# Double Bottom Petroleum Storage Tanks

*by Philip Myers*

## Introduction

The term *double bottom tank* applies to tanks which have been retrofitted with a second bottom located above the original bottom as in Figure 1. Most double bottom tanks are created when the original tank bottom has reached the end of its useful life. For most petroleum storage tanks, the bottom life may be limited from 10 to 30 years depending on how severe the corrosion is. When the corrosion is extensive, then a bottom replacement maybe warranted. Most often, the tank shell and roof can be used with little need for repairs because they typically last 2 or 3 times longer than the bottom.

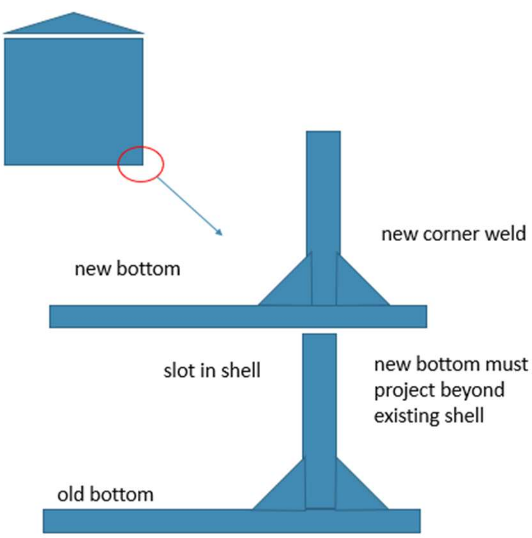


*Figure 1 Basic Double Bottom Configuration*

The basic rules for constructing double bottom tanks are outlined in Appendix I of API 650. Appendix I also has designs to include *release prevention barriers* (RPBs) because they are the modern way to minimize the potential for environmental contamination of the ground and ground waters. API 650's Appendix I also addresses RPB tank bottoms for new tanks. We do not address these here as Appendix I provides adequate guidance for these.

RPBs costs are negligible when installed at the time the new bottom is retrofitted.

*Figure 2 Photo of double bottom with both "chimes" visisble*

One final point about double bottoms; they reduce the tank capacity by the thickness of the double bottom which is obvious from the photo. This works out to slightly more than ½ %. In most applications this is not critical. However, if it is, then the standard protocol would be to remove the old bottom and replace it with a new one. If this is done, it is essential to remove all remnants of the old bottom since any remaining steel will accelerate corrosion of the new tank bottom as explained later.

## Evolution of the double bottom

The double bottom has its roots in the regulatory and industrial domains and began as a compromise to the needs and wants of regulators and industry. In the late 1980s, a major refinery responded to regulatory pressure due to leaking tanks and alleged contamination of ground waters by inventing the double bottom tank. Because this occurred in El Segundo California, a common nickname for the double bottom tank is *El Segundo Tank Bottom*.

From the regulatory perspective, the idea is simple, yet sound, and comes from the idea of double wall oil tankers that came into exclusive use after the Exxon Valdez oil spill incident. From the industry perspective, the solution was good because it gave the tank a new bottom without excessive costs and added many useful tools for the tank owner, including better control of tank corrosion, long tank life, better leak detection and monitoring and credit from the regulatory perspective.

Because of the widespread and increasing use of double bottoms to renovate tanks, the Tank Committee of the American Petroleum Institute (API) wrote a new Appendix I to API Standard 650 that covers double bottoms' basic requirements. This is a performance-based specification and does not cover the rationale behind the various designs, nor does it provide pros and cons of these systems.

There is one more historical point that is important to mention. In the 1980s and 1990s there were both proponents and detractors of the double bottom tank designs. Much of this arose because many companies including the majors did not understand that corrosion is and will be more aggressive with a double bottom that uses sand as a spacer in the interstice if the cathodic protection is either defective or is not used. Improper design and construction let many to say "double bottoms don't work". This is, of course, erroneously believed because they did not understand how to construct them properly. More on this later.

## Anatomy of a double bottom

While Appendix I of API 650 shows many different configurations, only a few basic methods have survived the test of time. Each has advantages and disadvantages. I will point out some of these and explain some of the pros and cons of specific type.

