Subject	:	Effective Fire Extinguishment in Settlers & Tanks in SX
Prepared by	:	Frank Rizzuto
Prepared for	:	ALTA 2016
Contact	:	**PROTECT GROUP** Email: frank.rizzuto@protecengineering.ca Tel: (+34) 666 418 007 (Europe) (+1) 604-720-0001 (North America)

ABSTRACT

The need for improved fire prevention and protection is strongly supported by historical fire losses in Solvent Extraction (SX) plants in hydrometallurgy, particularly in the mixer-settlers and tank farms associated with the SX process. History has shown that minimal code compliance is not usually enough to prevent fires from occurring or to control and minimize losses caused by fire in these facilities. This document focuses primarily on what happens inside settlers and tanks containing organic (kerosene based) when fire occurs therein or spreads to these vessels from outside, and how to respond to the event and reduce the loss. Its overall purpose is to provide an updated guideline for the protection of settlers and tanks.

Disclaimer

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1.0 GENERAL

This document focuses primarily on what happens inside settlers and tanks containing organic (kerosene based) when fire occurs therein or spreads to these vessels from outside, and how to respond to the event and reduce the loss.

This introductory Section outlines the principles and procedures to be observed in the design of a safer SX plant. The following sections focus on effective methodology for extinguishing fire in settlers and tanks in the SX environment.

1.1 Safety in Design – Principles of Fire Prevention & Protection

The classical and common approach to fire (loss) prevention in the hydrometallurgical industry has been to accept a hazard and to protect against it. This approach usually requires expensive and sophisticated add-on protection systems that are subject to failure during the life of the facility. Poorly designed or inappropriate fire protection systems are next to worthless. Cost-driven fire protection upgrades often end in a major asset loss.

The design, operation and maintenance of an inherently safer facility goes beyond hazard-centric thinking. An inherently safer facility has eliminated or reduced the hazard to where protection systems may not be needed or can be significantly reduced, saving initial capital cost investment, lifetime maintenance and testing, and potential loss costs should these systems fail. This approach, coupled with a rigorous process safety management programme can virtually eliminate the risk of fire in the facility.

Think of the SX Plant as a modern aircraft in flight. Inherently safe design coupled with mandatory scheduled maintenance and zero error tolerance, as well as control systems that compensate and correct for human element deviations, reduce failure to theoretical zero. If the SX Plant were designed and maintained throughout its service life as if it were an aircraft, there would be no need for expensive and inherently less reliable add-on protection systems. Fires in these facilities simply would not occur.

This document proposes to address the issue of improving fire protection in the high value/high risk area of the SX plant by stressing the following recommendations:

- Inherent Safety. Implement principles of inherent safety (IS) in the initial layout of the facilities, particularly in the mixer-settler trains and tank farm. Avoid projects where process safety and security are sacrificed to preconceived notions of cost.

- Fast and effective response. Provide a design for automatic fire detection and fire extinguishing at all stages of the SX process with minimal reliance on human involvement.

- Operability & Reliability. Provide a high degree of operational stability and survivability for the fire protection systems under all foreseeable conditions

- Damage control. Interlock the fire protection systems with the process plant's distributed control system (DCS or PCS) to shut off fuel flow to the fire area and minimize collateral damage, as soon as fire is detected. Automatically drain unburnt fuel from the fire area to an emergency pond or other safe location. Program the fire protection system to initiate an orderly plant shutdown via the DCS, in the event that operators abandon the plant.

- Ease of maintenance. Minimize maintenance needs and operational costs over the life of the facility. Keep it simple (but not too simple).

- Integrated emergency response. Integrate the automatic fixed fire detection and fire extinguishing systems with manual fire fighting equipment on the site (e.g., remotely controlled monitors and fire fighters' hose streams). Coordinate the performance of automatic fixed fire detection and fire extinguishing systems and equipment with the operational plans for first responders, specifically the plant's in-house fire brigade.

- Process safety management programme. Identify the most critical process scenarios that may lead to undesired consequences and design against the occurrence of these scenarios. A well managed process safety management programme and regularly scheduled HAZOP analyses can eliminate most conditions that lead to fire, thereby avoiding a loss.

- Avoid Black Swans. Identify the elements that increase risk and contribute to creating critical scenarios, e.g., reduce the possibility for emergence of a "Black Swan" event.

1.2 The Layers of Protection

There are four acknowledged tiers or "Layers-of-Protection" (Fig. 1.2.1) usually applied to loss prevention in SX facilities.[1] The layers are ranked on a scale of 1 to 4, in order of effectiveness:

- Layer 1, *Inherent Safety* (IS) - A protection layer that relies on the reduction or elimination of hazardous materials or processes through changes in the physical design or operation of a facility.

- Layer 2, *Passive* - A protection layer that requires no mechanical device or system to actively function to limit or prevent the loss. The most favourable aspect of a passive system is its performance reliability because it is not prone to failure upon demand. Examples of passive systems are non-combustible materials of construction, physical space separation between fuel storage tanks and treatment plants, dikes, drainage systems, and firewalls.

- Layer 3, *Active* - A protection layer that requires an electrical or mechanical device or system to actively detect and respond, to limit or prevent the loss. An active system must be:

    - reliably designed to work when intended
    - installed according to strict installation rules
    - maintained and tested over its entire life.
    - operates upon demand

An active system is more prone to failure than a passive system and may cost more over the life of the facility. Examples of active systems used in settlers and tanks are infrared fire detectors, heat detectors, foam fire extinguishing systems, automatic closing valves, and process safety interlocks that limit the flow of ignitable fuel into the fire area.

This document focuses mainly on Layer 3, that is, reactive fire protection systems that come into operation after a fire event occurs and whose intended purpose is to control the fire and reduce the loss. Level 3 measures cannot prevent fire from occurring in the facility.

- Layer 4, *Procedural* - A protection layer that requires human response to limit or prevent the loss. Because of the need for human reaction and response, this form of protection is highly subject to failure or improper action. Examples are an operator pushing a control button to close a valve in the organic stream or a fire brigade hearing an alarm, responding and attacking a fire with hose streams.

These systems can be shown as representing rings or layers of protection that guard the facility from fire. Failure of an inner layer can sometimes be overcome by outer layers, albeit often at higher cost and larger potential loss.

There is little or no on-going cost associated with Levels 1 and 2. Levels 3 and 4, however, require continuous investment in capital and time over the life of the facility and, in the final analysis, turn out to be the most expensive and least reliable.

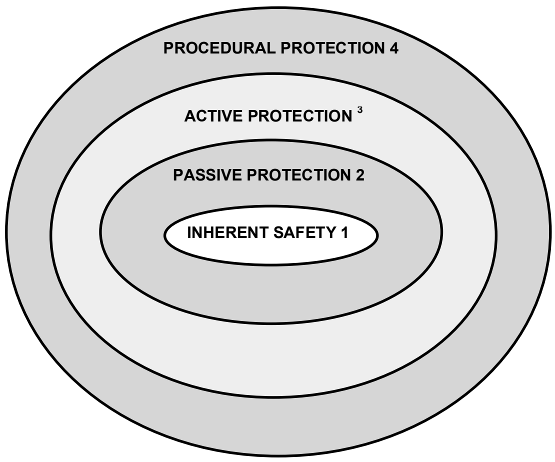

Figure 1.2.1 [1]

Most SX facilities have some features of all of these protection layers, such as the separation distance between settlers, bulk kerosene tanks and loaded organic tanks within dyked containment areas, but they are often inadequate to prevent fire spread or limited to the minimum separation distance allowed by the national fire codes and other governing standards. Minimal code compliance is not a formula for reduced loss potential.

