Design for Fire Prevention

"Where Engineering Meets Ingenuity"

Several years I drafted the newsletter below and sent it to over 300 of you to help you understand one of the key fire prevention issues we all face when designing and installing new tank batteries, proper grounding. Since then, a few of you have reported back that paying attention to proper grounding and related lightning protection has worked well, saving your facilities from fire and destruction. This, of course, is very good news. Offsetting this, however, some of you have reported that even though you have spent thousands on grounding and lightning protection with professional firms, you have still lost facilities to lightning and static discharge fires like the one pictured here. As I thought about this in broader terms I realized that I need to share more about the causes of facility fires. This white paper addresses a broader focus on fire prevention … or to paraphrase the famous Paul Harvey, "The Rest of the Story".

THE FIRE TRIANGLE

We are all familiar with the fire triangle. We know that it takes all three sides of the triangle to start and propagate a fire, and that if we remove one of the legs of the triangle we cannot have a fire. This is basic fire knowledge to us all. Yet, as basic as it appears, it is often overlooked when we design and construct oilfield facilities. I believe that if we truly understood the "Fire Triangle", and the chemistry and physics of fire, we could do a much better job of avoiding the circumstances that contribute to so many oilfield fires today.

Therefore, the purpose of this white paper is to broaden our understanding of the fire triangle as it relates to facilities designs and installations.

Let's begin with the subject of natural gas, since this gas often exists in a vapor layer above the liquids in the storage tanks in any oilfield facility. For natural gas to ignite and burn it must be in an environment where all three legs of the fire triangle can be satisfied … but there is more! All hydrocarbons can ignite and burn, but ONLY if the mixture of hydrocarbon and air is in the right proportion. For methane (pure natural gas) the mixture must be between 5% and 15% in air. We call this the "flammability limits" of methane. If we Google "Flammability Limits" we find that it is defined as the points where …"Above the ***upper flammable limit*** *(UFL) the mixture of the hydrocarbon substance and air is too rich in fuel (deficient in oxygen) to burn. This is sometimes called the* ***upper explosive limit*** *(UEL). Below the* ***lower flammable limit***

(LFL) the mixture of hydrocarbon substance and air lacks sufficient fuel (substance) to burn. This is called the **lower explosive limit** *(LEL)." Simply stated, methane can't burn if its concentration is below 5% or above 15% in air.*

The flammability limits of every hydrocarbon are different. For instance, acetylene (used in gas welding) has a lower limit of 2.5% and an upper limit of 100% … a very broad range. It burns in almost all concentrations with air. On the other end of the spectrum we find that Kerosene (Jet Fuel A-1) has a lower flammability limit of 0.6% and an upper limit of only 5% … a very narrow range! It's easy to burn hydrocarbons with a broad range, but much more difficult to get those with a narrow range to even ignite because the mixture concentrations have to be just right, and there's not much room for deviation.

In our real-world oilfield applications we deal with dilutions of methane. Our natural gas is a mixture of methane and other hydrocarbons, typified as follows:

Component	***Typical Analysis (mole-%)***	***Range (mole-%)***
Methane	*95.0*	*87.0 - 97.0*
Ethane	*3.2*	*1.5 - 7.0*
Propane	*0.2*	*0.1 - 1.5*
iso - Butane	*0.03*	*0.01 - 0.3*
normal - Butane	*0.03*	*0.01 - 0.3*
iso - Pentane	*0.01*	*trace - 0.04*
normal - Pentane	*0.01*	*trace - 0.04*
Hexanes plus	*0.01*	*trace - 0.06*
Nitrogen	*1.0*	*0.2 - 5.5*
Carbon Dioxide	*0.5*	*0.1 - 1.0*
Oxygen	*0.02*	*0.01 - 0.1*
Hydrogen	*trace*	*trace - 0.02*

Flammable ranges for each of these are

Component	***Flammable Limits***
Methane	*5.0-15.0%*
Ethane	*3.0-12.4%*
Propane	*2.1-9.5%*
iso - Butane	*1.8-9.6%*
normal - Butane	*1.8-8.4%*
normal - Pentane	*1.4-7.8*
Hexanes	*1.1-6.7*
Hydrogen	*4.0-75.0%*

We can see from these values that most of our natural gas has a rather narrow flammable range: in aggregate between about 3% and 15% hydrocarbons in air!. In the simplest of terms this means that if we keep the most of the surrounding air out of our tanks we stand a good chance of avoiding fires from any source.

So, the question is, "How do we keep the air out of our tanks?"

The answers have their roots in the conditions we can control and the type of tank battery we're designing or building. The conditions are few, as described next, while the type of facility can make all the difference. Therefore, let's look at each one separately.