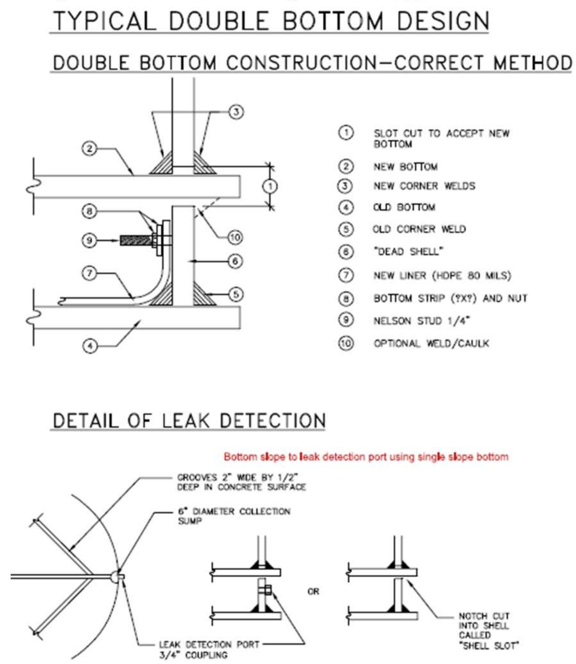

*Figure 3 Double Bottom Design Details*

Figure 3 shows old spent bottoms and dead shells that are the basic double bottom configuration (items 4,5,6). When the bottom is corroded and at the end of its useful life one typically removes the old bottom and replaces it. However, the double bottom allows the tank owner to leave the old bottom in place and use it as a "form" to install the new bottom.

The new bottom (items 1, 2, 3 in Figure 3) is installed by "slotting" the shell and inserting the bottom plates into it and making the new corner weld (shell-to-bottom weld) as shown. In the early days of double bottoms, owners sometimes would require fillet welding the bottom to the inside of the shell. This is prohibited by API 650 because it leads to early failures. The wrong way to install a double bottom is shown in Figure 4.

Therefore, the shell slotting method must always be used.

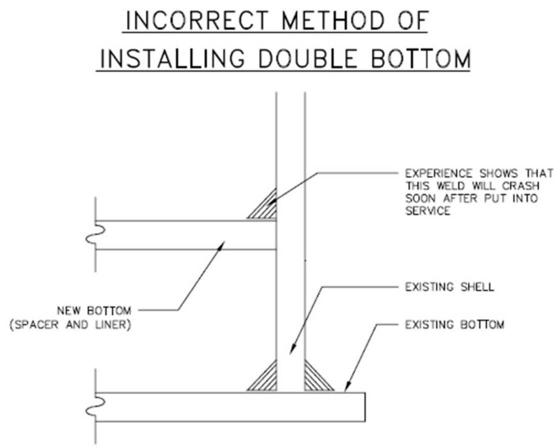


*Figure 4 Incorrect Method of Making a Double Bottom*

When a new bottom is installed, an RPB should be included (items 7, 8, 9 of Figure 3). Not only does the RPB prevent galvanic-corrosion problems that occur between the new steel in the new bottom and the old steel in the original bottom, but it also provides a leak detection and leak-monitoring function. Because the cost is negligible compared to the overall project cost, the RPB should always be used on all new double bottom installations. The optimal thickness for an RPB may be about 80-mils for a high-density polyethylene (HDPE).

There has always be controversy about whether the opening under the slot of the new bottom plates should be seal-welded and/or caulked (item 10 in Figure 3 ). While keeping water, especially contaminated or corrosive water, out of the space is important to reduce underside corrosion, there are problems with this. Sealing the space is difficult, can give a false sense of security and creates accelerated corrosion by retaining moisture in the space, which would have no way to evaporate or escape.

## Design options

Various double bottom designs have come into common use. While all these systems meet the requirements of API 650's Appendix I, it is useful to compare these options before deciding on a particular design. The Figure 5 and Figure 6 show more detail regarding the differences.

