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Above Ground Storage Tank Degassing Principles and Practices

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Under the Texas Natural Resource Conservation Commission (TNRCC) regulations that went into effect in 1996, certain stationary storage tanks and transport vessels must route vapors through a control device before atmospheric release. California has had a similar, but stricter guideline for ten years. In addition, National Environmental Standards for Hazardous Air Pollutants (NESHAP) and Occupational Safety and Health Administration (OSHA) regulations call for very strict exposure limits to hazardous air pollutants such as benzene.

This article discusses some key degassing principles; available degassing methods; the effects of tank types, residual product/sludge and environmental conditions on degassing time requirements; and logistical and safety issues. Also several empirical degassing models are discussed and are compared in light of actual field data.

Purpose of Tank Degassing

The main reasons for tank degassing are to reduce emissions of air pollutants and to

minimize human exposure to hazardous pollutants. Another important reason is to eliminate the danger of explosion during tank cleaning or tank repair.

There are different state and federal regulations that address these issues. For example, the TNRCC degassing regulation calls for a minimum of a low-volume sweep of tank vapor space through a control device or a reduction of the tank vapor concentration to 34,000 ppmv of methane for large tanks containing volatile hydrocarbon products. The control device is required to have a minimum 90% control efficiency.

The regulation requirements are more stringent in California. For example, the South Coast Air Quality Management District (SCAQMD) calls for a tank vapor concentration reduction to 700 ppmv for most underground and above ground storage tanks.

In addition, such federal NESHAP and OSHA regulations call for strict limits on human exposure to hazardous air pollutants, such as an 8 hour exposure limit to benzene of less than 0.5 ppm.

A well-designed degassing process

should be able to meet the latter as well as the spirit of the State and Federal regulatory requirements.

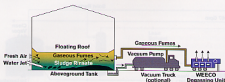
Typical Degassing Process

A typical degassing process is illustrated in Figure 1. For degassing before the cleaning operation, only the tank vapor is extracted. For degassing during the tank cleaning operation, the vents from the cleaning equipment (such as centrifuges, frac-tanks and/or vacuum trucks) are also collected and routed to the control device.

While tank vapor is being extracted into the degassing unit, air is introduced into the tank. For volatile products such as gasoline, the tank vapor is initially rich enough to be above the upper explosive limit (UEL) before degassing. As the tank vapor is diluted with air, it goes through the explosive domain before dropping below the lower explosive limit (LEL).

Because of the danger of explosion, all potential ignition sources should be completely eliminated. The static discharge danger should be avoided by bonding (grounding) all equipment. The danger of flashback

Figure 1. Illustration of Tank Degassing with a Control Device Before Tank Cleaning or During Tank Cleaning



from any control devices should be removed by the use of a properly designed detonation arrester, water seal and/or flame arrester.

In some cases, an inert gas such as nitrogen is used instead of air to eliminate the danger of explosion. Even in such cases, air is introduced as the last step to provide a working environment for a subsequent cleaning or repair operation, when the LEL level is lowered well below 100% so that the explosion hazard no longer exists.

Tank degassing is also used during a refilling operation. As volatile liquid product, such as gasoline, is introduced into a cleaned (empty) tank, it will flash and generate vapor. As additional liquid is pumped into the tank, hydrocarbon vapors in the vapor space will be squeezed out into the atmosphere until the floating roof becomes functional unless these vapors are controlled.

Since gasoline vapors contain many hazardous air pollutants (HAP), degassing during most refilling operations is required by Federal regulations such as NESHAP and

OSHA. At this time, only California enforces degassing during refilling operations, but other states are expected to follow in the near future.

Degassing Methods

Tank degassing can generally be divided into two methods:

- Single step methods
- Multi-step methods

Single-Step Methods

The single-step methods are combustion methods, where the combustion products are directly dispersed into the atmosphere. Widely used combustion devices are:

- Incinerator (thermal oxidizer)
- Catalytic incinerator
- Internal combustion engine
- Flame

Complete combustion in an incinerator requires a certain residence time at high temperatures. Typical thermal oxidizers are designed to hold the combustion mixture for 0.6 seconds at temperatures higher than

1,400°F.