A feature of most SX plants is the very compact nature and footprint of their component processes.[2] For example, the thermal radiation footprint for most SX trains (e.g., mixer-settler groupings) and their associated tank farms suggests that it is unlikely that fire in any vessel can be prevented from spreading to adjacent vessels in the grouping for the following reasons:

- Passive protection (Layer 2) is often insufficient or absent. Settlers are not separated according to code requirements for liquid hydrocarbon tanks in most jurisdications (usually ½ tank diameter between vessels). There is no internal compartmentalization between settlers and tanks within the bunded area and no functional firewalls, none of which are required by code. A spill issuing from one vessel in the grouping involves all vessels inside the bunded area, lending itself to a full surface bund fire and the potential loss of the equipment and product in all the vessels. Trenches provide open conduits for fire between areas, acting as fuses. Thermal radiation issuing from large open pool fires are >30kW/m^2, making it difficult or impossible for fire fighters to approach the burn.

Figure 1.2.2 Mixer overflow spreads to rich electrolyte and loaded organic tanks. There are no internal curbs inside the bunded area to prevent running spill fires.

- Active protection (Layer 3) must automatically detect and completely extinguish the fire within one or two minutes of ignition. Organic fires must be detected quickly and hit with overwhelming force while in the incipient stage (liquid spread phase before it achieves gaseous spread phase, e.g., a matter of approximately 20 seconds). Industry studies show that rapid fire extinguishment is hampered by the limitations of the NFPA 11 formula for foam-based fire suppression in large diameter (>30m) tanks containing Class II combustible liquids (e.g., kerosene-based organic).[3] In addition, the fences and changes of elevation inside settlers do not present a smooth liquid surface across which a foam blanket can easily flow in order to seal the surface of the burning organic against air and extinguish the fire. Foam flow cannot readily overcome the obstructions inside the settler.

Figure 1.2.3 Typical setter interior showing fences, columns, and other obstructions to foam flow across the liquid surface. This settler is operated without any freeboard, that is, a 150mm foam blanket cannot be contained and therefore is unlikely to close over the burning surface. Collapse of the fragile fiberglass roof may impede or neutralize the fire extinguishing system inside the settler unless the fire is extinguished within a few seconds after ignition. Air currents entering through the open ends of the settler add to the challenge.

- Procedural protection (Layer 4) involves emergency response from on-site first responders. Without a well-equipped, on-site fire brigade trained and practiced in combatting large volume liquid hydrocarbon fires, the opportunity for damage control is greatly reduced. The initial window in which practiced First Reponders can contribute to loss reduction is narrow and inexpert fire fighting may cause conditions to worsen and the fire front to spread. Procedural protection also includes plant operation and maintenance protocols in accordance with the facility´s Process Safety Management (PSM) Programme.[4] In the case of hydrometallurgical plants situated within mining operations, PSM may be inadequate or altogether lacking. Safety-related legislation such as the Seveso Directive in the European Union, although mandating PSM programme reporting for chemical plants within its jurisdictional authority, does not require hydrometallurgical plants using the SX process to have a PSM programme although such plants in reality operate a chemical plant (SX/EW) within the confines of a mining operation, with all the inherent dangers of a poorly managed chemical plant.[5]

A well protected SX plant therefore relies heavily on the inner IS and passive protection layers (Layers 1 & 2) which, if taken into account during the initial design of the facility, are highly reliable, rather than the outer active and procedural protection layers (Layers 3 & 4) that are more subject to human element and failure-upon-demand.

Because any flammable liquid fire presents a severe and fast acting hazard, all non-IS protection systems (Layers 2, 3, 4) must act together rapidly with very high reliability or the fire might gain control and overtax the protection system. If large volume organic storage tanks, settlers, piping or other process equipment fail under fire exposure and release additional fuel, the protection system design-basis may be exceeded. Active fire protection systems (Layer 3) are not designed to extinguish a complete and fully involved plant fire, but instead are predicated on a formula for providing maximum extinguishing potential for the single most demanding fire area that can be shifted as needed to any other less demanding fire area of the site. For example, the fire extinguishing foam systems in a mixer-settler train may be designed to fight fire in a number of the settlers of the grouping, which is usually the involved settler plus 1 or 2 adjacent settlers, but not fire in all settlers simultaneously or simultaneously occurring fires in separate areas (SX trains and tank farm).

Once a combustible liquid fire has grown beyond a controllable size, however, fixed protection systems may be unable to limit damage. Furthermore, active (Layer 3) systems have a defined failure rate and may not be available upon demand over the life of a facility. History has shown that the longer the chain of components in an active (Layer 3) fire protection system, the greater its chance of failure. As a result, a facility that relies on fixed fire protection (Layer 3) and/or first responders (Layer 4) will usually have a higher inherent damage potential than one which has designed in IS features (Layer 1) and passive (Layer 2) protection elements.

The primary emphasis for risk management during the design stage should be on building Inherent Safety (Layer 1) into the initial design of the SX facilities. Unfortunately, green-field projects are too often cost-driven and strive for minimal code compliance on the assumption that “It Can’t Happen Here.”

The primary emphasis for fire management during the operating life of the facility should be on a robust process safety management programme (Layer 4) and strict adherence to operating the process equipment as per specification and subject to rigorous management of change and period HAZOP analysis and action. This reduces reliance of active (Layer 3) fire protection systems that are reactive by nature. They cannot prevent fire from occurring.

1.3 Applying IS Principles (Layer 1)

According to Kletz[6], there are 5 stages in applying IS principles to the development of any facility:

1.3.1 Intensification

Intensification means reducing to a minimum the amounts of hazardous materials used in the facilities. In the case of a typical SX plant, the amount of ignitable liquid (organic) is a function of the process capacity and therefore is not reducible in its totality; however, the methodology for storing ignitable liquids in reduced volumes or using the liquid within separately dyked and adequately separated areas is achievable. For example, lack of intensification would involve all settlers and/or tanks located within a single spill containment area. Intensification would separate these vessels and provide separate spill containment for each, thereby reducing or eliminating the possibility of a running spill fire spreading to all the vessels in the plant.

1.3.2 Substitution

Substitution means replacing a more hazardous material with a less hazardous material. For example, the cooling oil used in electrical power transformers can be changed from petroleum based (mineral oil) products to synthetic products (polyol esters and others) to reduce combustibility. The use of soybean-based cooling oils reduces fire risk as well as eliminating the need for expensive spill containment systems since the oil is biodegradable.

