex I, section I.6, Figure I.6 illustrates a reinforced concrete slab with a sand pad to support the tank bottom. Wet or dry VCI may be used in the sand pad. An impervious flexible membrane is recommended between the sand and concrete. Figure 6 illustrates the use of VCI with this design.

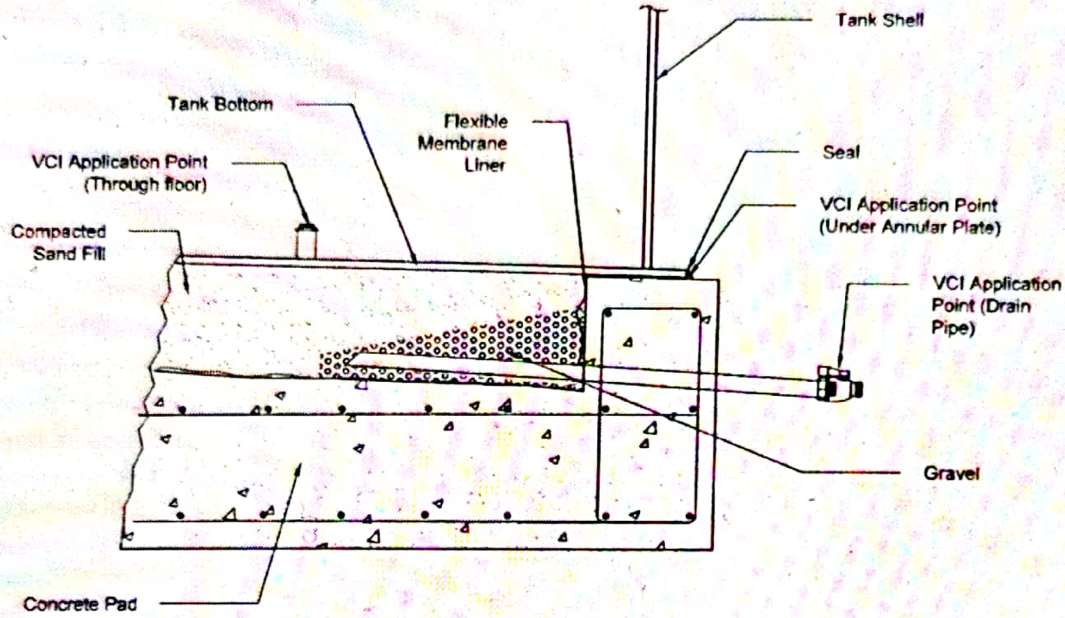

Figure 6—Reinforced Concrete Slab with Sand Pad

API 650, Annex I, section I.7, Figure I.7 illustrates a reinforced concrete slab without a sand pad. The bottom plates are installed directly on the slab. The concrete may have radial or lateral grooves in the top surface of the concrete that drain any product to the perimeter in the event of a breach. Dry VCI may be inserted in these grooves during new construction, or inhibitor solution may be inserted into drain pipes at the perimeter for existing in-service application. Figure 7 illustrates this design using VCI.