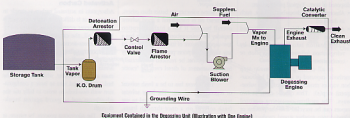
Catalytic incinerators have the advantage of requiring lower temperatures (typically lower than 1,000°F) to effect the same degree of combustion. The lower temperature translates into a lower fuel requirement for combustion. But in the case of degassing, the objective is to maximize the fuel burn rate. Furthermore, the catalyst is subject to poisoning by various contaminants. Therefore, catalytic incinerators are not widely used.

The internal combustion engines have become popular, due to their portability and versatility. We have used specially designed engines enclosed in trailers as the main workhorse of our business. The engines are ordered with special metallurgy for durability and loaded with dynamometers for increased fuel consumption. Suction blowers operate off the crank shaft. The engines are also equipped with controls for easy operation and safety shutdown systems. A process schematic with an engine unit is illustrated in Figure 2.

Engines offer the following advantages over other combustion devices:

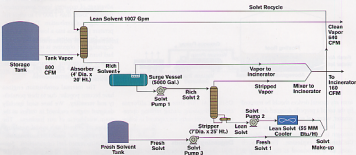
- Little warm-up time
- Easy adjustments to changing loads
- Higher turn-down capabilities without supplemental fuel
- If properly designed, ability to operate down to 60% LEL without supplemental fuel
- Lower emissions than other devices when equipped with exhaust catalytic converters (dual system, one for unburned hydrocarbon and CO and the other for NO_x)

Figure 2. Process Schematic of Degassing with an Engine Unit



Equipment Contained in the Degassing Unit (Illustration with One Engine)

Figure 3. Tank Vapor Control Via Absorption in Solvent
(81% Recovery of Hydrocarbon in Tank Vapor)



- Greater safety than the other devices when enclosed in a trailer.

Flares are the lowest cost option among the combustion devices. One definite drawback of a flare is the lack of assurance that the combustion is virtually complete. The flare tips are designed to effect good mixing for complete combustion, but they have definite limitations under widely varying loads. We often see flameouts and re-lighting of the flares.

Another drawback of the flare is, it is impossible to sample the combustion product to prove the combustion efficiency required by the regulatory agencies.

Multiple-Step Methods

In the multi-step methods, tank vapors are captured in a medium temporarily and then disposed of later. Typical processes are:

- Absorption in hydrocarbon solvent, such as diesel oil
- Adsorption in solids, such as activated carbon
- Condensation into liquid product by refrigeration followed by adsorption or combustion.

In all of the previous multi-step methods, captured or condensed hydrocarbon vapors must be disposed of in subsequent step(s). This can be done in two ways. The medium containing captured vapors can be recycled into the process or blended into another stored product. Or,

the vapors could be liberated from the medium, then disposed of via incineration, condensation, etc. A multi-step process is not a complete degassing method unless it has the recycling or regeneration-disposal steps.

Absorption in Hydrocarbon Solvent

A typical absorption scheme for degassing a 100 ft. dia. tank is shown in Figure 3. It is worth noting that:

- It takes a well designed counter-current contactor (e.g., a 10+ foot packed column)
- A large quantity of solvent (e.g., a circulation rate of 1,000+ gpm, or 600,000+ gallons of total fresh or regenerated solvent) is required to absorb 90% of tank vapor.

Some solvents are better than others. But diesel oil is considered a good solvent overall because it has a high-absorption capacity for hydrocarbon vapors and it has a low-vapor pressure of its own. Therefore, in any vapor absorption process, the quantity of solvent cannot be reduced substantially from the amount of diesel even for "exotic solvents."

The solvent has to be a fresh solvent or regenerated solvent. The huge solvent requirement makes it uneconomical to use fresh solvent on a once through basis, unless the enriched solvent can be mixed

into another stored product or used in a refinery process. With the solvent regeneration scheme, the desorbed vapors would have to be disposed of by combustion or by other suitable means.