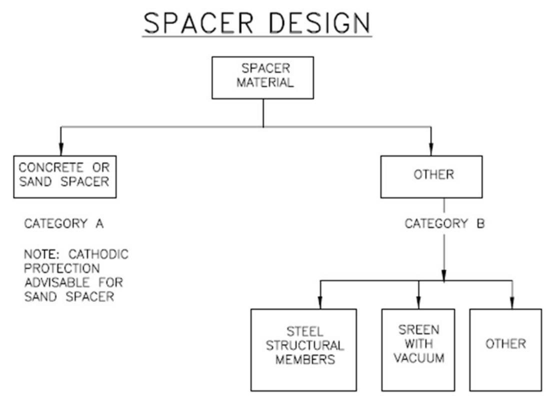


*Figure 5 Category A and B Spacer Designs*

There are two basic categories of design and construction as shown by Figure 5:

1. Category A--Sand or Concrete Spacer. The distinguishing feature of this category is the material used, which reduces the need for cathodic protection.
2. Category B--Structural Grille. This category has two subcategories: the first uses large standard structural shapes to form the spacer, called the grille; the second uses a wire mesh combined with a vacuum-monitoring system.

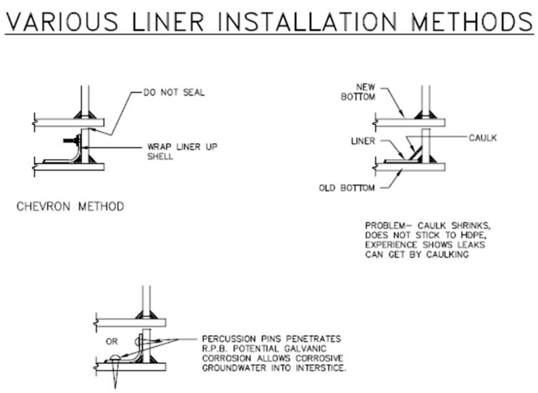


*Figure 6 Liner Installation*

The most common design is Category A. Category B has been used but primarily in specific industries or in special cases or simply because the engineer of record did not understand all the options pros and cons. Category B designs are in general costlier and have more problems in general than Category A designs.

One way to conceptualize the double bottom is by breaking it into functional components:

- the form,
- the RPB liner,
- the spacer and
- the leak-detection system.

## The form

The real advantage of the double bottom is that the old corroded bottom and deadshell can be left in place. It becomes the form that can be used to install concrete or sand to be the spacer material between the old bottom and the new bottom. It also serves as a working plane to set the slope or location of the new bottom.

New bottoms should not be installed directly on top of old bottoms because galvanic corrosion cells would be created. This is because new steel is more chemically active that old steel and is higher up on the galvanic potential scale than old steel. We say that new steel is *anodic* to old steel.

In the early days of double bottom installations, many owners installed the new bottom directly on top of the old bottom and were surprised to learn that the new bottom corroded in about one third to one half the expected life.

Also, even if a concrete or sand spacer is used, it is essential to install an electrically nonconductive elastomeric liner to prevent anodic current flow from eating up the new bottom.

## The RPB liner

Any material that is compatible with the stored material, is nonconductive and that will prevent liquid passage may be used as a liner. One of the most common materials has turned out to be HDPE.

Typically, a layer 40 - 80-mils thick is used. 80 mils is recommended as a minimum because it facilitates handling and has the ability to resist puncturing from sharp objects -- sticks, gravel and debris-- that are difficult to remove prior to laying the liner and during construction. Except in certain severe cases, the liner can be placed directly over the old bottom. Alternatively, a geotextile fabric may be used to act as a cushion between the old bottom and the liner.

While HDPE is the most common material, other materials are also used. Sometimes, a direct-spray coat of polyurethane is used. Other materials and elastomers also can be used. Each has some advantages and disadvantages. HDPE seems to provide an adequate liner at a reasonable cost.

One often hears arguments that better materials with higher compatibility, less swelling, higher tensile strength and lower permeabilities should be used for the liner. It must be remembered that the liner is a backup system for the new bottom and should rarely have to contain a leak if tank bottom is adequately constructed with appropriate non-destructive testing and managed in accordance with API 653.

Also, the liner will never have much pressure on it, regardless of the leak size. Because the leak-detection system must direct the leak to the perimeter of the tank, the pressure on the liner is limited essentially to atmospheric pressure. There is no need to treat the liner as though it will be used for pressurized immersion service.

Finally, both nondestructive and destructive testing of the liner is recommended. Because the plasticizers and additives in elastomers may not be tightly controlled or are out-of-specification, the seams can be weak. I once worked on a job where the liner installation was beautiful, but a pull test showed the seams separated as though glued together with butter.