Currently, there is no practical and non-flammable substitute for kerosene in the SX stream. Although anti-static additives are routinely used for dosing aviation grade kerosene (Jet A & A1), they have not been welcomed by the mining industry to reduce kerosene-based organic's high propensity for generating and storing a static electrical charge, especially where acid and organic flow in plastic piping systems. Static sparking has been identified as the cause of major fire losses in SX plants.[7,10]

Another example is the use of electrical cables that are fire rated, armoured or installed inside metal conduit instead of exposed plastic insulated cable, and use of stainless steel instead of plastic piping systems handling flammable liquids in the highly corrosive SX/EW environment.

1.3.3 Attenuation

Attenuation is commonly achieved by using as low pressures as are necessary to move organic through the SX process and pipelines. Using less energy means reducing operating costs and increasing profitability.

How attenuation is applied to plant layout can be a false friend. The traditional layout puts the SX tank farm in a cut below the mixer-settler trains, thereby needing only to pump organic in one direction while taking advantage of gravity flow back to the tank farm. This arrangement has resulted in large volumes of organic spillage from failed pipe in overhead racks entering the tank farm to burn. Worse, these gravity lines may run partially full, effectively acting as launders wherein an ignitable vapour-air mixture accumulates, waiting for an ignition source.[7] These fires are thought to be more common than is reported, often self-extinguishing with the ebb and flow of organic in the pipe, but eventually causing the pipe to fail and fire to occur in the plant. In this case, attenuation means ensuring that pipes run full, thereby eliminating any interior vapour space.

Attenuation means the application of IS principles in the design of organic piping to ensure that static generation in the pipelines and other points in the process are reduced to a controllable minimum. Reducing velocities in piping, employing long radius bends, and terminating inflow nozzles below the minimum liquid level in settlers and tanks to reduce splashing are examples of attenuation.

Attenuation also extends to procedural controls (Layer 4) for control of ignition sources within the SX plant. For example, the provision of grounding stations for 'sucker' trucks removing crud from settlers is a must, rather than relying on the transport contractor who generally grounds to the nearest available steel structure which may, or may not, be connected to the plant earthing grid. Oftentimes, these trucks do not carry grounding cables, their operators remaining blissfully unaware of the risk.

Figure 1.3.1.1 Grounding stations for mobile equipment in the SX plant.

Attenuation takes into account the location of facilities in zones where moderate to severe earthquakes are expected to occur within the service life of the plant. Any fire protection system (Layer 3) must be designed and installed to survive any foreseeable seismic event, including total loss of electrical power.

1.3.4 Limitation of Effects

Limitation of Effects means designing a process plant to minimize the impact of a release of hazardous material or energy. In the case of SX, the ignitable material is organic, although the release of large volumes of sulphuric acid is also a HAZMAT concern. Fire effluent from SX fires can include hundreds of cubic meters of vaporized acid as well as CO, CO_2 and soot, while heavy metals in the airborne and water-borne fire effluent contaminate air, water and soil in the surrounding area. In disaster planning, fire fighters (Layer 4) must take into account the release of acid during an SX fire event, this being a serious environmental as well as life safety issue.

Deflagrations are known to have occurred in atmospheric leach tanks where an oxygen-enriched atmosphere combined with elevated temperature (>90°C), agitation (causing static generation), and unacceptably high levels of tramp organic in the barren leach solution stream were all contributory elements.[8] Released energy can cause deflagration and/or fire, and is a serious life safety hazard as indicated by the thermal footprints developed in thermal radiation assessments.[12]

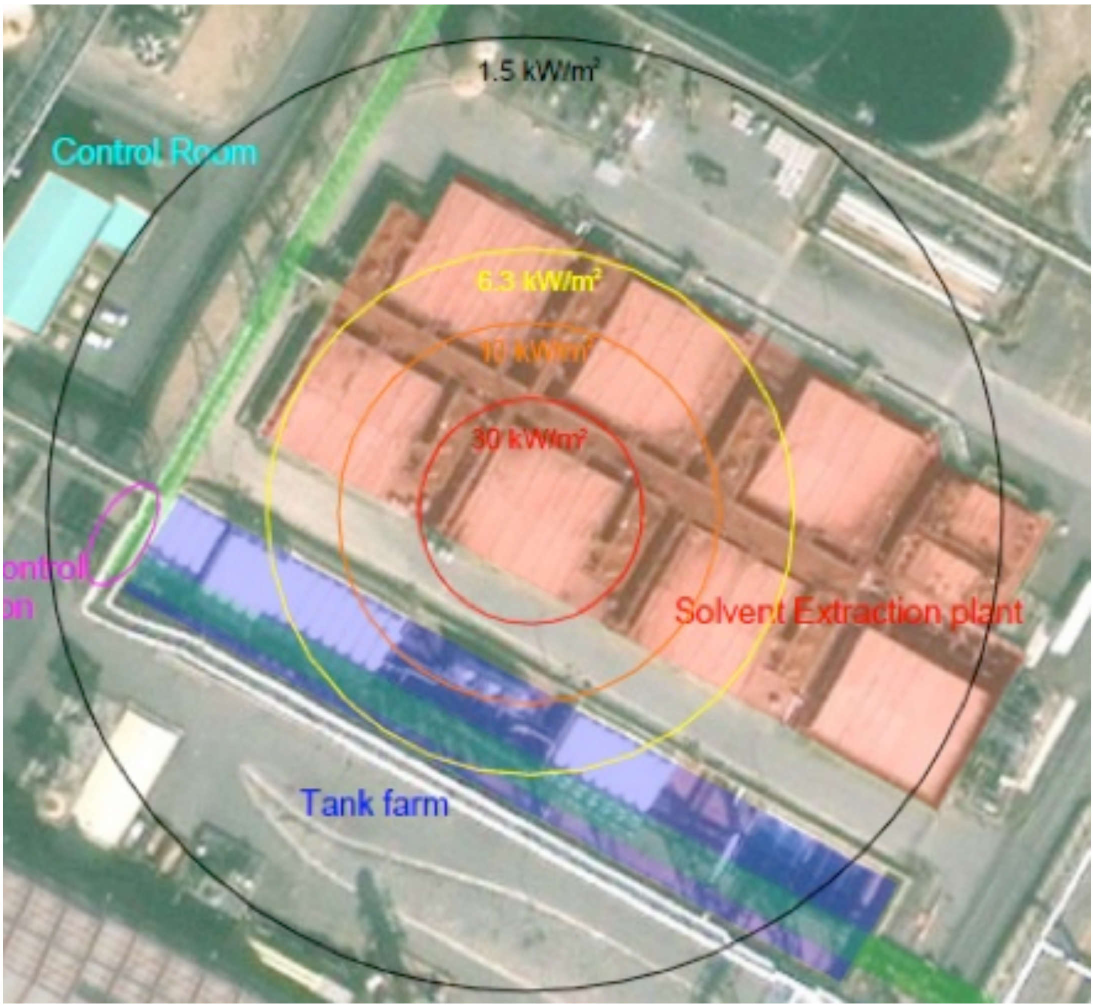

Figure 1.3.4.1 The above radii indicate thermal radiation levels for a typical single settler fire. 10 kW/m² (orange circle) is the level at which plastic and FRP materials are subject to ignition and anything within the 30 kW/m² (red circle) radius is expected to spontaneously ignite. It is therefore inevitable that all HDPE (plastic) piping in the immediate vicinity of a settler fire will fail very quickly after the event becomes a full surface fire (e.g., in this example 400m² per settler). This does not take into account fire in the main trench that acts as fuse. There is virtually no separation or firewalls between the mixer-settlers which all share a common secondary containment and a single communicating trench. A full plant fire is almost inevitable. See Figure 1.3.4.2.

