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ALUMINUM TANK COMPONENTS—1

Aluminum a good alternative to steel for fixed-roof tanks

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Aluminum, used for major aboveground-storage tank (AST) components, has advantages and disadvantages when compared to the conventional steel materials of construction.

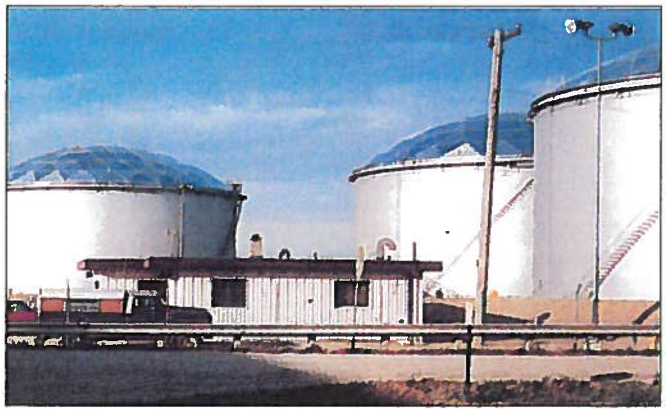
For fixed-roof tanks, refiners can save money and gain improved quality if they consider the advantages of aluminum over steel.

This article is the first of a two-part series that discusses the use of aluminum structural components for ASTs. The first article presents a comparison of covered tanks vs. uncovered tanks (tanks with a floating roof but no fixed-roof) as well as a comparison of aluminum-dome roofs (ADRs) vs. steel-cone roofs (SCRs). The second article compares various types of aluminum and steel internal-floating roofs.

For large ASTs, fixed roofs should be aluminum because the roof-support columns can be eliminated when using aluminum domes (Fig. 1). Large SCRs require columns. Aluminum domes maximize tank capacity, reduce coating costs, and have fire-safety advantages.

For internal-floating roofs, aluminum and steel each has its own merits. Instead of just bid prices, tank managers and operators should consider the long-term operational, safety, environmental, and economic issues of aluminum and steel components in ASTs.

Although API 650 defines a minimum standard of quality, in some cases, when safety and total cost of ownership are considered, the standard may not be adequate for desired long-term performance.



Aluminum domes maximize usable tank capacity, avoid coating costs, and avoid column problems. Photo courtesy of Temcor (Fig. 1).

Covered vs. uncovered tanks

An AST that includes a floating roof and is covered by a fixed roof is considered an internal-floating roof tank (IFRT). An existing external-floating roof tank (EFRT) can be converted to a covered IFRT by retrofitting it with a fixed roof or cover.

Although the EFRT may have a lower initial cost than the IFRT, it may not have the lowest total ownership cost when long-term operating costs, maintenance costs, and potential risks are considered. The factors which favor building or retrofitting EFRTs with fixed roofs are incident prevention, environmental protection, safety, and reduced long-term maintenance and operating costs.

Table 1 summarizes the considerations for the use of covered tanks (IFRTs) vs. uncovered tanks (EFRTs).

Overloading external-floating roofs

External-floating roofs are vulnerable to overloading. The fixed roof eliminates the intrusion of rainwater, snow, ice, and dirt into the tank.

In EFRTs, precipitation can sink the floating roofs during heavy rainfalls or prolonged winter storms. Historically, several external-floating roofs sink each year in the U.S. during the winter or as a result of extreme rainfall events. This number may be underestimated because these incidents are not required to be reported through any public channels.

Snow, ice, dirt, and debris accumulation can render the drains inoperable, resulting in overloading. Overloading can result when drain systems freeze close or when drain capacities are inadequate.

In addition, heavy snowfall can result in an unbalanced load condition if the snow collects on the windward and shaded surfaces. In the Middle East, where rainwater, snow, and ice are not a concern, some users require IFRTs to avoid accumulations of windblown sand.