CONTROLLABLE CONDITIONS

There are three legs to the fire triangle and there are also three legs of con triangle we should apply. They are:

1. *Keep the thief hatches closed.*
    a. *Keeping the air out.*
2. *Get the facility properly grounded.*
    a. *Call an expert like "Lightning Master".*
3. *Design the vent system to include flame/detonation arrestors.*
    a. *Keep the ignition source away from potentially flammable vapors.*

DESIGNING PRODUCTION TANK BATTERIES FOR FIRE PREVENTION

In the typical production tank farm the separators and heater treaters typically separate all vapor phase natural gas and move it into a sales gas system under pressure. They feed liquids to several oil tanks, and to one or more water tanks. Both oil and water contain "solution gas", and that gas tends to evolve from solution as the liquids are de-pressured into atmospheric storage tanks. When the sun heats the tanks the evolution accelerates. The evolving natural gas concentrates in a hydrocarbon vapor layer above the liquids. And, since hydrocarbons are typically heavier than air the evolving gases displace the air out of the tanks … usually within a day or two after being put in service. This means that the vapors in the tanks may be in the flammable range upon commissioning a new facility, but only for the first few days. After that, the chances of a flammable mixture of gas and air are unlikely … that is, until we pump a tank full of liquids out!

When we sell a tank of oil, or pump water out of a water tank, the vent valves and thief hatches open to prevent a strong vacuum inside the tanks as the liquids are pumped out. When the vent valves or thief hatches open, the tanks receive an influx of air. As the air concentration reaches the LEL (lower explosive limit) the tank vapors enter the flammable range where they can burn, given an ignition source. As more and more air enters the tank the mixture reaches the UEL (upper explosive limit) and the mixture no longer burns. Then, as the tank is refilled with oil, the evolving gas displaces the air, and the mixture once again enters the UEL explosive range, passes through the explosive range from high to low, and finally becomes lean enough to exit the flammable range where it is below the LEL. This process will take a day or two, so the tank is in the danger zone during that time.

There are a few practical things we can do about this as we design and build our tank batteries.

1. *We can "blanket" the vapor phase of all tanks with our produced natural gas. This keeps all air out and maintains the vapor phase in a concentration well above the UEL where it is not flammable. To do this we typically run a common vent line, installing a flame and detonation arrestor at the vent end of the manifold, and exit the gas to atmosphere through a pressure-vacuum vent valve. A small back pressure regulator allows the produced gas to enter the tank vapor line whenever the tank pressure falls close to atmospheric pressure (i.e. 0.25 ounces). The quantity of natural gas it takes to provide this safety level is minimal, making it a very cost effective solution.*
2. *We can tie all oil tanks together with a common vent line, and keep one tank normally empty as the emergency storage tank. Once the battery is commissioned the vapors stored in that empty tank will be sufficient to refill any other single tank when oil is being sold from it, excluding the entry of air into the oil tanks. While not foolproof, this is a step in the right direction.*
3. *We can separate the vapor spaces in our oil tanks from the vapor spaces in our water tanks. In the design of many tank batteries designer overflow oil from the water tank(s) back into the oil tanks to make sure they capture all produced oil carried over with the water. Since this can be 0.2-1% of the produced oil volume, this practice is clearly advisable from an oil sales perspective. However, once the water tanks and the oil tanks are equalized via the overflow line, the vapor spaces in all tanks are also equalized, allowing the free flow of vapors between them. If the tanks are gas blanketed through a common vent line this is not an issue, but if they are not then potentially lean vapors containing air can flow into the normally rich vapors in the oil tanks, diluting them into the explosive range between the LEL and UEL. This is not good, and since it can be a perpetual situation, it puts all tanks in jeopardy nearly all the time!*
    a. *To resolve this we can install downcomers in the oil tanks. A downcomer is a pipe from the normal oil inlet in the deck (roof) of an oil tank extended down to below the one-foot level near the tank bottom. Once the tank is filled with oil, its level will not be below the pipeline connection level at the one-foot level, so the bottom of the downcomer will always be below the oil, sealing it from the flow of any/all vapors.*
        i. *It should be carefully noted that it is common oilfield practice to install downcomers in oil tanks, AND to drill an equalizer hole in them near the top of the tank to prevent siphoning. In this case, the equalizer hole should NOT be drilled, as it would allow the vapors to equalize, defeating the purpose altogether!*

There is a school of thought that says all tanks should be vented individually to atmosphere. This way, if one tank catches fire the fire will not spread from tank to tank through a common vent line. This logic is irrefutable. However, it can create process issues! When all tanks are vented separately they may not operate at the same pressure. This is not an issue if the feed to them is from a pressure vessel operated under pressure, but when the flow is from an atmospheric tank like a Gunbarrel, for instance, a few ounces of pressure difference can spell process serious inconsistencies.