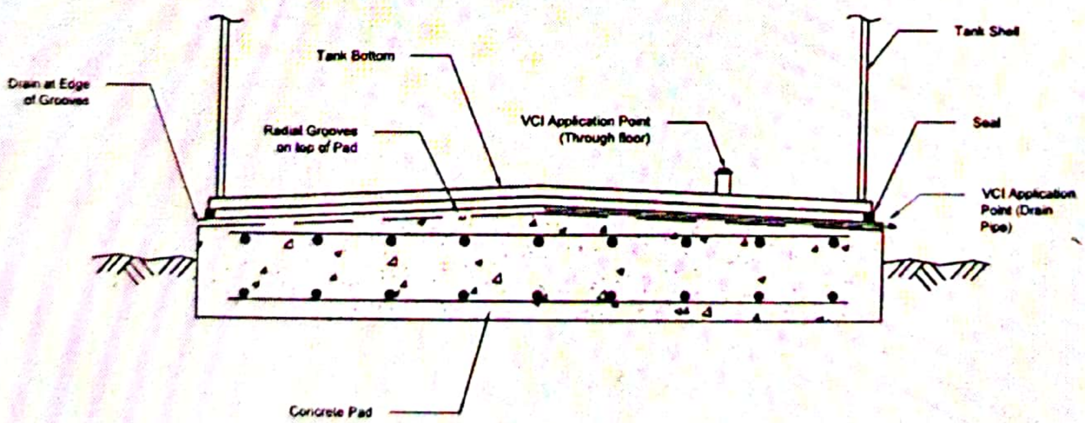

Figure 7—Single Bottom on Reinforced Concrete Slab

4.8 Sumps

4.8.1 A sump may be designed and installed in any tank bottoms. An RPB is used to contain liquids under the tank, and drain pipes are designed to move any liquids to the perimeter of the tank where they may be observed during inspection. The drain pipes would provide a VCI application point in addition to application through the bottom or at the bottom edge projection. This would be more suitable for an inhibitor solution than for dry VCI. There may be other application options at the bottom edge projection or through the bottom if the tank is out of service. See Figure 8.

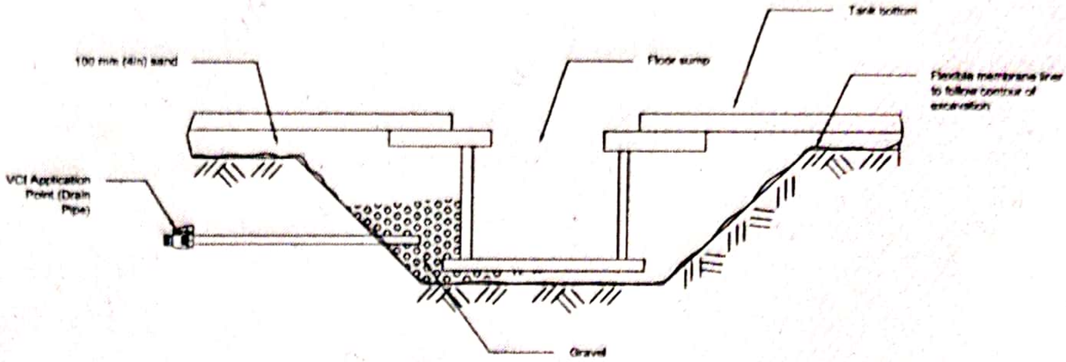

Figure 8—Typical Sump

4.9 Other Foundation Designs

This document has not discussed every foundation and bottom design. There are new designs being developed and if VCI is being considered, provisions should be made in the design to incorporate dry VCI or, alternatively, inhibitor solution so that VCIs may be added to the original construction or may be added at a later time. Consult a VCI professional for examples of designs.

5 Elements That Affect VCI Installation and Maintenance

5.1 General

5.1.1 Each tank should be evaluated individually for VCI. Tank pad material, quality of installation, weather conditions, material sourcing, welding procedures, operating temperatures, fill and empty cycle history, and corrosion-protection methods and maintenance will affect the corrosion rate on the soil side of the tank bottom.

5.1.2 VCI will protect any components that are located within the containment, including sump underside, piping, and any steel supports, along with the tank bottom.

5.2 Dike Liners

5.2.1 A dike liner is not the same as an RPB. Dike liners are designed to cover the tank dike to protect from overfills and typically connect and are sealed to the outside of a ring wall or the tank bottom edge projection. Dike liners will not provide containment of a liquid VCI solution unless they are incorporated into a RPB design, whereby the impervious layer is continuous beneath the tank bottom.

5.3 Sand

5.3.1 Sand quality parameters are specified in API 650, and API 651 recommends sand quality and resistivity. When an inhibitor solution is added to sand, the resistivity of the sand will decrease. This will affect the CP requirements including design, operating parameters, inspection, and maintenance intervals.