Figure 1.3.4.1 shows a plant layout that has not taken Limitation of Effects into account. There are no elements designed to break a chain of events that can lead from a minor upset to progressively more serious consequences. Unless fire in this facility is detected and extinguished in the incipient stage, the fire protection system cannot save the plant once these levels of thermal radiation are achieved, since the intensity of the fire will likely have already destroyed the detection and extinguishing systems.

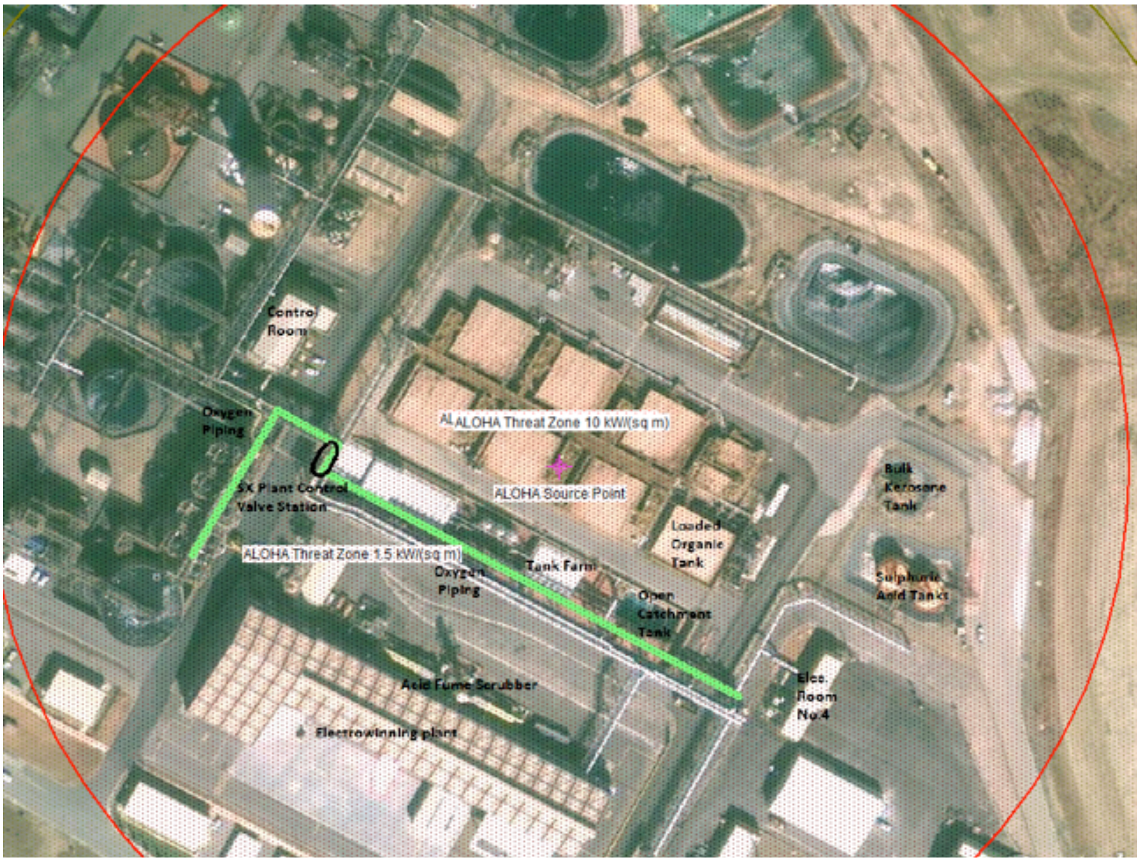

Figure 1.3.4.2 Thermal footprint for a fully involved SX plant fire. The red circle indicates a 30 kW/m² radius. Fire fighters cannot approach this fire, even when wearing protective clothing.

Limitation of Effects aims to limit the magnitude of a process deviation should one occur, thereby breaking the chain of circumstances leading to a “Black Swan” event.

1.3.5 Simplification and Error Tolerance

Simplification and Error Tolerance means designing the facility so that operating errors resulting in explosion and/or fire are less likely or the process is more forgiving and the risks more manageable if errors are made.

Central to Simplification and Error Tolerance is the concept that all critical systems must be fail-safe, that is, they should be at least two failures away from a catastrophic failure. This is a critical safety management principle for managing risk and reducing the odds of a major fire event occurring in the SX Plant.

The SX plant’s distributed control system (DCS or PCS) and instrumentation must be designed to operate at the highest IEC Safety Integrity Level (SIL 4) or its equivalent. [9, 10]

Various operating conditions and scenarios within the SX environment pose a risk of fire. For organic transfer, pumps without seals or double-sealed pumps are preferable. Piping should be non-combustible and welded wherever possible (no HDPE or other plastic piping materials).

Grooved-style and threaded couplings should be minimized or eliminated and glass level devices in organic lines eliminated. Sample points should be avoided, but if necessary should have double block valves and spill collection pots. All organic and crud removal hose connection points should incorporate "dry break" connections to reduce spillage when making and breaking off. These are only a few of many examples.

Fire alarm management, which helps discriminate nuisance alarms from critical alarms, is an example of Simplification and Error Tolerance. Nuisance fire alarms sooner or later result in detection systems being neutralized by the operators. It is common to find that buzzers and horns have been disconnected to avoid the need to reset fire alarm control panels after multiple false alarms. The faults are simply allowed to accumulate in the controller's database without any follow-up by maintenance, and a corresponding reduction in the level of protection.[11]

Simplification and Error Tolerance in the design of fire protection systems (Layer 1 enhancing Layer 3) means that the shorter the chain of components needed to detect the fire and get the fire suppressant agents to it (less complexity in operation), the better and more reliable the system and less likely that it will become neutralized over time.

For further information on the application of principles of inherent safety in the design of solvent extraction plants, see "Using Principles of Inherent Safety For Design of Hydrometallurgical Solvent Extraction Plants", Larry J. Moore PE, FM Global US.

2.0 LAYER 3 – FIRE DETECTION AND SUPPRESSION IN SETTLERS AND TANKS

The focus of this document is the practical application of effective design principles for the rapid extinguishment of fire inside setters and tanks in the SX plant.

2.1 Why Fire Needs To Be Detected Quickly

To insist that fire should be detected as quickly as possible would be to state the obvious: loss reduction is a function of how rapidly an upset condition can be brought under control. In the case of ignition occurring inside a setter or tank, the window for detection and extinguishment is only seconds.