External-floating roofs are especially vulnerable to overloading when the product level is low or while the floating roof is landed on its supports. There are several reasons for this:

- Per API 650-Appendix C.3.4, the design buoyancy is based on supporting 10 in. of rainwater (or 52 psf); however, the supports are only designed to support 25 psf, per API 650-Appendix C.3.10.2.
- When the roof is floating at a low elevation, the head pressure forcing rainwater through the drains is reduced. This head reduction increases the amount and weight of water on the deck during rainfall.
- In an annular-pontoon floating roof (flat-center deck), the center deck is highly flexible and will rise when vapors evaporate as the deck is heated by solar energy. The deck also deflects downward at the center as it is loaded with water. When the roof is floating near the bottom, loaded with water and sagging at the center, the center deck supports can contact the bottom and fail as a result of being overloaded. The floating roof supports have also been known to puncture the

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bottom, resulting in serious leaks.

- The drain sizes of the external-floating roofs identified in API 650-Appendix C3.8, are minimal. The purchaser should understand and identify the drain requirements for each location, based on anticipated rainfall.

Water intrusion

The covered tank minimizes rainwater entry into the tank.

Rainwater can intrude into the tank stock by seeping past the seals. Water will mix with or leach out certain additives or components, which may compromise product quality. In addition, contaminated water bottoms require the long-term cost of collection and disposal as a hazardous waste.

Another problem associated with water entry into the tank has to do with methyl tertiary butyl ether (MTBE) and other ether or alcohol-based additives, which are commonly used as a gasoline additive to meet requirements of the Clean Air Act.

Because MTBE and alcohol are preferentially soluble in water, remediation is more complex for them than for hydrocarbons; therefore, it is important to minimize any introduction of water into a tank storing oxygenated gasoline.

Elimination of EFRT drains

By covering a tank, the need for an EFRT-rainwater drain is eliminated. The removal of the drain avoids the risk of drain-line failure, reduces the initial tank equipment cost, and results in significant long-term operational and maintenance savings. Fig. 2 shows how the drain is attached to the EFRT.

The drain removal is environmentally desirable because the potential for a major spill or release as a result of a roof-drain failure is eliminated. A substantial spill may occur if the roof drain ruptures and the valve on the roof drain has been left open.

Table 1

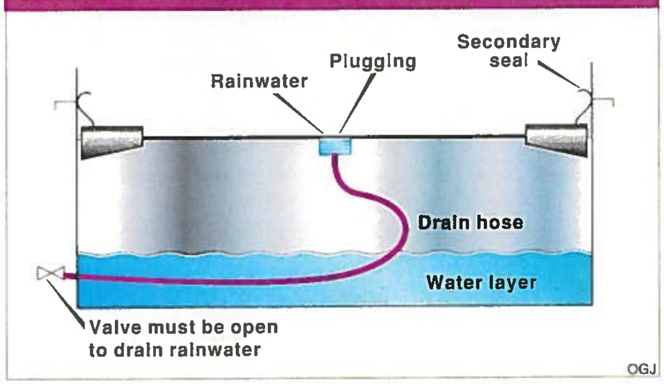
COVERED VS. UNCOVERED TANKS

Covered tanks	Uncovered tanks
Eliminates rainwater entry (Environmental loading)	Rainwater can: • Sink floating roofs if roofs are not drained or if drain plugs • Add to water bottoms which may increase disposal/treatment costs or cause product contamination • Accelerate bottom corrosion Snow and freezing can cause floating-roof mechanical failures or sinking
Eliminates roof drain	Requires roof drain which: • Uses more vertical space to allow sufficient hydraulic head • Is a potential for serious external spills if the drain is not properly operated • Increases the potential for liquid on roof if roof drain is damaged
Requires only a primary seal*	Requires primary plus secondary seal which: • Requires secondary seal inspection and maintenance • Requires more vertical spacing to accommodate secondary seal
Seal fires rare†	Seal fires relatively common

* Although EPA 40 CFR 60 - U.S. EPA New Source Performance Standards does not require a secondary seal for IFRTs, local air quality management districts (such as the Baaqmd in California) have stricter requirements †Incidents of internal floating roof fires are far more rare than external floating roof fires; however, IFRT fires have been extremely serious.

Fig. 2

EFRT DRAIN



Many companies require EFRT-drain valves to be kept closed. This policy, however, increases the risk of overloading the floating roof because it requires manual intervention to drain the floating roof during rainfall. Some companies have installed hydrocarbon-sensing valves and other detection devices on the roof-drain outlets; however, these devices have not proven effective to prevent the release of hydrocarbons through a damaged roof drain line under all conditions.