5.3.2 While sand compaction is an important factor for foundation stabilization, compaction should not influence the delivery or effectiveness of a VCI application. Higher compaction will assist in the capillary dispersion of an inhibitor solution through the sand. Whether installed in a dry VCI application or by inhibitor solution, the VCI will diffuse between the sand grains and contact the tank bottom through the air gaps in the sand and through any gaps between the sand and tank bottom.

5.4 Concrete

5.4.1 Concrete foundation design includes cone-up, cone-down, flat, or shovel bottom configurations. The orientation of the bottom will affect the design of the VCI delivery system. API 651, section 5.3.3.3 states that "care should be observed with tanks on concrete pads since cathodic protection may be ineffective in this case."

Gaps between the concrete and steel will exist under any tank bottom. Dry VCI or inhibitor solutions can provide corrosion protection in the gap and void spaces between the concrete and steel.

5.5 Asphalt or Oiled Sand (Bituminous Sand/Bitsand)

5.5.1 Delivery of VCI under tank bottoms with asphalt or oiled sand pads, while the tank is in service, can be very difficult and may not be feasible. Dry VCI may be installed at the perimeter beneath the bottom edge projection; however, the VCI may only offer protection in the annular areas and not beneath the entire bottom. Consult a VCI professional in these special situations.

5.6 Gravel

5.6.1 Gravel is not recommended for the pad, and owner/operators should consider replacing gravel with suitable tank pad material at the next out-of-service inspection. While VCI may permeate around the large particles, the contact points between the gravel and tank bottom may still be a source of accelerated corrosion.

5.7 Contaminants

5.7.1 Pad contaminants can significantly affect the type and rate of soil-side corrosion. Contaminants can be natural elements found in the sand or debris introduced into the sand at the source, or during transportation and installation. Naturally occurring contaminants can include chlorides, sulfides, sulfates, etc. VCIs may be helpful in reducing the harmful effects from contaminants. The soil analysis report can be used to determine the type and concentration of VCI that will be most effective.

5.7.2 Table 1 shows the desired properties of sand pad material per API 651 and per NACE SP0193-2016. All of the values below are recommended for CP systems. The values shown are not required guidelines for a VCI application, but actual values for each in the sand pad material are good to know when designing a VCI system.

Table 1—Desired Chemical Properties of Sand Pad Material

Property	Test Method	Value per API 651	Value per NACE SP0193–2016
Electrical resistivity	ASTM G57	> 10,000 ohm-cm	> 5000 ohm-cm
pH	ASTM G51	> 8.0	≥ 5.0
Chloride levels	ASTM D512	< 10 ppm	< 10 ppm
Sulfate levels	ASTM D516	< 200 ppm	< 200 ppm
Sulfide levels	EPA 0376.1	< 0.1 ppm	< 0.1 ppm

5.7.3 Chloride levels that are significantly higher than levels shown in Table 1 may result in VCI being ineffective. Different concentrations or types of VCI or the addition of contact inhibitors may be required.

5.7.4 Other contaminants may include wood, vegetation, paper, plastic, rocks, clay, silt, welding rods, or other foreign objects. Thorough inspection of the pad is critical, and any visually observed contaminant shall be removed prior to the installation of the new bottom plates.

5.8 Additives

5.8.1 Additives such as Portland cement or limestone can be added to the source sand to increase the pH of the sand pad. Refer to API 651, section 5.3.2.1 for recommended dosages. In the alternative, VCIs and contact inhibitors can be added to the source sand to pH balance naturally occurring contaminants. If the opportunity exists during new construction and bottom replacement, select an alternate source of materials that is free from contamination as opposed to attempting to offset the harmful effects of a contaminant. If that is not a viable option, if high levels of contamination are present in the source sand, consult a VCI professional to help determine the adequate type and dosage of contact inhibitor that may be used to minimize corrosion.