Studies have shown that fire occurring in steel tanks storing liquid hydrocarbons very quickly results in the tank shell becoming out-of-round. This is a major problem in floating roof tanks where pontoon roof-to-shell tolerances are small (<25mm). A super-heated tank shell presents potential for reignition if there is no effective cooling of the tank shell although interior flames may have been extinguished or at least brought under control. The result is almost always the loss of both the tank and its contents.

The most important parameter for fire growth across a liquid fuel is the temperature of the fuel relative to the flashpoint. In experimental work with kerosene[13] (organic), two distinct flame spread regimes were identified, resulting in two different flame spread velocities:

- surface flame spread of approximately 0.1m/s for liquid-phase controlled flame spread, and
- approximately 2m/s for gas-phase controlled flame spread.

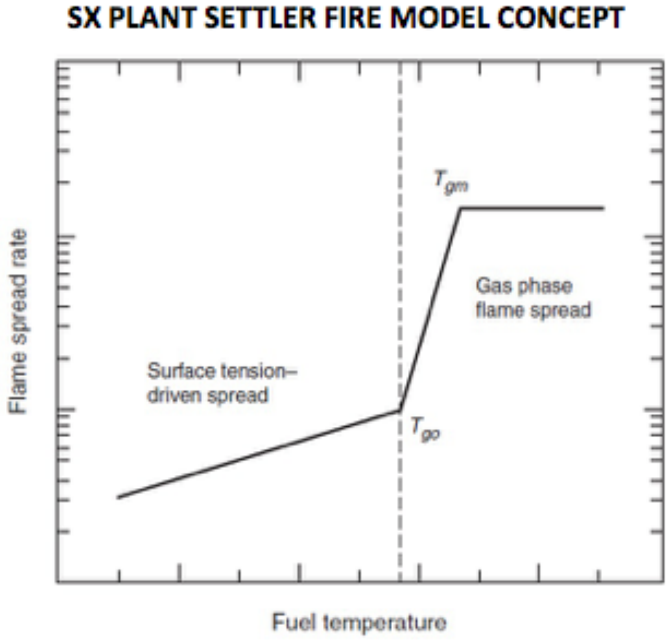

Figure 2.1.1 Graphic representation of the definitions of T_{go} and T_{gm}.

T_{go} Liquid temperature at transition from liquid to gas phase – controlled burning
T_{gm} Minimum liquid temperature at which asymptotic gas phase spread occurs [13]

To avoid loss of both the tank and its contents, fire in a typical API 650 tank must be detected and completely extinguished within five (5) minutes of ignition, and preferably before the incipient fire reaches gaseous phase spread. This is the base case for vertical atmospheric steel tanks in SX tank farms.

Rectangular tanks (loaded organic, rich electrolyte, wash tanks, etc.) and settlers are often constructed of fibreglass reinforced plastic (FRP) materials, sometimes having wood interior and exterior framing. Even a rich electrolyte tank or barren leach solution after-settler contains a sufficient volume of tramp organic at the liquid surface to ignite. While the loss of bulk acid and kerosene tanks can be compensated for by the temporary use of tanker trucks connected to process lines, other process tanks, as well as mixer-settlers, are not easily replaceable and result in loss of production. Owners need to take into account that insurance coverage does not guarantee or protect against fire occurring in the plant, and deductibles, which often include the value of the first two weeks production losses, may far exceed an initial investment in proper fire protection measures.

The case for mixer-settlers is rather more complex and critical than that of the SX tank farm. The odds for fire originating under normal operating conditions inside a settler are reduced, given that normally there are no ready ignition sources inside these vessels and all instrumentation is ATEX-rated (ex-proof). For a variety of reasons, SX plant fires tend to start in the tank farm. The usual problem is fire migrating to the settler from outside or from malicious mischief. Nonetheless, the potential for large asset losses is constantly present, since even a single settler cannot be bypassed without a concurrent reduction in plant throughput and consequent loss of production (e.g., less tonnage of metal produced per month).

National fire codes and private institutions such as the American Petroleum Institute stipulate a minimum separation between tanks containing liquid hydrocarbons, usually one-half the diameter of the largest tank in the grouping, and a standard minimum distance of any tank wall from the edge of a dyked containment area. This is rarely the case in SX plants where settlers are grouped chock-a-block with only sufficient separation distance to contain the required interconnecting piping. Settlers sometimes feature wood internal structures with FRP walls and roofs that become saturated or coated with organic over time. Even concrete basin settlers will have a combustible polymer liner. Without effective separation, these settler groupings, that may include loaded organic tanks as well, must be treated as a single large tank for purposes of fire protection design. Uncontrolled fire in one almost certainly guarantees fire in all. Whereas fire in an API 650 petroleum product storage tank may be left to burn itself out without spreading to adjacent tanks, fire in a wood and fibreglass settler having only one or two meters separation from other settlers must be extinguished within seconds if loss of the entire plant is to be avoided.

2.2 Settler Construction

2.2.1 The Hazard

Typical settlers used in hydrometallurgy resemble API 650 tanks in the sense that they are vessels that contain a combustible liquid. Settler surface areas are generally in the range of 400m2 and larger, or equivalent to vertical atmospheric storage tanks of =>25m diameter. This is where the resemblance ends.

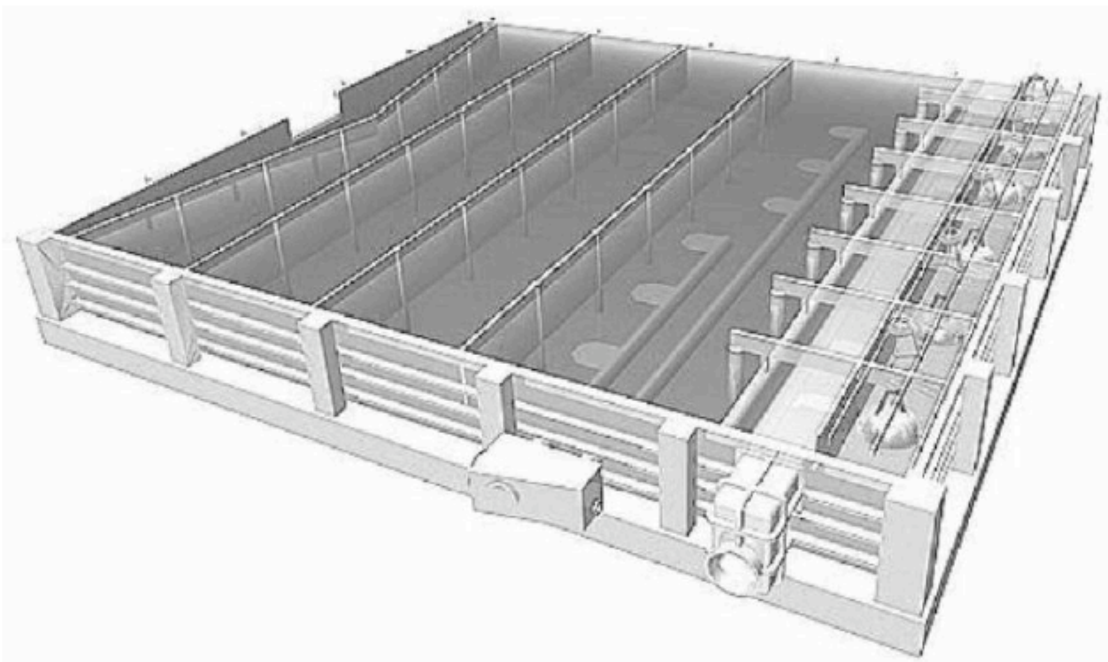

Figure 2.2.1.1 Interior of a typical settler showing internal fences, organic discharge launder and acid launder (far right). The fences extend above the liquid surface. The flow is from left to right, that is, toward the acid launder.