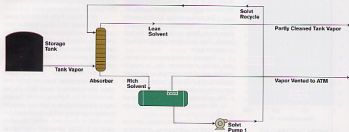
An absorption scheme without solvent regeneration is shown in Figure 4. Sometimes tank vapor is bubbled directly into the surge vessel, bypassing the absorber column. On some other occasions, diesel oil is pumped directly into the tank. The schemes without the absorber column would not provide a 90% absorption efficiency. But without the proper stripping unit and vapor disposal step, the overall vapor control efficiencies of these schemes would still be zero.

Adsorption in Activated Carbon

Adsorption in activated carbon is simple in concept, but is difficult to implement and is almost never economically competitive. First of all, the carbon bed has to have enough cross-sectional area to slow down the vapors traveling through the bed. Generally, a superficial velocity of 20 to 100 ft/min. is recommended to provide as good mass and heat transfer, while not lifting the bed. It is a good idea to have a configuration with two-beds in series to fully use the adsorbents and to guard against breakthrough.

The adsorption process, by nature, is

Figure 4. Tank Vapor Control Via Absorption Without Any Solvent Regeneration
(Enriched Recovery Efficiency: Virtually 94%) (Exception: Bypass System - Rich Solvent Sent to a Process Unit)



similar to absorption or condensation and is exothermic. The amount of heat generated when hydrocarbon vapors are adsorbed on activated carbon is substantial. When the tank vapor concentration is higher than a few thousand parts per million (ppm) in hydrocarbons, the bed will become hot and the adsorption process will become inefficient because of shifting adsorption isotherm. Typical tank vapors contain much higher concentrations of hydrocarbons than a few thousand ppm hydrocarbons. Any attempt to treat such tank vapors with activated carbon could lead to fire and explosion.

Activated carbon beds, however, are

very effective for controlling trace amounts of hazardous air pollutants or odorous vapors. A rule of thumb is to count on using approximately 10 pounds of activated carbon (at one to two dollars per pound) per pound of pollutant for a well-designed system. Once the bed becomes saturated with vapors, it would have to be removed for proper regeneration or disposal. Again, desorbed vapors from the regeneration step would have to be disposed of properly by combustion, etc.

Condensation by Refrigeration

Condensation (Figure 5) is attractive because of product recovery. The degree of

required refrigeration is determined by the vapor pressure of the vapor components themselves. A product such as MTBE is a good candidate because of its high vapor content and high value of recovered product. If tank vapor is in equilibrium with liquid at a 100°F, one can recover up to 75% of MTBE contained in the tank vapor by cooling the vapor stream to a -40°F, as illustrated in Figure 6.

It is uneconomical, if not impossible, to make the condensation process so complete so that the residual vapor stream could be vented to the atmosphere. Therefore, the residual stream is often combusted or sent to a carbon bed. If the residual stream is

Figure 5. Tank Vapor Control Via Condensation Followed by Adsorption

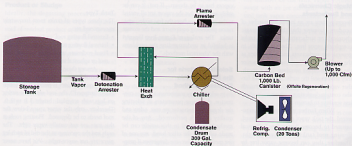
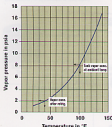


Figure 6. Vapor Pressure of MTBE



combined or treated with carbon (if the residual vapor concentration is less than 2,000 ppm), the refrigeration unit scheme provides the additional advantage of reducing the load on the polishing device by up to 75%.

In case of chilling below 32°F, the formation of ice on the exchanger surfaces poses a serious problem. A deicing solvent, such as glycol, can be sprayed on the exchanger surfaces to control the ice problem.

Because of safety considerations, it is desirable to have the process chiller placed a safe distance away from the refrigeration compressor unit, using glycol or brine as a cooling medium. A cross heat exchanger shown in Figure 5 can save the refrigeration capacity by a factor of two or more.