5.8.2 Application of VCI solution additives to the source sand will lower the electrical resistivity due to the electrolyte (water) and the VCI chemical ionic nature. The electrical resistivity values listed in Table 1 only apply to the source sand material tested without VCI. When VCI solutions are used to modify the sand, ionic contributions from VCI anti-corrosive compounds will lower resistivity similar to contaminants. These two results should not be confused. Contaminants that lower resistivity are undesirable.

5.9 Oxygen Concentration Cells

5.9.1 Oxygen is dissolved in moisture. Dissolved oxygen is known to cause severe pitting on carbon steel at concentrations lower than 50 parts per billion. For AST bottom plates, pitting corrosion may result in product leaks and removal from service due to unanticipated accelerated corrosion. When bottom plates flex due to product level changes, there will be air exchange beneath the tank bottom. Air, along with oxygen, enters underneath the tank via the bellows effect. The bottom plate flexing also creates uneven contact points to the sand pad, and air pockets may be created underneath the tank. The presence of moisture and oxygen in these air pockets causes pitting. VCIs dissolve in moisture and adsorb to the steel surface through the process of chemisorption. VCI molecules take precedence over oxygen and prevent oxygen concentration corrosion on steel surfaces. Consult a VCI professional when dealing with oxygen concentration issues under the tank bottom.

5.10 Microbially-Induced Corrosion (MIC)

5.10.1 Bacteria and other organisms are responsible for MIC. Soil samples can be taken and analyzed during each inspection to test for the presence and type of bacteria if MIC is expected or suspected. Some bacteria may be present in the source of material used in the tank pad. Some may be present because of flooding, rain, or some other source. Some VCI formulations can neutralize the acid generated by the acid-producing bacteria. Adjusting concentration levels of the VCI may be necessary to successfully neutralize the biological by-products. Consult a VCI professional if MIC is present.

5.11 Wet or Saturated Tank Pad

5.11.1 A wet or saturated tank pad affects the installation of VCI. The estimated water content of the tank pad needs to be considered when the amount of VCI required is calculated so that the final concentration of VCI is adequate. Injected inhibitor solution will need to displace existing water. The inhibitor solution will not immediately distribute throughout the entire tank pad. Pumping inhibitor solution into the interstice will not result in immediate mixing with existing water, and the final equilibrium will require time to occur.

5.12 Drain Pipes

5.12.1 Leak detection or drain pipes (also called tell-tale ports) are typically installed under a tank bottom to demonstrate the tank is containing the product without leaks. Drain pipes may also be used as inhibitor solution injection points under the tank bottom or as ports for probe monitoring devices to measure the life of the VCI. The number and location of drain pipes is relevant to the VCI application design. Consult documentation or conduct a field inspection as needed. Following application of inhibitor solution and allowing ~30 days for equilibrium, any residual inhibitor solution should be allowed to drain from the interstice by way of the drain pipes. When concrete is used, some of the inhibitor solution will be absorbed by the concrete, but nevertheless, minimal amounts of residual solution may be still be present. On the first port opening following the VCI injection, be prepared to find residual VCI fluid. While some VCI will be lost with the extraction of residual liquid, sufficient VCI will remain in the interstice.

5.13 Weather and Temperature Effects

5.13.1 Humidity, ambient temperature, and rainfall amounts affect the use of VCI. If temperatures are too cold, the volatilization process will decrease or cease. If temperatures are below freezing [~32 °F (0 °C)], the inhibitor solution may freeze and solidify in the delivery tank and hoses, making installations impractical and possibly ineffective during colder months.

VCIs containing contact inhibitors may have a high temperature threshold (up to 400 °F), but VCIs are typically limited to below 200 °F (93 °C). As temperatures increase, the rate of volatilization of the VCI increases, potentially reducing the effective life of the VCI.