In the long-term, avoidance of maintenance costs stems from eliminating the manual-drain operation. Maintenance can be annual cold-climate protection or eventual drain-line replacement. To prevent drain-system damage during prolonged winter conditions, external-floating roof drains are often filled with antifreeze, which introduces an additional hazardous waste handling and treatment cost.

Increased usable tank capacity

For covered-floating roof tanks (converted from an EFRT) and for IFRTs, federal regulations do not require a secondary seal. The elimination of the secondary seal reduces the initial tank equipment cost and associated long-term maintenance and inspection costs. Perhaps most important, it increases the usable capacity (or working volume) of the tank.

Because only a single liquid-mounted primary seal is required for an IFRT, floating roofs can be operated at a higher level, closer to the fixed roof without interference from the secondary seal.

The capacity savings from eliminating the EFRT weathershield-type secondary seal can be in the range of 24-36 in.; however, eliminating a secondary seal from an internal-floating roof will save only 8-12 in. For new construction, the lower design loading of API 650-Appendix H (Internal Floating Roof), will further reduce outer rim-profile clearance requirements by an additional 10-24 in. depending on the type of internal-floating roof.

Corrosion

External-floating roofs corrode and must be maintained by initial and periodic recoating. Costs for recoating old tanks with lead-based paints can be significant. By covering the tank, the need to coat the floating roof is eliminated. Even if the external-floating roof is due for a coating removal and paint job, it is not necessary if the tank is covered.

The severity of internal-

Table 2

STEEL CONE VS. ALUMINUM DOME CHARACTERISTICS*

	Steel cone	Aluminum dome	Additional comments
Corrosion	Columns increase corrosion under column bases. Poor coatings preparation and application can aggravate corrosion.	No columns	Corrosion will be more severe if a water-bottoms layer is present under the column bases. This is common for finished-fuel tanks.
Inspection	Columns make inspection under column bases difficult and often overlooked.	No columns	Inspection under column bases is typically not done due to the difficulty of lifting the column and roof to visually inspect under the column bases.
Linings and coatings	Columns tend to cause lining erosion and poor lining application at column bases due to movement and sharp edges.	No columns	Column bases rest flat on the tank bottom and are not attached.Because of settlement, thermal expansion, and small movements, the column base wears any coating on the bottom. It is also very difficult to properly apply coatings in areas such as around column bases.
Fire hazards	Columns trap hydrocarbons which are hazards when hotwork occurs during maintenance.	No columns	There have been many cases of injuries and fires associated with liquid hydrocarbons trapped in roof columns. The problem is more serious with pipe columns than built-up members. API 2015 has a complete discussion of this topic.
Maintenance hazard	Columns often have to be jacked up to install double bottoms or to do other work.	No columns	The jacking process is a dangerous operation in which improper procedures cause roof collapse as well as injuries.
Emissions	Columns represent points of emissions.	No columns	The EPA program, Tanks 3.1, can be used to determine the effect of emissions from fixed-steel roof tanks vs. aluminum-dome roofs. This program is available to the public on the internet.
Floating-roof binding	Columns can bind on the floating roof causing liquid to enter the roof or, in the worst case, to sink it.	No columns.	
Frangible roof	Frangible roof is possible. This is a clear advantage.	Frangible roof not possible.	Although the frangible roof specified by API 650 is a valuable explosion and overpressure protection, it is not known how the aluminum dome will perform under similar overpressure situations.
Cost	Typically, steel cone roofs have a lower initial cost.	Typically, aluminum-dome roofs have a higher initial cost. If coating costs are included or if life span is considered then aluminum often gives a better total cost of ownership.	Proper cost analyses by competent personnel are required to examine the true and total costs of ownership.

*Comparison does not apply to self-supported steel-roof tanks (usually 20 ft in diameter or smaller). Larger tanks have more columns.

shell corrosion is normally reduced by covering the tank. For tanks which are fully coated on the internal shell, the life of the coating will be increased as a result of the reduced weather effects.

Safety and security

Fixed-aluminum dome and steel roofs are less likely than EFRTs to cause fire and access problems.