## The spacer

The spacer, which is the material between the old bottom and the new bottom, is typically placed on top of the liner and is three to four inches thick and has the following functions:

- It provides a control working surface for the new bottom (and concrete is the best for this purpose). It also elevates the new bottom and keeps the underside of the new bottom dryer. The control over slope reduces bottom waviness and puddling which assists in better water removal (i.e. water draws), less corrosive water or brine at the bottom of the tank, and better drainage.
- Because settlement occurs on almost all tanks, it allows for "regrading" the new tank bottom to a profile that the owner wants.
- It provides an "interstitial space" or a collection area where leaks from the new bottom can accumulate and be directed to leak-detection ports (see Figure 3).

While sand, steel or other media may be used, some companies choose concrete as the spacer material upon which to install the new or second bottom. This material gives control over the slope of the tank bottom, allowing better water drainage, and reduces corrosion due to stagnant water in the tank bottom.

There are several good reasons why concrete is used:

- It is alkaline, and it actually reduces corrosion rates from the underside. In many inspections, I found the concrete extended tank-bottom life by 25 percent to 50 percent due to reduced underside corrosion attack.
- It does not require the supplementary use of cathodic protection as do sand based spacers. Sand bottom cathodic protection systems are often damaged on installation due to dragging of new bottom plates through the sand and cutting cathodic protection anodes, wires and connections.
- Concrete provides a good, hard work surface that not only speeds construction of the remaining tank but also maintains good permanent slope for water drainage. This is important to prevent standing water in tank bottoms, which tends to cause corrosion problems. Concrete allows cleaner, water-free products for fuels.
- Sand spaces are the most common because the first costs are less than those of a concrete double bottom spacer. However, there are some important caveats to sand spacers.

- Sand must use a cathodic protection system (either impressed current or sacrificial ribbon) because of the galvanic corrosion potential difference between the new and old bottom and must also have a dielectric material (elastomeric liner) to reduce corrosion to a reasonable level. Proper design of the cathodic protection system is essential as well as fragile. This is because there is little distance between the two bottoms and the spacing of the cathodic protection elements is critical. In addition, if the sand ever gets flooded by high waters in the secondary containment or leaks through the old bottom, the salinity of the sand/water can change causing the protective cathodic protection current to be inadequate. This is because cathodic protection systems are designed with a specific resistivity of the sand in mind and if it changes due to moisture or flooding, the system will be inadequate for cathodic protection. There are other problems with sand spacers and this is the reason that some companies have standardized on concrete spacers despite the higher first costs.

## Leak Detection System

The double bottom can be an incredibly effective leak detection system with few false positives and the ability to detect very small leaks. Many tanks which were thought to be ready to commission in service have be flagged by the leak detection system as defective when conducting a hydrostatic test or on first filling with product. My personal estimate of new tank bottoms that have a defect sufficient to trigger a leak detection hit is estimated to be about 1 – 3%.

Any liquid at the bottom of a tank is usually less than 20 psi. When it leaks through the tank bottom its pressure is reduced to atmospheric and the liquid accumulates until it can run over to a leak detection port (see Figure 3) where it will be visually detected by the operator.

There are a few important concepts to note:

- The liner and old bottom do not have to function as a pressure containing vessel because there is very little pressure driving the liquid into the ground through the old tank bottom. Recall that the leak from the primary bottom is reduced to atmospheric pressure and hence there is little to no pressure driving the liquid into the ground. Rather if flows preferentially in the interstice over to a visual leak detection port where it spills out and is easily detected before it can do any damage. For this reason, any reasonable design will be adequate and there is no need to design the interstice as though it were a pressure vessel.
- Because of the previous principle, a new tank sitting on either clay or a concrete foundation acts as a tank with a leak detection system because a leak will come out at the perimeter long before it can penetrate significantly into the ground. API recognizes this principle in documents such as API 2610.
- The double bottom leak detection system is passive. It relies on gravity and people being present at the facility to observe any leaks that may occur.
- A closed interstice (see discussion later) invalidates the principle of atmospheric pressure and visual detection described earlier and is therefore not recommended.
- The best way to install leak detection ports is to use a 1-inch threaded coupling welded to the deadshell and the drilled so leakage can escape. Some companies do not use the threaded coupling but simply drill a hole or use slots in the deadshell. The advantage of a threaded fitting is that if there is a leak, the port can be temporarily plugged reducing the amount of contamination that will have

to be dealt with after the tank is drained for repairs.