5.14 Importance of Interstice Containment Integrity

5.14.1 Even though the design of the containment makes every provision for a completely watertight seal at all gaps, some losses are expected over time. Movement of VCI molecules, once they have volatized from their source material, works by partial pressure. Vapor molecules will continue to volatize until they reach equilibrium conditions. Volatilization ceases until an imbalance occurs from the VCI being consumed or escaping. VCI may need to be added to the interstice over the life cycle of the tank to allow for VCI losses, as well as the diminishing effectiveness of the existing VCI over time.

5.14.2 The partial pressure of the vapor molecules will only distribute the molecules a limited distance. In most VCI chemistries used under tank bottoms, this is between 5 to 15 feet. In instances of dry application to the annular area that has been sealed, the VCI can be expected to migrate under the tank bottom. Conversely, if VCI is installed beneath the bottom, with an unsealed bottom edge projection to foundation, the VCI within 5 m (15 feet) of the tank edge will be depleted faster than the VCI under the rest of the bottom. Sealing the bottom edge projection will slow this process considerably.

5.14.3 API 654 provides information regarding sealing the bottom edge projection of a tank to create a sealed environment under the tank bottom. API 654 allows owner/operators to evaluate the need for sealing the bottom edge project projection to the foundation, and shares various designs along with caveats related to the different methods, with respect to unintended consequences for future inspection of the corner weld and for creating potential corrosion areas in that area.

5.14.4 If flooding occurs such that rain or groundwater enters the interstice, the VCI is diluted by the flood water and fresh contamination may be introduced into the enclosed space. Water ingress into the interstice will reduce the effective life of the VCI.

5.14.5 During filling and emptying of the tank contents, flexing of the bottom will occur. During this cycle, air under the tank will exhaust and ingress. Some of VCI molecules will be exhausted during the filling process. These losses should be considered when calculating the recommended concentration of VCI. Because assumptions are made about the number of cycles and the amount of air exchanged, the actual depletion rate may be different than predicted for each tank.

5.15 Installation of VCI on Tanks While in Service

5.15.1 When installing VCI into an interstice on an in-service tank, inhibitor solution injection is the recommended method. A review of the design is needed to ensure containment is present. An inspection of the seal between the tank bottom and the impervious layer should be conducted to determine effectiveness, and any alterations or repairs should be made to ensure the integrity of that seal, whether it be by caulking, taping systems, or welding. This would be different depending on the design of the existing tank and whether there is a double bottom or a single bottom with an RPB. The tank pad materials will vary and VCI amounts will be determined by the volume of the interstice and pad material. If feasible, samples of the sand should be taken from the drain pipes and evaluated. The presence of any contaminants and the resistivity will affect the recommended selection and concentration of VCI.

5.16 Installation of VCI on Tanks While Out of Service

5.16.1 VCI delivery systems and installation methods should be considered when designing for new tank construction or for bottom replacement. The design stage is the most opportune time to select the best VCI delivery system, and this can be incorporated into the design prior to the start of the construction or bottom replacement. Obtain tank pad samples for testing during repairs or bottom installations only if it is feasible to do so. At this time, if you are considering using VCI, ensure that the design includes accurate details of the penetration areas so there is adequate watertight containment. The design should include the number and location of channels in the pad, as well as the number and location of drain pipes for monitoring and adding VCI in the future.

5.17 Dry VCI Applications

5.17.1 A dry powder VCI delivery system can be designed for both in-service and out-of-service tanks. For tanks without access to the center of the pad beneath the bottom, the application of dry powder may be limited to the bottom edge projection area around the circumference. In many designs, slotted pipes may be used in the interstice for the introduction of dry VCI; however, if these are not already installed, it might be more practical to use inhibitor solution. It may not be feasible to use existing drain pipes for dry VCI because they may not necessarily provide adequate coverage of the entire bottom.