Magic Chemicals and Surfactants

Recently, there are an increasing number of vendors claiming that they have magic chemicals or surfactants that make tanks completely vapor free. These chemicals, in general, are surfactants and concentrate at the surfaces of the liquid-vapor interface or the liquid-liquid interface. As a result, they tend to seal the surfaces and retard further vaporization. Most of these chemicals also contain denaturants, which make them less sensitive to human noses.

When further vaporization is minimized, the tank vapor space can be vented, agitated to become "vapor-free." Typical floating roof tanks are not vapor-tight. Therefore, they can become vapor free by

natural breathing if given enough time. Enhanced breathing via pumping of liquids in and out of the tank will certainly accelerate dilution of the existing vapor.

The surface sealing action is usually temporary. The surfactants eventually either break down or absorb into the bulk liquids. Then, the trapped vapors will begin to vaporize again.

The tank cleaning process, by nature, uses various surfactants. But, in order to validate any of the chemical or surfactant methods, the following technical points have to be conclusively shown:

- The percentage of tank vapors absorbed by the chemical solution inside of the tank.
- The fate of absorbed vapors that are liberated in subsequent separation processing equipment or holding tanks.

Because of the general rule that solvents that are similar in chemical composition to the vapor are better solvents, none of these chemicals or surfactants is expected to be a significantly better solvent than diesel oil. Then, it becomes obvious that one would need as much chemical as the amount of diesel described previously. Some vendors claim that their chemicals have magic capabilities for encapsulating vapors. It is possible to seal the surface of liquid (and call it encapsulation), but it is not feasible to encapsulate vapors and move the encapsulated vapors to a different location. In other words, the only mechanism for capturing vapors is absorption in the chemical itself.

As with any other multi-step degassing methods, the fate of desorbed vapors has to be shown. If not, it can be safely assumed that the vapors are all vented to the atmosphere from the line tanks, separation processing equipment and the storage tanks. The analogy of Figure 3 vs. Figure 4 is helpful in understanding the problems with the "chemical methods."

Selection Criteria for the Most Suitable Degassing Method

As in selecting any maintenance service contractor, the major parameters in selecting the degassing contractor are cost, safety and quality of work performed. Any of the methods discussed in this article can be made safe. On the other hand, any one of the methods can become dangerous if prop-

er precautions are not exercised. Proper equipment and well-trained personnel are the key to safe operation as in any refinery services.

In addition, there are feasibility and reliability issues. For the control of tank vapors containing trace amounts of hazardous or odorous air pollutants, activated carbon adsorption might be the most reliable and economical method. But the opposite is true for concentrated vapors.

As mentioned before, many degassing operations begin with the tank vapor concentration at above UEL. During the course of the degassing process, the tank vapor concentration is lowered into the explosive envelope and finally lowered further until it drops well below LEL when completed. If the operation is interrupted, the concentration could build up again, due to vaporization from residual product/sludge. So, it is desirable to run the operation around the clock until completion to minimize the time spent within the explosive range. This means proper planning for personnel changes and other supports.

Some tank farms use dikes as the firewall and the roadways. Some of these dikes are not designed to accommodate heavy equipment. One advantage of the engines is their portability and compactness that are important for such situations. We have used the engine units most frequently for reasons of the cost, safety and operational flexibility reasons.

Major Parameters Affecting the Degassing Process

Tank Type

The three types of tanks most frequently encountered are:

- External floating roof
- Internal floating roof
- Fixed enclosure tanks, such as fixed cone roof or spherical tanks.

Among these, the easiest to degas are the external floating roof tanks. By the time all the liquid product is pumped out (often called "stripped"), the roof would be sitting on legs with a typical height 3 ft to 6 ft. Therefore, only the vapor space below the roof needs to be degassed. Floating roofs at this state are not usually vapor-tight. The seals and the openings at the end of each leg piece are not vapor-tight. We have never

experienced the pressure inside of the tank deviating significantly from the atmospheric pressure (i.e., 1 in. of water in pressure or in vacuum) with the external floating roof tanks.

When an external floating roof tank is degassed, air enters various places through the roof. Some air passages tend to short-circuit. Therefore, often an opposite manway is cracked open during the course of degassing to provide a better sweep of the vapor space.