Because an internal-floating roof is within a closed conductive structure, the "Faraday Cage Effect," which isolates the interior from the effects of external electrical events such as lightning strikes or static charges, reduces the risk of fire. Even direct lightning strikes will not cause sparks to discharge from the floating roof to the tank shell.

Fires or explosions involving internal-floating roof fires are hundreds of times less likely than those involving uncovered EFRTs. Existing EFRTs have also been covered simply as a result of their proximity to an ignition source (such as a flare stack). Despite increased potential, rim fires on EFRTs are usually quickly extinguished.

A fixed roof controls access to the hazardous or "confined space" environment in the tank. The U.S. Occupational Safety and Health Administration (OSHA) requires that each facility designate those areas that are confined spaces, and entry must meet all requirements under OSHA 29 CFR 1910.146. Typically, for petroleum-storage tanks, the space within the shell of an EFRT is considered a confined space if the roof is below 5 ft of the rim. For an IFRT, however, any space within the shell or under the fixed roof is always considered a confined space.

Many EFRTs in remote areas have been covered due to concerns of unauthorized access. In one case, children were found riding their bicycles on the deck of a 200-ft diameter EFRT slated for gasoline additive (MTBE) service; spent bottle rockets were also found on that same deck.

In the 1980s, the U.S. Air Force Strategic Air Command began a program to cover existing EFRTs, primarily to eliminate water problems with jet fuel and antifreeze additives. A side benefit of covers was to conceal base-fuel inventory levels from aerial surveillance.

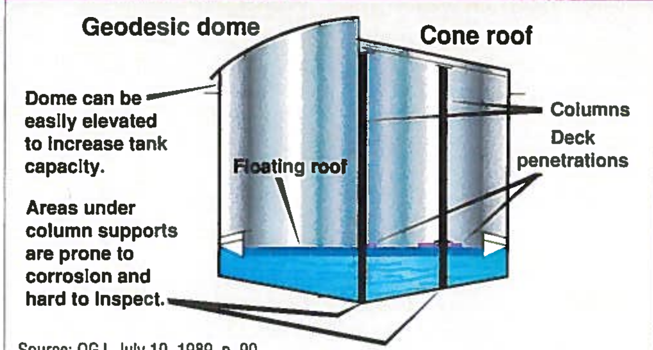
Steel-cone roofs vs. aluminum-dome roofs

Clear-span ADR tanks have more advantages than do column-supported SCR tanks. Table 2 compares ADRs and SCRs.

The ADR is usually the

Fig. 3

GEODESIC DOME VS. CONE ROOF



Source: OGJ, July 10, 1989, p. 90.

OGJ

most favorable option for the retrofit of an existing EFRT with a new fixed roof. For new tank construction, or replacement of an existing cone roof, an evaluation should consider the initial bid price as well as other fundamental variables:

- Operating capacity savings
- Initial coating cost and long term maintenance
- The elimination of columns and their related problems: emissions, penetration seal, bottom corrosion, maintenance obstruction, settlement, and incident risk costs.

Steel, self-supported dome-roof tanks and small-diameter tanks with self-supported fixed roofs are excluded from this evaluation; they share, however, many of the benefits of ADR tanks.

Similarities

Functionally, the roles of the ADRs and the SCRs are similar:

- Both types protect the floating roof from environmental loading.
- Both types minimize dirt and water entry into the tank.
- Both types eliminate the intrusion of rainwater into the tank; however, the quality of the aluminum-dome weathertight design will vary by manufacturer. It is critical to specify a proven-ADR design which is leaktight.
- Both types reduce weather-related corrosion on the internal-shell surfaces.
- Both types eliminate the wind-related component of tank emissions.
- Both types improve fire prevention, improve safety, and enhance security.

Cost effectiveness

Technically, the ADRs and SCRs have different requirements. When retrofitting an existing EFRT with a new fixed roof, the conversion to an ADR tank is usually the most cost effective, regardless of tank size. This conversion does not require removal from service, tank cleaning, or extensive downtime for hotwork.

The aluminum dome is a bolted structure that can be assembled on the tank with no hotwork. Steel roofs require hotwork because they are field welded; therefore, the hazards increase for steel construction.