5.18 Inhibitor Solution Applications

5.18.1 When using inhibitor solution, the viscosity of the mixed VCI and water is approximately the same as water and is injected into the interstice using low-pressure pumps or gravity feed. Only use enough pressure that is required to inject the solution without causing damage to the bottoms from overpressurization of the interstitial space. The inhibitor solution flows well over and around solid foundations, including concrete and asphalt, and easily through sand tank pads. In the case of oiled sand or bituminous sand (bitsand), adequate wetting and penetration throughout the pad may require more time. Since the VCI vapor molecules eventually volatize and disperse from their source, the inhibitor solution may not need to completely cover all the surfaces. In a cone up design, the inhibitor solution may not necessarily reach to the center at the top of the slope. The capillary action of a sand pad will draw the inhibitor solution upward. Even if the actual liquid fails to contact the entire tank bottom, the vapor molecules should eventually be able to provide protection to all the tank bottom because of vapor pressure seeking equilibrium through the complete space.

5.19 Determining the Optimum Type and Concentration of VCI

Each VCI manufacturer has its own method of calculating VCI concentrations. This includes the amount of dry VCI needed or, if inhibitor solution is needed, the proper concentration and quantity recommended for each specific tank. A VCI professional can review the calculations with the storage tank engineer.

6 Monitoring and Replenishment

6.1 Monitoring

6.1.1 With current inspection techniques, it is difficult to evaluate the effectiveness of VCI on in-service tanks. Owner/operators may consider using techniques currently used with CP to establish representative corrosion rates using coupons and probes.

6.2 Coupons

6.2.1 Coupons, also called mass loss or weight loss coupons, should be made of the same metal as the existing bottom they are supposed to represent. They are available in different configurations to meet the intended application. The coupon is weighed and marked prior to insertion; then, its location is clearly marked on the tank drawing. A predetermined length of time for their removal is established by the owner and VCI professional. Removal, handling, and packaging are performed in accordance with established procedures. The coupon is then shipped to a laboratory for proper cleaning and accurate weight measurement. The pre- and post-weights are then used to calculate mass loss and determine an estimated corrosion rate. Corrosion rates should be documented.

The coupons should also be inspected for pitting corrosion. Pitting corrosion may be occurring beneath the tank bottom that is not identified by a coupon since there may be conditions beneath the bottom that are not reflected where the test coupon is located. Isolated pitting is a cause for concern has may cause a breach in the tank bottom.

6.3 Electrical Resistance Probes

6.3.1 Electrical resistance (ER) probes have been historically used in various corrosion rate monitoring applications, including inside pipe casings or process lines. This equipment determines the corrosion rate by measuring the change in resistance of an exposed steel probe and correlating that change to a change in metal loss. There are multiple probe types and designs that are suited for different applications. ER probes may not identify isolated pitting corrosion that may be occurring beneath the tank bottom. Consult with a VCI professional to determine probe selections for each specific case.

6.4 Ultrasonic Testing Probes

6.4.1 Ultrasonic testing probes may be installed in permanent locations to monitor corrosion rates. These probes only read corrosion rates where they are located, and this may not be representative of all locations beneath the tank bottom.

6.5 Out-of-service Inspection

6.5.1 For tanks that are out-of-service, corrosion rate and isolated pitting corrosion on the bottom can be determined by various techniques identified in API 653 and API 575. It is during an out-of-service inspection that there is adequate data to determine performance of the VCI system. Unfortunately, out-of-service inspections are not often done short-term so it may require years to obtain accurate data.

6.6 Replenishment

6.6.1 Vapor corrosion inhibitors (VCIs) may need to be replenished during the life cycle of the tank. VCI may be lost or VCI may become ineffective over time. Monitoring, as described above, is to provide estimates of the replenishment cycle for each tank. Currently, there is no technology available to determine the VCI concentration present beneath the tank bottom so indirect methods must be used to determine effectiveness. These methods include coupons, probes, robotic inspection, and out-of-service inspections. Data from probes may indicate that corrosion rates are increasing, which may require additional VCI. The operation of the tank resulting in bottom flexing, proper maintenance of the RPB, and unforeseen catastrophic weather events can alter conditions that will affect the tank bottom soil-side corrosion rate as well as the concentration of VCI beneath the bottom.