A classic example of this is the design where FRP water tanks are used for water storage and steel tanks are used for oil storage. API 12P FRP tanks are normally fabricated for a maximum of 4 ounces, and are therefore fitted with 4 ounce thief hatches. API 12F steel tanks are normally fabricated for 8 or 16 ounces and are fitted with equivalent thief hatches. If a Gunbarrel tank is tasked with separating oil and water which then overflows into FRP water tanks and steel oil tanks, it may be unable to do so in that the receiving tanks are at different working pressures. For instance, if the Gunbarrel were fabricated from FRP, it would operate at a maximum of 4 ounces pressure, but the oil tanks could be pressured up to 16 ounces. If they we fitted with downcomers, sealing the vapor space, the oil would not flow to the oil tanks, but would instead attempt to overflow the Gunbarrel. The results would be that the oil would backflow through the Gunbarrel water leg gas equalizer, sending oil to the water tank! While this would not affect the fire hazard condition, it would certainly affect the expected performance of the new tank battery and reflect poorly on the designer!

RECOMMENDATIONS

Proper grounding is a must, but fire prevention doesn't end there. I recommend that all operators be trained to keep all thief hatches closed. This training should be repeated monthly and at every safety meeting to drive it home, since leaving thief hatches open is all too commonplace. Then, as we design and install tank batteries we need to pay attention to the vent line designs, the use of flame or detonation arrestors, the use of pressure vacuum vent valves, and finally, downcomers.

HERE IS A REPEAT OF OUR 2010 LIGHTNING NEWSLETTER

"Lightning Strikes Destroy Oilfield Surface Facilities"

Lightning strikes destroy millions of dollars' worth of oilfield surface facilities each year. Most are avoidable!

And yet few of us understand why this happens or what to do about it. The fact is that lightning related oilfield fires are common to both steel tanks and fiberglass tanks, though many in the industry believe this is a phenomenon linked mostly or only to facilities with fiberglass tanks. This is not the case, as the article explains.

Static/Lightning Protection for Tanks
By Alan Roachell, Rosewood Resources Inc. and Bruce Kaiser, Lightning Master Corp.
May/June 2010

Lightning may be the cause of some incidents, but it is not the likely culprit in most cases. It is unlikely that lightning attachment caused burn-through or heating ignition of vapor in these tanks. Therefore, the most likely cause is static discharge. The source of static may be the result of normal operations such as filling or draining, or it may be secondary effect from a direct or nearby lightning strike. Secondary effect arcing is also static discharge, albeit high *energy and occurring over a short time frame. This arcing is produced by the inrush of ambient ground charge toward the point of a lightning strike. The inrushing charge can arc across gaps in its path, thus providing both a static charge and a static discharge. Therefore, the ideal protection system would address both causes.*

Probability versus consequences

The probability of this type of incident is unpredictable. It could be years between incidents or years without incidents, followed by a single or series of catastrophic events. The consequences of this type of incident include lost production, the cost of replacement, the damaged facility, environmental impact and clean up, and bad press, especially if the subject tanks are located in a populated area or a local fire company responds.

Conditions leading to ignition

According to API 2003, A.7, in order for an electrostatic charge to become an ignition source, four conditions must be met:

1. *A static charge must be generated*
2. *The charge must be accumulated to the level at which it is capable of producing a incendive spark (A.6.2), that is, a spark with adequate energy to ignite*
3. *An appropriate gap across which the accumulated charge may arc (source of ignition)*
4. *An ignitable gas mixture must be present around the source of ignition*

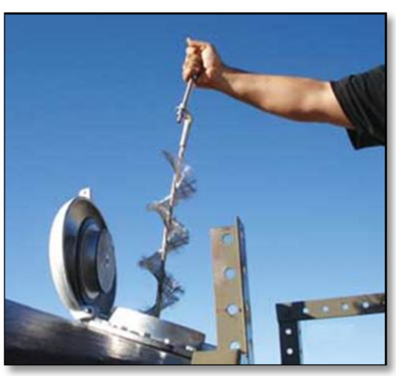
Sources of static charge (rub two molecules together)

The primary source of static charge appears to be turbulence from mixing fluids either from through pumping, particularly through non-metallic pipe, or from filling, especially splash filling with the falling fluid penetrating standing fluid. Air/foam injection to increase flow rates may also be a primary source.

