TANK BATTERY FIRE PREVENTION

A focus on Eliminating Oilfield Tank Fires

Innovation has been slow in the oil and gas industry. A key reason is the paradigm "Because we've always done it that way." Together, we can change that!

A Technical Paper

Prepared for

Facility Engineers and Designers

KBK Industries
Houston, Texas

Authors:
Steven White, CEO
Bill Ball, Staff Consultant

EXECUTIVE SUMMARY

The oil industry is full of hazards. Of those, few are more devastating than an oilfield fire. The bad news is that each year the upstream oil sector experiences between twenty-five and fifty fires like the one pictured here, fires that destroy millions of dollars' worth of tanks and related facilities, and sadly also may take a life. The good news is that fires like this are avoidable.

The key to avoiding a fire is a good understanding of fire itself. This paper attempts to broaden that understanding. It explains the reasons a fire starts, and the steps we can take to prevent a fire in the first place. It sheds light on common oilfield practices that have led to fires in the past and explains how to avoid them in the future. The goal here is to prevent fires and save lives. To do this it starts with the basics … the "fire triangle".

THE FIRE TRIANGLE

We should all be familiar with the "Fire Triangle" pictured here. If we are, we know that it takes all three sides of the triangle to start and propagate a fire. If we understand that by simply removing or eliminating any one leg of the fire triangle, the fire can no longer exist, we will have discovered the key to fire prevention.

While this is the most basic of all fire knowledge, as basic as it appears, it is too easy to overlook it during the design and construction phases of oilfield facilities. The fact is that if we truly understood 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. So, let's focus there first.

Let's begin with the subject of natural gas. Typically, this gas often exists in a vapor layer above the liquids in the storage tanks in oilfield facilities. For natural gas to ignite and burn it must be in a condition where all three legs of the fire triangle are satisfied.

The only condition that allows hydrocarbons to ignite and burn in the first place is when the mixture of hydrocarbons and air is in the right proportion. For methane (pure natural gas) the mixture must be between 5% and 15% hydrocarbons in the air. This span between five and fifteen percent methane in air is referred to as 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** (UEL) the mixture of the hydrocarbon substance and air is too rich in fuel and too deficient in oxygen to burn.

This range is above the **upper explosive limit** (UEL).

Below the **lower flammable limit** (LEL) the mixture of hydrocarbon substance and air lacks sufficient fuel (methane) to burn. This range is below the **lower explosive limit** (LEL)."

Simply stated, <u>methane can't burn</u> if its concentration is below 5% or above 15% in air.

The flammability limits of every hydrocarbon vary. For instance, acetylene (used in gas welding) has a lower explosive limit of just 2.5% and an upper limit of 100% … a <u>very broad</u> range compared to methane! This means that acetylene burns in almost all concentrations with air. Another common fuel is kerosene. Kerosene (Jet Fuel A-1) has a lower flammability limit of 0.6% and an upper limit of only 5% … a <u>very narrow</u> 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 must 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:

Typical Analysis (mole %)

Components

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%

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From these values it is clear that blends of natural gas have a narrow flammable range: about 3% and 15% hydrocarbons in air. This range varies slightly as composition changes. Nevertheless, it means that if we can keep air from mixing with produced natural gas there is a very good chance of avoiding fires from any source, even lightening!

The problem is, however, that operators and contractors frequently open tank thief hatches, allowing air to enter and mix with the natural gas inside.

So, "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 are designing or building. The type of facility can make all the difference, but the fire triangle is the key.

CONTROLLABLE CONDITIONS

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

1. Fuel.
    a. This is methane gas in oilfield operations.
2. Keep all the air (oxygen) out of storage tanks.
    a. Keep the thief hatches closed.
    b. Equalize the vapors space of all tanks to keep the vapors above the upper explosive limit (UEL of methane in air is 15%).
3. Eliminate all ignition sources.
    a. Design the vent system to include flame/detonation arrestors.
    b. Keep the ignition source away from potentially flammable vapors.

And in oilfield operations, proper grounding is key to fire prevention.
    c. Get the facility properly grounded.
    d. Call in an expert like grounding contractor.

CAUSE AND EFFECT

In the typical production tank battery production separators and heater treaters separate most of the vapor phase natural gas and move most of it into a sales gas system or flare under pressure. All liquids move into tanks. Both oil and water also contain "solution gas" (gas dissolved in the liquid), and that gas tends to evolve slowly as the liquids are de-pressured to near atmospheric pressure.
At night, the gas evolves slowly, but during the day the sun heats the tanks accelerating gas evolution. The evolving natural gas concentrates in a hydrocarbon vapor layer above the liquids in storage tanks. And, since natural gas is heavier than air, the evolving gases accumulate on top of the liquid and displace the air out of the tanks. This begins to happen the instant these tanks are placed in service.