7 VCI and Cathodic Protection

7.1 General

7.1.1 VCI and CP are independent corrosion control techniques, however their benefits when combined are currently being studied. Synergistic effects of using combined techniques are currently being evaluated, however, cathodic inhibitors are not recommended for combined applications, as they may be antagonistic toward CP.

7.2 Synergistic Effects of VCI and CP

Because VCI volatilizes, it may offer advantages where CP has been depleted or is no longer properly functioning, or where portions of the bottom have lost direct contact with the pad. VCI will penetrate void areas that are difficult to adequately protect using CP methods as they currently exist.

7.3 Effect of VCI on Resistivity and CP

7.3.1 VCIs lower the resistivity of the sand pad. This is largely due to the ionic strength of the VCI molecules, which increase the conductivity of the pad. The new lower resistivity of the sand pad will affect rectifier current output as well as increase anode depletion rate, affecting sacrificial anodes as well as ground bed anodes. This change should be accounted for when maintaining the CP system. There will likely be a requirement to adjust, modify, or replace existing CP components.

7.3.2 There may be benefits of the decreased resistivity through the addition of VCI in situations where decreased resistivity will improve CP performance. This should be evaluated on a case-by-case basis by consulting with both a VCI and CP professional.

7.3.3 Owner/operators that specify resistivity and choose to design including VCI may need to update their specifications for the pad. This should be done in accordance with API, NACE, and other industry guidance documents along with the VCI manufacturer. Table 1 shows allowable ranges of resistivity that differ slightly for each entity. There is currently no industry consensus value.

7.3.4 Selection of dry VCI or inhibitor solution design will affect the CP requirements since each will have a different effect on the sand pad resistivity. Owner/operators that are choosing between the two and have CP systems should make allowances for the different performance characteristics.

Annex A
(informative)

Recommended Tank Data for VCI Design

Responses to these questions are needed to properly specify a VCI delivery system.

1) Tank diameter and intended service?

2) In-service or out-of-service VCI installation?

3) Is this a PHMSA "break-out" tank?

4) Where is the tank located (state or province)?

5) Can the foundation or bottom be modified?

6) Specifications of tank bottom steel if available?

7) Foundation design drawings, if available?

8) Foundation photos?

9) Perimeter foundation details—concrete, gravel, at grade, elevated?

10) RPB presence?

11) Impervious liner—flexible membrane, natural clay, or geo-textile?

12) Depth of sand between tank bottom and RPB (volume of containment)?

13) Single or double bottom?

14) If single bottom, is there containment beneath the bottom?

15) Sand, concrete, asphalt, bit sand, or other pad material?

16) If single bottom, is the gap between the bottom edge projection and foundation sealed?

17) If single bottom with dry VCI application, is the gap between the bottom edge projection and foundation adequate for effective VCI delivery system design?

18) If a double bottom, is the gap underneath the new bottom sealed by welding or caulking?

19) Are there any drain pipes? If so, how many and what size? Do they have valves? Are they accessible?

20) Do they extend beneath the entire bottom? Any drawings showing configuration?

21) Is the bottom cone up, cone down, shovel bottom, or flat?

22) Any sumps?

23) Any channels in the concrete pad that may be used for dry VCI?

24) Operating temperature of the tank (range of temperatures?

25) Choice of monitoring devices, if any? ER, UT probes or Coupons? Datalogging needed?

26) Is the CP system currently functional? To what extent?

27) Is there any liquid (water) in the containment space? If so what estimated volume?

28) Any samples of existing pad?

29) Any MIC bacteria or other microorganisms present?