The two major differences between settlers and conventional liquid storage tanks are:

- Settlers generally feature internal structures and other obstructions; there is no smooth liquid surface as in storage tanks

- The liquid inside a settler is never still. Inflow and outflow are continuous. Liquid moves from one end of the settler to the opposite end where the phases separate and exit the settler. Whereas inflowing kerosene during filling of an API 650 steel storage tank may contain a static electrical charge, the charge is rapidly dissipated as soon as the liquid is at rest. Organic (kerosene based) is never at rest in the settler

- There is a change of elevation of the 2 phases, organic exiting the settler from a lower strata while surface strata acid cascades into and flows out its launder

The name of a settler describes what it does, that is, it causes ‘crud’ (undesirable by-products and residue) to stratify and settle out of the process stream while the mixers agitate and cause the 2 phases (organic and acid) to contact. A settler’s internal fences act as screens while allowing the phases to remain in contact. Sediment and crud are then removed from the settler and reprocessed, then recovered organic and acid are returned to the process stream while residues are removed for disposal. The metallic content ends up in the final electrolyte phase (rich electrolyte) whence it goes to the Electrowinning (EW) Plant for production of cathode copper, the finished product. Even at this stage, there is sufficient tramp organic in the electrolyte to cause explosion and fire in the EW cells if ignitable vapour is allowed to accumulate under closed cell covers.

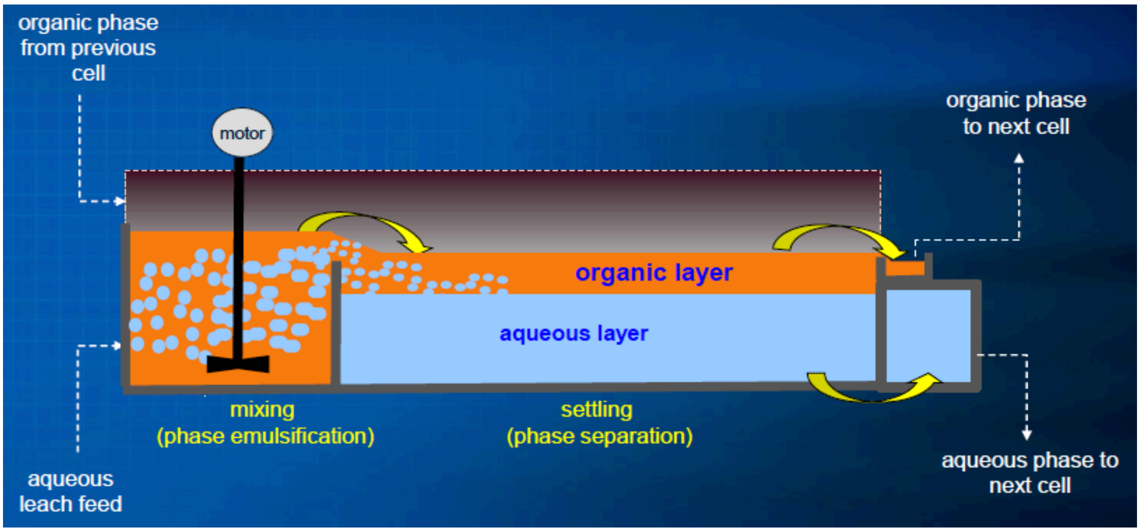

Figure 2.2.1.2 Liquid flow into and out of a settler. Diagram courtesy of FM Global.

2.2.2 Settler Construction & Fire Behaviour

There are probably as many different types of settlers as there are SX plants, all slightly different in characteristics but all operating more or less in the same way. From a risk management standpoint, the points made in Section 1 of this document apply to all. From a fire protection engineering standpoint, however, the physical configuration of the settler and its materials of construction make a great difference.

Figure 2.2.2.1 Open settlers. Photo courtesy FM Global.

Figure 2.2.2.2 Semi-open settler.

Figure 2.2.2.4 Totally enclosed settler.

Some settlers are completely open to atmosphere, that is, they are essentially uncovered ponds with unlimited access to oxygen and where windborne incendiaries can easily enter. Other designs feature entirely enclosed vessels that can be sealed relatively tightly. Protec Group has successfully inerted these type vessels using nitrogen to allow safe cutting of holes for installation of fire protection pipe and cabling inside the settler without removing the settler from service.

Some factors that determine how fire behaves inside a settler are:

- Fire size is limited to the extent allowed by the air volume inside the vessel. Open settlers enjoy unrestricted access to air (oxygen) and wind. Airborne incendiaries can be carried from the settler to adjacent process plant areas and vice versa.

- Air infiltration affects the rate of fire growth and intensity and how rapidly a settler's walls and roof can be expected to fail

- Fire size is unrestricted to the extent that ventilation permits until it reaches the extent of the tank, after which it may spread to the rest of the plant if there are no firewalls or adequate separation distances to contain it. Water curtains can help reduce fire spread by cooling adjacent structures but are not definitive and rely on a long electro-mechanical chain of components that must all function perfectly during an emergency.

In common with all settler designs, is the fact that organic is always held below its flash point of approximately 72°C, usually around 40-45°C, while temperatures taken at enclosed settler roofs can reach >60°C. Settler walls and roofs, which are often heavily coated with tars from dried organic, can easily approach the flash point of the organic and, in case of fire, become super-combustible in spite of any fire retardants (antimony trioxide or other) used in the fabrication of the FRP roof and wall panels or the interior basin polymer liners. Internal wood framing adds to combustibility since these structural members become thoroughly saturated with hydrocarbons over time.