Initially, tanks are filled with air. Then, as they are commissioned, they fill with oil, water, and natural gas. The vapors are likely to be in the flammable range soon after commissioning, but as they fill the liquids and heavier vapor phase hydrocarbons displace the air. After that, the chances of a flammable mixture of gas and air are unlikely … that is, until we empty a tank.

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 vacuum inside the tanks as the liquids are pumped out. When the vent valves or thief hatches open, air flows into the tanks. As the air concentration reaches the 3-5% LEL (lower explosive limit), the tank vapors enter the flammable range. This is the danger point where tank vapors are flammable and can burn. All they need is an ignition source.

As more and more air enters the tank the mixture reaches the 15% UEL (upper explosive limit) where the mixture is no longer flammable.

However, as the tank is refilled with oil or water, the liquid and evolving natural gas in it displaces the air. The air-gas ration changes, and the mixture drops below the UEL entering the explosive range. Eventually it may become lean enough to fall below the LEL, exiting the flammable range again. During this transition, the tank is in danger if it is exposed to any ignition source.

Ignition sources can be as simple as a static electric discharge, or as dramatic as lightning.

PRACTICAL SOLUTIONS

There are a few practical solutions.

1. We can "blanket" the vapor phase of all tanks with a side stream of produced natural gas. The gas keeps all air out and always maintains the vapor phase in a concentration well above the UEL so it is not in the flammable range.
    a. To do this we add a common new gas manifold, installing a detonation arrestor at the start of the manifold, and controlling its pressure using a back pressure regulator. Each tank is fitted with a pressure-vacuum vent valve. Whenever a tank pressure falls near atmospheric pressure (i.e. 0.25 ounces), the regulator opens refilling the tank vapor space with natural gas.
        i. The quantity of natural gas it takes to provide this safety level is minimal, making it a very cost-effective solution.
2. We can interconnect the vapor space of all tanks together with a common gas line. Once the battery is commissioned the vapors from the VRT will be sufficient to keep the vapor space above the UEL, even when oil is being sold.
    a. This excludes the entry of air into all tanks.
3. We can separate the oil tanks from the water tanks. In such a design oil tanks are clustered and equalized with a common gas line. Water tanks are isolated and clustered. Many designers use KBK's HWSB® oil skim tank to capture all oil from produced water, flowing oil back into the oil tanks. This is so simple and efficient it has become a standard of the industry because it.
    a. However, since the oil and water tanks are now separated, the

oil feed from the skim tanks to the oil tanks needs to terminate in a downcomer pipe installed in the oil tanks.

   i. This precludes the mixing of vapors in the vapor spaces of all oil and water tanks.

      1. A downcomer pipe is a pipe extending from the normal oil inlet connection in the roof of an oil tank to 12" from the bottom of the oil tank receiving oil from a HWSB®.

b. This is very important since once the water tanks and the oil tanks are equalized via the oil overflow line from a HWSB® (or any other type of oil skim tank), the vapor spaces in all tanks will be equalized, allowing the free flow of vapors between them.

   i. If all the tanks are gas blanketed through a common vent line this is not an issue

   ii. If all the tanks are not blanketed potentially lean vapors containing air can flow into the normally rich vapors, diluting them into the explosive range.

      1. This is not good, and since it can be a perpetual situation, placing all tanks in jeopardy nearly all the time!

c. Installing downcomers in the oil tanks is a key solution. 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 liquid level will never be below the pipeline connection level, which is above the bottom of the downcomer pipe. This means the downcomer is always below the lowest oil level, sealing it from the flow of any/all vapors.

   i. It should be noted that it is common oilfield practice to install downcomers in oil tanks. Downcomers normally have a gas equalizer hole in them near their top, inside the tank. This is done to prevent siphoning oil out of oil tanks to avoid oil theft.

1. In this case, **the equalizer hole should NOT be drilled**, as it would allow the vapors to equalize, defeating fire prevention altogether!

In the past many tank batteries have been constructed with each tank vented individually and separately to the atmosphere. The logic here is that if one tank catches fire the fire will not spread from tank to tank through a common gas vent line.

This logic is irrefutable, but flawed.