## Some Liner Design Details

There are two schools of thought on liner installation. The first is that the liner should be flat and trimmed to the inside diameter of the tank dead shell as shown in Figure 6. While the tank bottom still functions as intended, the liner has caused certain problems.

One problem is that, if a leak occurs, there can be short-circuiting to the ground if the attachment between the liner and the deadshell fails. This would only be a concern if the ground were highly permeable. Another problem is that false indications of a leak is possible if previous oil contamination from old bottom leaks works its way back up through the old bottom and around the liner back into the leak-detection system. While not common, this has occurred often enough to cause some companies to redesign of the bottom liner to form a "bathtub" as discussed below.

Figure 6 illustrates all the designs that depend on an elastomeric liner, such as 80-mil HDPE, to form a circular disk that functions as the RPB and that is terminated to the "dead shell." The problem of short circuiting or leaking at the periphery is a significant problem to overcome.

The nailing method shown in Figure 7

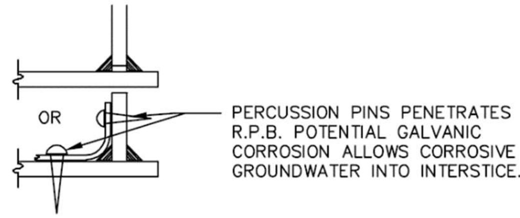


*Figure 7 Nailing Liner To Bottom and Dead Shell*

typically uses "percussion pins" that are driven at high velocity through the liner and through the old bottom. There are several problems with this. This process makes a hole completely through the liner and RPB so that if there is a leak in the bottom and the pin or nail head works loose a leak could develop in the liner although the impact of this should be small because the leak detection system is able to pick up leaking tank bottoms quickly.

Another method uses glue or caulking. (see Figure 8)

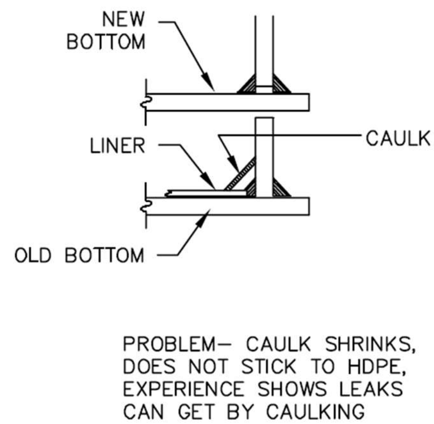


*Figure 8 Caulking Liner To Bottom and Shell*

Although this design has served adequately for decades, operators and engineers with experience have noticed that few if any materials stick to HDPE and that all elastomeric liners shrink across the diameter several centimeters leaving annular gap between old bottom and the deadshell. Also, removal of old double bottoms shows that there had been some shrinkage of the liner over time. Any glue, even if it could be made to stick, would peel loose, and the seal would be broken. (As I have mentioned, I do not believe this seal is critical, but others may, and the appropriate design details must be decided on by the stakeholders).

An improvement related to this design problem is to create a "bathtub" out of the liner that is at least one to four inches high (see Figure 9). This is done by wrapping the liner on the inside of the deadshell, seaming it together and fastening it to the deadshell.

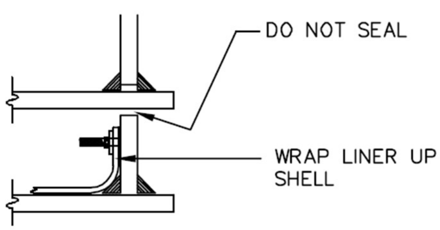


*Figure 9 Bathtub Seal of RPB to Tank Shell*

You can use a steel baton strip to seal the liner to the deadshell. This involves using stud welding to bolt the baton strip to the shell. This technique creates a bathtub by "heat seaming all seams to the point at the top of the baton strip. In this system, there is little dependence on caulking to provide a tight joints and liner shrinkage fails to become an issue.

There are a number of other designs in the field, some of which are proprietary. These should be evaluated using the criteria provided in this article and performing a cost/benefit analysis to see if they are worthy of installation.

However, there is one more point to be made about designs which completely seal the interstice and depend on vacuum to determine the integrity of the leak detection system.