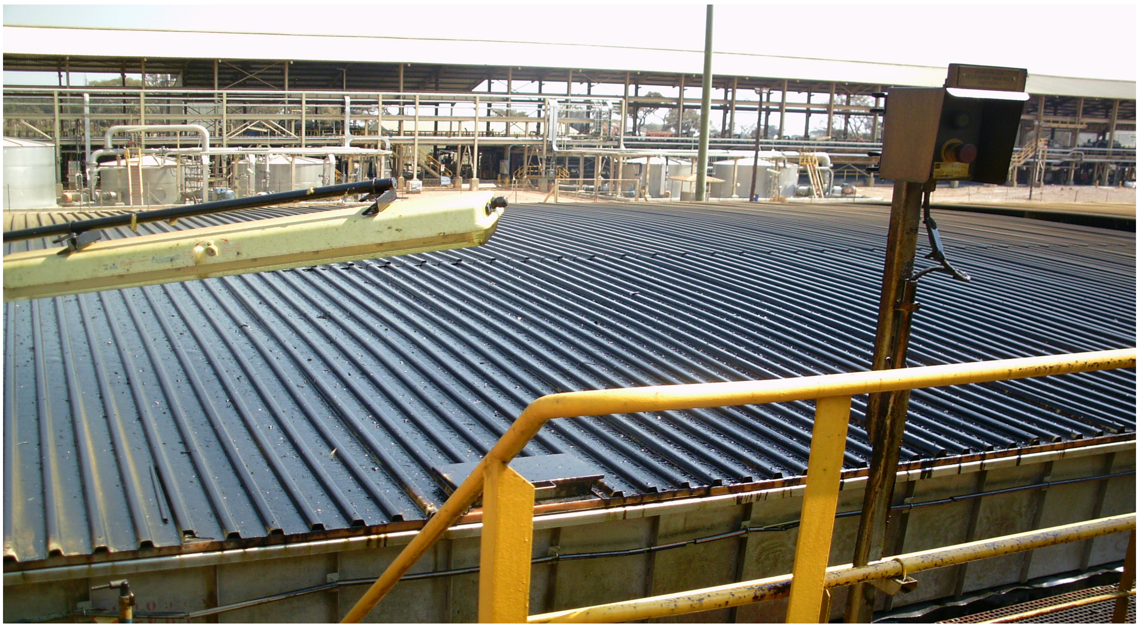

Figure 2.2.2.5 The fibreglass (FRP) settler roof is coated in an ignitable layer of dried organic, thereby defeating any fire rating the FRP may have. Windborne incendiary materials may be carried toward the electrowinning plant in the background.

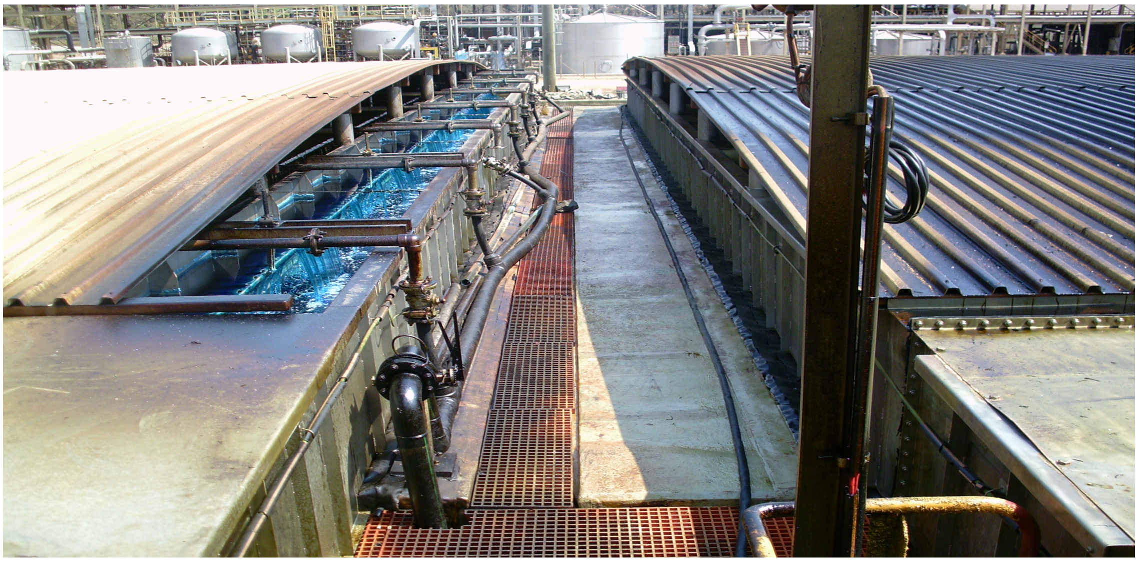

Figure 2.2.2.6 Semi-open settlers with 1 meter separation and interconnecting open trench. These trenches usually contain organic and act as a fuse during a fire, carrying the fire to other areas of the plant. Controlling the amount of extraneous fire loading is a matter of housekeeping.

Figure 2.2.2.7 Temperature readings for the settler FRP roof surface reached 63 °C due to solar gain during the month of April. Material temperature can be expected to reach higher levels in July-August when ambient air temperature peaks at >50°C. Liquid inside the settler is maintained at +-42°C. Flashpoint of the organic is +-72°C. Note:

- The roof is thickly coated with dried organic both inside and outside, adding to combustibility
- Frothing and misting occur inside the settler. The froth seen in the photo is ignitable
- Wooden structural members inside the settler are saturated with organic
- Settler roof access hatches are routinely left open overnight without barriers, allowing airborne incendiaries to enter as well as presenting a personnel hazard
- Hoses and lances used for crud removal are routinely left overnight as shown in the photo, presenting a tripping hazard and contributing to the organic build-up on the roof's exterior surface
- Clearance between the liquid surface that the underside of the settler roof is 900mm
- There are no ladders or other internal means of escape from the settler

3.0 FIRE EXTINGUISHING METHODOLOGY

It is important to recognize the different behaviour of various fire-extinguishing agents before specifying any particular method for fire extinguishment in the SX environment.

3.1 Water or Foam?

A common assumption among designers and firefighters alike is that the more water one throws at a fire, the quicker it can be extinguished. This widely accepted myth could not be further from the truth. In the case of Class A combustibles (wood and paper), water is indeed an effective extinguishing agent, especially where deep-seated fires occur such as in wastepaper baskets or wooden structures (homes, barns). The more water that can be brought to the fire, the better.

Water is not a good choice for extinguishing Class B (liquid hydrocarbons) fires. History has shown that training hose streams on liquid hydrocarbon pool fires such as occur in SX plants, only serves to move the fire from where it originated to other areas of the plant, increasing the destruction.

A rule of thumb for SX fire fighting is:

Water is for refrigeration (cooling). Foam is for extinguishing.

In the case of fire extinguishing in mixer-settler units and SX tank farms where large flows of burning organic may gush into the environment from failed plastic pipe or ruptured tanks, water is only useful for cooling adjacent structures that are not already burning.

Foam is the most reliable and effective fire-extinguishing agent for settlers, tanks, bunded areas and trenches in the SX plant.

Equally important to the effectiveness of foam in extinguishing liquid hydrocarbon fires is the manner in which the foam is discharged into the fire area. Foam must be used correctly and the delivery system designed specifically for the protected area, since settlers and tanks are not all alike.

3.2 Other Fire Suppressants

Gaseous fire suppressant agents show promise when applied correctly in the right environment, that is, inside closed settlers and tanks. If a settler or tank can be inerted, that is, the internal oxygen level in air reduced to below 12%, then gaseous fire suppressants are a cheap and effective alternative to foam.

Gaseous fire suppression involves relatively simple technology with few moving parts and responds quickly to the fire detection system's call for extinguishment, without reliance on a long chain of components (fire water pumps, foam pumps and proportioners, deluge valves, etc.) for correct operation in emergency. As soon as the single control valve opens, the interior settler or tank space is almost immediately flooded to the design concentration, well before fire reaches the gaseous spread phase and the entire liquid surface is involved in fire. Kerosene, a Class II combustible liquid, features a slow starting fire because an ignitable vapour is not normally present at the liquid surface, unlike gasoline and other Class I liquids where an ignitable vapour is normally present across the surface of the liquid.