Today, new SCR construction should minimize the number of SCR-support columns to avoid penetrations of the internal floating roof and their related initial costs, increased emissions, and column-seal replacement costs.

Without considering other initial and long-term cost factors (listed below), the aluminum dome usually becomes cost effective for tank diameters of 40 m or more, the diameter for which multiple rings of columns would be required for an SCR. The aluminum-dome roof is cost effective for tanks larger than 20 m when compared to a steel-dome roof and larger than 10 m if internal coatings are needed for steel.

Capacity

The capacity of an SCR is reduced because the cone-roof support structure (including roof rafter-to-shell attachment gussets) extends 12-18 in. below the top of the tank shell, and the floating-roof seal may run into the fixed-steel roof. Although the tank shell could be extended upward, this is typically not practical or cost effective for a project to cover an EFRT. The ADR tank does not usually restrict capacity because the attachment of external framing permits full travel of the seal to the top of the tank shell.

Analyses should always be performed to confirm clearance with other deck obstructions (e.g., foam dams and pressure/vacuum vent). Larger-diameter domes have a steep rise at the periphery, which helps avoid interior-deck obstructions. For additional clearance, the aluminum dome can be installed with a skirt, which effectively raises its base elevation.

Coatings

When comparing the differences between steel and aluminum, it is important to consider the rather substantial costs of surface preparation and coating. Aluminum domes are typically not coated, whereas steel roofs are always coated externally and often coated internally in corrosive environments.

ADRs are justified for tanks with diameters as small as 10 m for tanks which require internal coatings. This conclusion is based on consideration of the coating cost, the special construction-detail requirements, the internal seal-welding requirement, and the extensive preparation required for an effective internal coating. In addition, coatings have maintenance costs and recoating charges as a result of normal wear.

Beyond the initial roof coating cost on an SCR, there is the future maintenance. Of all the externally coated surfaces on a typical tank, the cone-roof coating will fail first as a result of horizontal exposure to sunlight and ponding of rainwater. These factors result in rust streaks that run down the tank shell and create a cosmetic problem.

The use of an ADR extends the time interval between tank-shell recoating and eliminates the cost of recoating the roof-surface area.

Steel roofs often have uncoated internal surfaces. These roofs can produce tons of corrosion products that eventually delaminate from the underside of the fixed roof and collect on the bottom of a tank. In one case, an estimated 70 tons of corrosion products were removed from the bottom of a 280 ft-diameter SCR tank in crude oil service.

Had an internal-floating roof been used, the exposure of the fixed roof to corrosive-sulfur compounds would have been minimized. Preventive maintenance, however, would still have been required to remove some corrosion products from the deck. The ADR would not have generated corrosion products.

Emissions

The emission of organic or hazardous vapors from an ADR is lower than that of a similar SCR. Unlike the cone roof, the dome is a free-span structure. The SCR tank has columns that extend from the fixed roof, through the floating roof, and to the tank bottom. The SCR has one or more column penetrations from which emissions escape to the atmosphere. The use of an aluminum dome reduces the total facilities emissions inventory by avoiding the emission factors for column penetrations.

Fig. 3 illustrates the differences between the ADR and SCR tanks.

Chapter 19, Evaporative Loss Measurement, of the API Manual of Petroleum Measurement Standards provides a basis for the EPA emissions calculation program. Although not currently part of the emission calculation formula, the API Committee on Petroleum Measurement is considering better defining the variables that influence bulk and surface liquid temperatures to improve accuracy. For example, although bulk temperature is currently based on ambient air conditions, the method of delivery and turnover rates are more influential in determining the bulk temperature.

Currently, there is only a general "paint factor" to adjust bulk temperature for roof variables. External-floating roofs exposed to direct sunlight should have higher surface-liquid, shell-surface, and deck-fitting temperatures than covered-floating roofs. Current bulk-temperature calculations, however, do not include these solar-radiation effects.

Although not currently considered in the emissions calculation, the type of material used in the tank should also be considered. Because aluminum has higher reflective and lower emissive properties than steel, emission calculations should include the following variables:

- Adjustment of liquid-surface temperature to reflect the impact of heated-shell and EFRT surfaces.
- Addition of solar impact and material variables to reflect reduced internal-surface temperatures by either a steel or aluminum fixed roof.
- Addition of solar impact and material variables to reflect reduced surface-liquid temperatures by using various types of aluminum internal floating roofs.