An internal floating roof tank is degassed the same way except two differences:

- An air inlet has to be provided if the outer tank is vapor-tight (e.g., by opening a roof hatch).
- The tank has to be allowed to degas through the internal floating roof longer in order to degas the vapor space above the floating roof.

For a fixed enclosure tank, an opening for air passage is definitely required. Usually a roof hatch is opened at the beginning and then a side manway is opened later during the course of degassing.

Tank Vapor Volume

Obviously, a tank with a larger vapor volume takes longer to degas. In Texas, ENRCC calls for a minimum of a 4% sweep of vapor volume for most tanks.

Tank vapor volume is an important parameter for determining degassing performance, as will be discussed later in this article.

Amount of Residual Product or Sludge

Ideally, the degassing process would be rather simple if the tank were completely void of residual product or sludge. In reality, this is not the case. Only on rare occasions will the tank be virtually free of residual product/sludge. In general, substantial vaporization occurs from residual product/sludge during the course of degassing, continuing to enrich the vapor space and counteracting the degassing effect. Obviously, the more residual product/sludge is present in a tank, the longer it takes to degas a tank, as will be illustrated later.

The vaporization rate from a quiescent pool of liquid into a sweeping gas stream can be estimated from Pasquill's cor-

relation:

Vapor Pressure of Residual Product/Sludge

The initial tank vapor concentration is largely determined by the vapor pressure of the residual product/sludge present in the tank. As the degassing progresses, the additional vaporization from the residual product/sludge is also determined by the vapor pressure. Therefore, when degassing tanks containing high vapor pressure products (e.g., MTBE), it is not possible to reach low tank vapor concentration (e.g., less than 10% LEL) until all the residual product is completely vaporized.

Vapor pressure of hydrocarbon liquids increases with temperature. In general, it doubles with every 30 to 40°F increase in temperature. Because of this reason, it generally takes longer to degas a tank in summer.

Degassing Geometry

The inlet of air or make-up gas has to be at the opposite side of the tank from the degassing point to get an effective sweep without short-circuiting. In some cases, this is not possible and the degassing geometry has to be improvised.

When an external floating roof tank is filled with several feet of sludge, the only available access is the roof. In this case, we usually degas the tank by lowering a degassing hose into the tank vapor space through a roof hatch with the tip placed about one foot above the sludge level. The small annular space between the hatch opening and the degassing hose is sealed with plastic cover and duct tape. Another roof-top hatch or manway at the opposite side is opened for an air inlet for degassing.

Vapor Extraction Rate

There are two limitations on the extraction rate:

- Physical limitation
- Process limitation

The physical limitation is determined by the blower capacity and by the size of the recovery device. The process limitation is determined by how fast vapor can be absorbed, adsorbed or combusted in the recovery device.

When the tank vapor is highly concentrated, the process limitation generally governs the extraction rate. In the case of

an incinerator or the degassing engine, it is the ability of the device to burn so many Btu's worth of fuel (i.e., the Btu rating) that determines the extraction rate. As the tank vapor becomes more dilute and as the Btu contents are lowered, tank vapors can be burned at higher rates until the device's physical limitation is reached.

For example, the physical limitation of Weeco's degassing engine is 400 acfm (per engine). But because of the process limitation, the extraction rates, for many cases, begin at about 100 acfm and increase as the degassing progresses. The same holds true for the absorption, adsorption and refrigeration processes.

DEGASSING MODELS

As discussed previously, the degassing process is rather complex, due to varying geometries, vapor flow patterns and evaporation from residual product, etc. Therefore, it is not realistic to expect that a simple empirical model would describe all degassing processes. However, it is helpful to define certain models, which represent idealized cases. These models provide insight into the degassing process itself. In fact, some degassing data follow the idealized profiles rather closely. But, most degassing processes are weighted combinations of these idealized models, depending on the geometry, amount of residual product, etc.