A secondary source may be bubbling of the air/gas mixture. This leads to a suspicion that the boundary layer between the liquid and gas may play an expanded role in this problem. There are also miscellaneous sources such as clothing on people. This factor is humidity sensitive similar to touching a doorknob on a dry day and the charge does not usually build to the level where it becomes incendive.

Accumulation of static charge

Charges dissipate from a fluid into points and sharp edges, not flat surfaces. That is why a charge does not readily dissipate into the shell of a metal tank — it is flat. This allows the charge to accumulate at a rate faster than it dissipates. The presence of a carbon veil in a fiberglass tank does not accelerate charge dissipation. It still presents a flat surface to the bound charge on the liquid. An epoxy-lined steel tank is similar to a fiberglass tank regarding static charge dissipation.



Because the static charge eventually relaxes, an incendive spark is most likely while the charging mechanism is active.

Source of ignition (sparking)

When the static charge exceeds the dielectric of the intervening medium, the medium breaks down, and a potential equalizing arc occurs. The arc may occur between masses of inductance such as piping, fittings, the thief hatch and its collar (if it's loose enough to rattle, it's loose enough to arc), electronic sensors on the tank, and vacuum trucks, or between the bound charge on the stored protect and any of the above.

Ignitable mixture

The likely source of gas is the "Coca Cola" effect. Gas is suspended in the fluid underground. When it reaches the wellhead, the reduction in pressure allows the gas to escape much like carbon dioxide escapes from Coca Cola when you first open the can. The turbulence involved with further handing allows more gas to escape, much like drinking Coke through a straw, then blowing it back into the can and drawing it out again. Splash filling, while helping to accelerate molecular breakdown and speeding the separation process, also allows additional gas to escape.

Air/foam injection to increase flow rates also generates gas.

To allow combustion, oxygen must be available in sufficient concentration. Oxygen may enter the tank from atmospheric vents or from a thief hatch left open. Oxygen may be introduced to prevent a vacuum in the tank during the process of emptying. Therefore, the conditions for combustion may be high just after a tank is emptied, as static has been generated by the flowing liquids and oxygen that have been introduced into the system.

Lightning caused ignition

Ignition due to lightning is caused by the ground charge induced by the cloud base charge on the surface of the earth beneath the storm. The storm cloud generates charges within the storm cloud, and a charge on the base of the cloud. This charge induces an opposite charge on the surface of the earth beneath it. The attraction of opposite charges attempts to pull this ground charge off the surface of the earth, so it is dragged along the surface of the earth beneath the cloud. When lightning strikes the surface of the earth, it relatively vacates the ground charge at the point of the strike. The surrounding area remains highly charged, so the remaining ground charge flows toward the point of the strike. If this inrush of charge crosses a gap, it may arc. This all happens very quickly, with the storm cloud providing the source of the charge and a sufficient accumulation of charge to form an incendive spark. The tank structure and appurtenances provide the source of ignition and the ignitable mixture.

Solutions

The most common lightning fix is a catenary (overhead wire) system. This system consists of grounded masts or poles supporting a wire or wires over the site. Based upon the above description of the problem, this system is far from ideal. The catenary wire is intended to "get in the way of" a lightning strike and convey it to ground. When used to protect tanks and similar structures this system cannot mitigate secondary effect arcing — the primary cause of ignition. In fact, if a catenary performs exactly as designed, it brings the lightning energy to ground near the base of the tank, thereby maximizing the likelihood of secondary effect arcing across the tank

and appurtenances. The catenary system has no effect on the bound charge on the stored product, does not provide bonding to miscellaneous masses of inductance on the tank, and does not affect the likelihood of a direct strike by influencing streamer formation.
Other solutions to control the conditions necessary for an electrostatic charge to become an ignition source have been tried, but none have proven totally adequate.

New approach

The wild card in tank protection has always been equalizing the bound charge on the stored product. Charge dissipates from a liquid onto points and edges. In a steel tank there are no points and edges to help dissipate the bound charge on the stored product. The liquid simply lies against the side of the tank and the charge must inductively couple onto the flat surface. It takes time for the potential to relax, allowing the static charge to accumulate faster than it dissipates.

A remedy for this condition on a steel tank is an in-tank static drain consisting of a stainless steel cable with stainless steel electrodes inserted into the wind of the cable. This type of drain, installed through the thief hatch and secured to the top of the tank, introduces thousands of electrically sharp points into the stored product, offering a low-resistance path for bound charge to leave the liquid and vapor space. It "sucks the charge" out of the product, allowing it to relax much more quickly. This allows the charge to dissipate faster than it accumulates. On a steel tank, the only additional bonding required is a jumper between the thief hatch and collar.