Because the purpose of the interstice which is the space between the old and new bottom is not to serve as a pressure containment system it has much less stringent design criteria. However, some have used systems that do indeed required a completely sealed space. Some systems use vacuum to monitor the space. The problem is that these systems all have some small degree of leakage. The result is that the owner may be faced with a false positive, that is, the indication of a leak when there is none. This has in fact happened numerous times and results in expensive procedures to validate whether there is actually a leak. Litigation has resulting in some cases because there was no leak and the costs of checking for it was significant.

## Open vs. closed system

Most double bottom systems are open, which we define as *not* welding or caulking the underside of the new bottom plates, as well as leaving the leak detection nozzles open. However, there is a school of thought that favors the closed systems, especially from the regulatory perspective. See Figure 10.

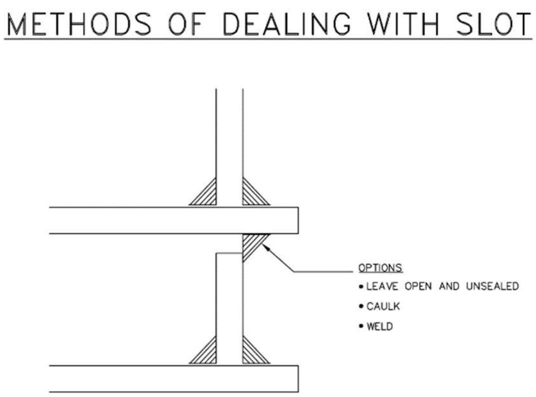


*Figure 10 Open and Closed Double Bottom Slots*

The closed system is defined as one in which the leak-detection space, or interstice, between the new and old bottom is sealed closed and is essentially air tight. This requires the ports to be closed, using valves, and the junction between the deadshell and the new bottom (the stub of the shell under the new bottom) to be sealed by caulking or seal welding. I previously discussed some of the problems for this type of system and large consequences they can produce.

There are other significant problems with closed systems. Making a weld that actually seals the new bottom to the "dead shell" or the stub that is left after cutting the new bottom is almost impossible. In most cases, there is inadequate room to make the weld. The weld is, therefore, of poor quality and would not keep out water or dirt. Due to the difficulty of making this weld and to the nature of fillet welds, which are the welds that have been used to seal the interstitial space by welding to the underside of the new floor, this seal weld is prone to have cracks and flaws. Since this is the most highly stressed region in the tank, it makes the possibility of a serious failure much more likely. Such a weld during large settlement or an earthquake or flooding could cause a catastrophic propagating crack leading to sudden failure of the bottom or shell.

From the principle of fracture mechanics, crack growth or sudden propagation occurs in the presence of flaws and stress. Flaws and stress are likely with the weld. It is for this reason that API Standard 650 makes such stringent nondestructive examination requirements for the topside-fillet corner welds in this highly stressed area. It would be basically impossible to verify the integrity of the underside weld.

Sealing the bottom space has caused catastrophic bottom failure by pressure pumping the trapped air in the interstice. If and when a failure develops, no matter how small, the air in the sealed space can become pressurized by the head of liquid on top of the bottom. When reducing pressure by lowering the liquid level, the air expands the bottom. Even slight changes in pressure cause the large flat areas (the old and new bottom) to bulge. Slight pressures can be caused by temperature changes, a leak or other factors.

Sealing the bottom space also defeats the principles of early leak detection. It violates API 650 's Appendix I requirements for making leaks detectable at the perimeter. Complying with this requirement requires the addition of an electronic sensors to monitor the interstice. This creates design complexity and potential system failure.

It was originally thought that water and corrosion could be minimized on the underside of tank bottoms, reducing underside attack. Due to the large size of the tank double bottom space and the humidity of the air, however, when the bottom is sealed into a closed system, water will condense on the underside of the tank bottom plates, causing accelerated corrosion. This is similar to a crawl space in a house when moisture damages the flooring unless adequate ventilation is provided.

For this reason, open systems may be superior by allowing ventilation to remove any moisture that enters the space. Even if the bottom could be perfectly sealed and constructed with no moisture, the concrete or sand itself has moisture that evaporates from it and creates a humid, corrosive environment where the space is not allowed to breath. No studies have been done that conclusively shows that open or closed systems are superior from a corrosion perspective.

In general, I recommend and advocate not using a closed interstice system for a double bottom tank.

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