Separate gas venting can create serious process issues! When all tanks are vented separately each is likely to have a different liquid level. This means that no two tanks have the same liquid levels or 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 into tanks of differing liquid levels is from an atmospheric tank like a desanding tank, gunbarrel, or HWSB® skim tank, the pressure difference will result in serious flow and process inconsistencies.

EXAMPLE

1. A classic example of this is a design when fiberglass 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.
2. The design pressure difference can be a problem.
    a. If a gunbarrel or HWSB® skim tank is tasked with separating oil and water, with water overflowing into FRP water tanks and oil into steel oil tanks, liquids flow may be restricted in receiving tanks that are of different liquid levels.
        i. For instance, when a gunbarrel or HWSB® skim tank is operated at 4 ounces pressure and steel oil tanks are

operated at 16 ounces, the pressure in the first tanks is too low to move the oil to the oil tanks. This would cause the gunbarrel or HWSB® to overflow oil, creating a serious fire hazard.

RECOMMENDATIONS FOR FIRE PREVENTION

Proper tank and facilities grounding is a must, but fire prevention doesn't end there. All operators should 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 very commonplace.

Additionally, as we design and install tank batteries, we need to pay attention to the gas vent line designs, the proper application of flame and/or detonation arrestors, the correct use of pressure vacuum vent valves, and finally, oil tank downcomers.

"Lightning Strikes Destroy Oilfield Surface Facilities"

The following is a repeat of a 2010 Lightning Master newsletter.

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 following article from ***Lightning Master*** explains.

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"Static/Lightning Protection for Tanks"

The following articles was authored by Alan Roachell, Rosewood Resources Inc. and Bruce Kaiser, Lightning Master Corp. in 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. The 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 in a populated area or a local fire company responds.

Conditions Leading to Ignition

According to API 2003, A.7, 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 can produce an incendive spark (A.6.2), that is, a spark with adequate energy to ignite.*
3. *The charge must be accumulated to the level at which it can produce an incendive spark (A.6.2), that is, a spark with adequate energy to ignite.*
4. *An appropriate gap across which the accumulated charge may arc (source of ignition).*
5. *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 which increases flow rates may also be an ignition source.

A secondary ignition 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 static on clothing. This factor is humidity sensitive like touching a doorknob on a dry day, though 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 like 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.

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 produced fluid underground. When it reaches the surface, 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 handling 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 the liquids.

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 drainpipe, 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.

Conclusions

Managing fire safety in oil field facilities is a complex issue. In facilities where produced natural gas is abundant, the use of common gas manifolds on all atmospheric storage tanks helps to maintain tank vapors above the upper explosive limit, mitigating fire and explosions even in the presence of lightning or other ignition sources.

In facilities where produced natural gas is not abundant, as is the case in most salt water disposal (SWD) plants, manifolding the vapor spaces of oil and water tanks separately and the use of downcomer pipes in oil tanks can also minimize the likelihood of tank vapors entering the flammable range. These efforts can maintain tank vapors above or below the flammable range of tank vapors, and in doing so, making it possible to mitigate the likelihood of fires and explosions, even in the presence of a static charge or any other ignition source.

And finally, when produced gas can exist in the flammable range for any reason or in any tank battery design, the use of proper and thorough grounding techniques minimizes the likelihood of gas ignition and fire.

Contributors to this Paper

This paper was created using contributions from key industry fire safety experts Alan Roachell and Bruce Kaiser.

Alan Roachell served as HSE director for both Rosewood Resources and Advanced Drilling Technologies (ADT). He is accredited as a board-certified safety professional. Roachell is an innovative leader in the HSE arena. His most important work has been researching and developing ways to create cultures where safety is the core value for achieving economic success.

Bruce A. Kaiser founded and served as CEO of Lightning Master Corporation. He authored articles on lightning and static protection for industrial facilities and holds the patent on static dissipation technology. Mr. Kaiser served as a member of NFPA 780 Committee on Lightning Protection, and Lightning Protection for Hydrocarbon Storage Tanks (API 545).

ABOUT THE AUTHORS

Steven White is CEO of KBK with over 25 years of oilfield and equipment manufacturing experience. Steven resides in Houston, Texas.

Bill Ball is a senior staff consultant to KBK Industries with over 50 years of oilfield engineering experience and holder of twenty-three oil and gas industry related US patents. Bill resides in Bixby, a suburb of Tulsa, Oklahoma.

CONTACT

Please contact Steven White at 832-405-3742.