A solution for fiberglass tank protection is to install a conductor system that bonds the top vent pipe or manifold, the in-tank static drain, thief hatch collar, walkway handrail system, and tank conductive elements such as a carbon veil and the drain pipe, at the base of the tank.

The bonded mass of the tank system is then electrically bonded (grounded) through existing electrically continuous metallic piping or with dedicated conductors on non-conductive piping to the injection well, truck load-out, and site electrical service ground. This brings all site components and structures to the same potential and to ground potential, thus reducing the possibility of arcing. Truck drivers should be trained to bond their trucks to the site bonding system without exception. The truck bonding system may consist of a retractable reel grounding wire, or may be as simple as a flexible cable with a spring pressure clamp attached to its end. In either case, provide a means of strain relief to compensate for the driver who drives away with the grounding clip still attached to the truck.

Conclusion

In controlling the problem, it is generally only possible to mitigate — not eliminate — the production of a static charge and the creation of a flammable mixture. So consider implementing a system for steel and fiberglass tanks that dissipates the charge, bonds all the masses of inductance, and includes air terminals. It certainly will enhance the safety of employees, contractors and the public.

ABOUT THE AUTHORS: *Alan Roachell is currently the HSE director for both Rosewood Resources and Advanced Drilling Technologies (ADT). He received his Bachelor of Science degree in occupational safety and health from Columbia Southern University and is accredited as a board certified safety professional.*

Roachell is an innovative leader in the HSE arena and has been recognized for his work on many occasions. He has contributed to the safety profession on many topics and feels his most important work is researching and developing ways to create cultures where safety is a core value and a tool to achieving economic success.

Bruce A. Kaiser is founder and president of Lightning Master Corporation, Clearwater, Florida. He is the author of numerous trade publication articles on lightning and static protection for industrial facilities. He holds the patent on static dissipation technology and is a principal member of NFPA 780 Committee on Lightning Protection; and API 545, Lightning Protection for Hydrocarbon Storage Tanks.

ABOUT BREAKTHROUGH ENGENUITY'S OWNER/INVENTOR

Bill Ball is the founder and owner of Breakthrough Engenuity LLC. He has a distinguished history of oilfield separation system designs, and a comprehensive list of related patents. Bill's hands-on oilfield experience and career portfolio make him one of the industry's leading separation authorities today. After his university studies he launched his career in a 1,000,000 b/d waterflood operation where he was responsible for the evaluation and performance improvement of all surface facilities. He sent most of his work days crawling through the process equipment of the day, making improvements wherever possible.

This hands-on experience was the foundation Bill needed to improve, develop, and advance the technologies necessary to improve process equipment efficiencies across the board. In the early years Bill learned what works, and what doesn't! In the decades since his accumulated separation knowledge and experience led to his many patents, each of which speaks for itself.

The result is a unique approach; one where, "Engineering meets ingenuity!"

Bill's efforts continue to innovate improvements like the patent pending combination free water knockout- heater treater in one vessel. It's called "KOTREAT®". Each new KOTREAT® eliminates the time and expense of installing two separate vessels. And, through the use of highly efficient internals, KOTREAT® is a game changer when it comes to performance.
Another example of ingenious innovation is the MorOil™ system. MorOil™ is a patent pending system designed to condense the valuable C4+ hydrocarbon liquids from produced natural gas streams to generate a new producer stream of cash flow in the form of saleable, highly valued NGLs.

These are just a few of Breakthrough Engenuity's unique contributions.

Today, Breakthrough Engenuity is one of the industry's leading low-cost engineering and design firms. We specialize developing designs for the industry's most efficient high and low pressure, two and three-phase heated and unheated separators, as well as providing general engineering services geared to specialty subjects like:

- *Natural gas handling to optimize income and liquids recovery.*
- *Proper line sizing to avoid turbulence, erosion-corrosion, and mixing energies.*
- *Specialty vessel internals designed to maximize separation performance.*
- *The application optimization of oilfield chemicals geared to reduce cost and improve performance.*
- *3D modelling to avoid costly facility installation delays.*

Now, more than ever, Breakthrough Engenuity can be found in every sector of the oil and gas industry, adding cash flow to operators and efficiency to their operations. We're a full service engineering firm. We pledge to meet and exceed every client expectation.

CONTACT US

If all else fails, or if you just have a question, don't hesitate to call Bill Ball at Breakthrough Engenuity for assistance. You can reach Bill at the office at 918-298-6841, or on his cell phone at 918-231-9698.