Some of the idealized models are discussed. In these models, normalized tank vapor concentration is expressed in terms of the number of the tank vapor volumes swept with air (or nitrogen). The normalized tank vapor concentration is the actual concentration of degassed vapor divided by the initial concentration. The initial concentration is sometimes close to the vapor content in equilibrium with product liquid, as determined by vapor pressure. But it is often less than the equilibrium value due to diffusion with air via "breathing."

The Tank Virtually Free of Residual Product/Sludge

Well mixed model. In this case, the tank vapor would be always homogeneous in concentration profile as if it were constantly mixed by dozens of ceiling fans. In this case, the concentration would follow a classical exponential decay pattern shown in

Figure 7. Cons. Profiles for Plug Flow, Well Mixed and By-pass Models

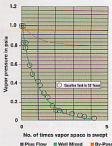
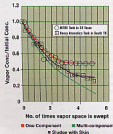


Figure 7. The degassing data of a well stripped gasoline tank closely matches this model as shown in Figure 7.

Plug flow model. In this case, the degassing would occur as if a pipeline were swept with air or nitrogen preceded by a pig (or a plug). The concentration at the degassing point would stay constant until one volume has been swept, at which time it would drop to zero as shown in Figure 7.

In reality, this profile is obtained only in the case of pigging a pipeline and never during degassing of a storage tank.

Figure 8. Degassing Profiles with Large Amounts of Product



Nevertheless, this model is useful in defining the idealized boundary (limit) when attempting to achieve a perfect sweep profile.

By-pass (or short circuit) model. If the degassing point were located right next to the air inlet point, there would be a short circuit and the stagnant portion of the tank vapor space would remain un-degassed. Figure 7 also illustrates such a case.

Any sensible contractor would not knowingly degas with this configuration. Needless to say, we do not have any data representing this case.

A Tank With Residual Product/Sludge

The tank with large amounts of residual product. As one can picture, the residual product/sludge would continue to vaporize as degassing progressed. The concentration of the extracted vapor would decrease until it reached a steady state. Under this condition, the rate of product vapor extraction would equal the vaporization rate.

If the tank contained one component chemical (e.g., benzene), the concentration would stay rather constant once it reached the steady state value until the tank became dry. For a multi-component system such as crude oil or gasoline, the vaporization rate would decrease as the liquid product was stripped of light components and the steady state concentration decreased gradually. In case of vaporization from sludge, the rate of vaporization would be retarded as a diffusion barrier was formed by the "skin" on the sludge surface. These cases are described in Figure 8.

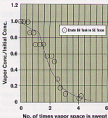
Degassing data for MTBE (with residual product) and crude oil (with a few feet of sludge) are also shown in Figure 8 for illustration of above cases.

The tank with small amounts of residual product/sludge. During the course of degassing, the residual product/sludge would be vaporized off and the tank would become virtually product/sludge free. Then the concentration profile would follow the cases discussed in the previous section. This case is illustrated in Figure 9, together with an actual degassing profile of a gasoline tank.

Application of the Modeling Study

It is interesting to observe that some profiles

Figure 9. Degassing Profile with Small Amounts of Residual Products



generally follow the exponential decay pattern. Some others follow the patterns with large amounts of product/sludge and small amounts of product/sludge. But, most data are complex combinations of the models described previously.

Before we bid a job, we inquire about the tank geometry, tank size, the leg height (for floating roof tanks), product stored, vapor pressure of product, amount of residual product after stripping and the amount of sludge at the tank bottom. But, it is indeed a rare occurrence when all of the above information is available from the client in a timely fashion.

Based on whatever information is supplied by the client, we apply one or more of the models discussed above to arrive at a maximum degassing time estimate. This estimate, together with information from our internal data bank, allows us to make a reasonable bid on most jobs. We have been able to provide rather accurate time and cost estimates for our jobs, of course with a few exceptions.

Summary

This article discusses most of the important regulatory, safety, operational and logistical aspects of storage tank degassing. In addition, various degassing models are discussed in light of actual data. The modeling exercises have been helpful in conducting degassing business. Hopefully, this article provides a touch of science to the art of degassing for planning and evaluating degassing projects. ■