Corrosion caused by columns

Roof-support columns increase the potential for tank-bottom corrosion and roof corrosion.

API standards do not allow columns to be attached to the tank bottom so that the tank bottom can settle without distorting the roof. The movement of the column base on the tank bottom erodes any coating on the tank bottom and creates conditions conducive to crevice corrosion.

Corrosion damage that occurs near or under the column bases is rarely inspected (even during formal API 653 internal inspections) because the base plate covers the corrosion damage. Column guides and base plates, welded to the tank bottom, make coating-surface preparation and application difficult, which increases the potential for corrosion attack.

Because there is a higher probability of tank-bottom leaks as a result of corrosion in SCR tanks, the potential for resulting environmental contamination increases.

Also, if the SCR support columns vertically settle, the cone roof surface plates will deflect downward and pond water (accelerating corrosion). A clear-span aluminum dome is supported by the tank shell, and uniform shell settlement can be facilitated by the use of a concrete ringwall foundation design.

More column problems

Columns can cause problems if they are out-of plumb, trap hydrocarbons, or are improperly jacked during maintenance.

Columns which are out-of-plumb with each other and the tank shell can cause the column-penetration seals to wear. In severe cases, floating roofs have hung up on columns as the product level rose.

Closed-shaped columns, such as pipe columns, can hold trapped hydrocarbons even if they are designed to be self draining. Many fires and explosions have been initiated by trapped hydrocarbons in roof columns during internal-tank work.

Tank columns are often jacked up when new tank bottoms are being installed or during maintenance. Columns and jacking structures can collapse if improperly jacked. The aluminum dome, because it has no columns, is not affected by interior-bottom settlement and offers no obstruction to bottom inspection or maintenance.

Roof frangibility

API 650 provides rules for designing a frangible roof for new CRTs. If a tank is internally overpressurized, a frangible roof will fail at the roof-to-shell joint and vent the excess pressure harmlessly to the atmosphere.

In some instances, the shell-to-bottom joint has failed while overpressuring or overfilling tanks without frangible roofs. This failure causes the tank to rocket upward, spilling flammable contents or releasing liquids. Frangible roof failures historically have not released liquid and have resulted only in relatively minor damage to the tank.

API 650-Appendix G, which covers the design and construction of ADR tanks, states that the roof-to-shell joint is not considered frangible. Certainly, the structural attachments are not designed to be frangible.

For all reported ADR-overpressurization incidents to date (less than six), however, the peripheral flashing has behaved as if it were a frangible component. Even on ADR tanks less than 40 ft in diameter, in which frangible joints are not considered reliable for SCR tanks, the flashing has behaved as a frangible component.

The vent area of the aluminum-dome flashing should exceed the vent area required under API 2000, Section 2.4.3.2, which covers emergency and normal venting for "Tanks Without Weak Roof-to-Shell Attachment." There is an open API agenda item to allow the aluminum-dome manufacturer to document the frangibility of a panel component and allow the documented component to contribute to the vent area as required by API 2000.

Component frangibility is not the same as a frangible roof-to-shell joint, which is defined under API 650, Section 3.10.2.5 and API 2000, Section 2.4.3.1. Component frangibility is categorized separately under API 2000.

Safety access

In the rare event of a fire within an IFRT, the aluminum dome panels provide good access to the fire surface for extinguishing. The panels will melt away or allow an ax to penetrate the surface. In one incident concerning a tank with an aluminum roof, during a fire started by welding adjacent to a wastewater basin, the panels quickly melted away allowing the fire to be promptly extinguished.

This same ability to remove ADR panels facilitates access to the tank interior in the event that personnel within the tank require emergency-vertical retrieval.

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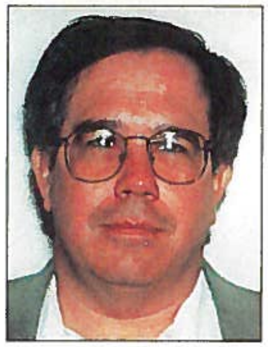

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