Both carbon dioxide and Novec 1230 can be used effectively; however, there are obstacles to using gaseous media, both technical and political:

- The protected settler or tank must be sufficiently closed to retain the gas for the design duration therefore open and semi-open settlers cannot be protected in this way. Sealing is not as critical an issue with Novec 1230 since it is a liquid that is pumped and transforms to a gas upon discharge from simple nozzles inside the fire area. The system is only limited to the volume of Novec 1230 liquid stored in the head tank, and the design density can be maintained by pumping more liquid into the fire area. The calculated fire extinguishment time for such a Novec 1230 system operating inside a 20m x 20m settler with 400m^3 interior space above the liquid surface is <6 seconds. In this way, pumped water mist systems (proven ineffective for fire suppression inside settlers) can be repurposed using Novec 1230 liquid instead of water. As with foam systems, a spare charge is needed on standby in case of reignition; however, a bank of installed cylinders or extra Novec 1230 liquid in the head tank of a pumped delivery system is more reliable in emergency than having to refill a foam concentrate tank or bladder tank from spare foam stocks that may not be readily accesible.

- Underwriters' standards do not currently recognize the use of gaseous fire suppressant agents in settlers and tanks in SX.

- Owners are generally shy of innovation and tend to favour more traditional approaches. The inclination is toward minimal investment in fire protection although gaseous systems, especially CO_2, are relatively inexpensive to build and CO_2 gas is cheap and available everywhere. Novec 1230 is a liquid with no transport restrictions (can be transported on aircraft) and system tanks are easily replenished.

3.3 What is Wrong in the NFPA 11 Formula?

The primary reason why traditional foam systems designed to the NFPA 11 formula do not extinguish fires in hydrocarbon storage tanks larger than 35 meters diameter is simple: **There is an error in the NFPA formula. The formula allows tank surface area to increase indefinitely without a corresponding increase in design density (application rate expressed as litres per minute per square meter of surface area). Instead, the NFPA formula calls for more foam chambers and long foam flow durations, up to 55 minutes**.

In reality, after approximately 5 minutes of burn time in a fully involved hydrocarbon tank or settler, the intense heat of the fire irreversibly damages both the roof and shell. This situation is especially serious where settlers and tanks are of wood and fibreglass construction and where obstructions to the flow of foam across a liquid surface are present. According to both the FM Global and the NFPA 11 design formulae for kerosene fires in a 400m^2 tank (settler), only 2 foam chambers (discharge points) are required. The system must contain sufficient foam concentrate and water to maintain a 20-minute flow to the fire area. In this scenario, the foam blanket can never close over the burning liquid surface.

- The intense thermal radiation hardens and vaporizes the foam faster than the blanket can close

- Uniform foam distribution is impossible due to the large surface area and obstacles (fences, columns, etc.).

As explained in previous sections of this document, 20 minutes is too long an allotment to extinguish fire in a settler or tank in SX. If the fire cannot be extinguished in less than 5 minutes, then it very likely will not be controlled until all the fuel (organic) is consumed and the fire self-extinguishes.

In order for a foam system to quickly and effectively extinguish a fire inside a settler, the following design parameters must be followed:

- The fire extinguishing time must first be established, preferably less then 2 minutes (not a 20 minute duration) and the system designed to achieve this+
- Design density (liters per minute of foam discharged per square meter of liquid surface) must increase with the surface area of the settler if the thermal energy of the fire is not to vaporize the foam as it issues from the foam discharge points
- There must be an infinite number of foam discharge points (not 2)

3.4 System Configuration

Conventional foam delivery systems come in a variety of configurations, from the relatively simple to the very complex. Once the fire detection system detects a fire in the settler and the fire pump is started, pressurized water is made available to supply the foam systems. Without water, conventional foam systems cannot function. Without electrical energy, the electric-driven fire pump cannot operate and foam proportioner pumps cannot deliver foam concentrate to the water stream. These systems feature a long chain of vulnerable components that must all function perfectly in an emergency. They are not well suited to the SX environment.

During the Olympic Dam (Western Mining Corporation) fire of 2001, the electric-driven fire pump failed to start due to a faulty circuit breaker and it took operators 30 minutes to bring the diesel backup fire pump into service. To make matters worse, the electric foam concentrate pump failed, thereby neutralizing foam flow to the fire area. By that time it was too late. WMC declared an AUS $300 million loss attributed to the fire which was limited to the tank farm.

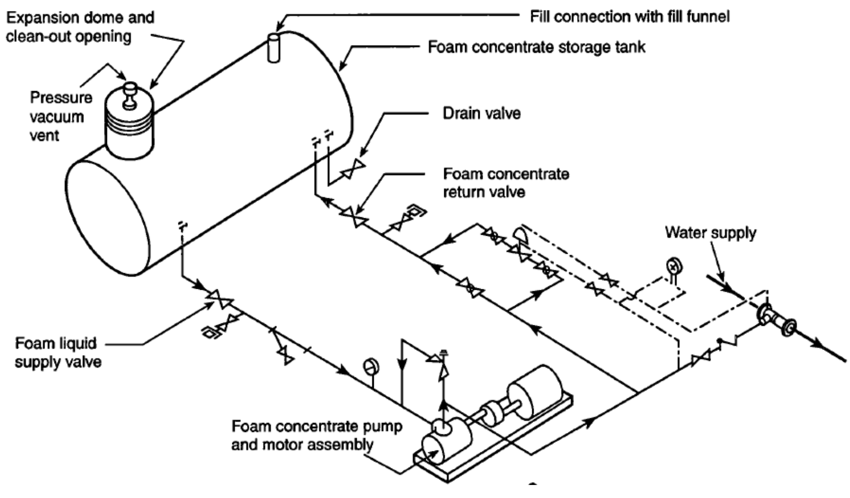

Figure 3.4.1

3.5 Making the System Work Effectively and Reliably

In order for the extinguishing formula to be effective, the design density (foam application rate) must increase with the increasing surface area of the protected settler or tank. In order the ensure functionality in the system, the chain of dependant components must be reduced to the absolute minimum.

The designer's objective is to reduce the foam system component chain to No Mechanical Moving Parts (NMMP), or as few as necessary, for highest reliability.

To increase reliability and reduce the chain of electro-mechanical components, the following design guidelines should be adopted:

- Utilize a reliable water source of sufficient capacity to satisfy the design flow for the design duration or at least 2 hours, preferably gravity-fed to eliminate the need for fire and jockey pumps
- If a gravity-fed firewater distribution network is impossible, then utilise at least three (3) diesel driven fire pumps, each sized for 50% of the design water flow plus 50% back-up
- Utilise a foam concentrate bladder tank or water turbine-driven foam concentrate proportioner assembly (FireDos) that relies only on water pressure in the fire mains to provide foam solution to the distribution piping. There is no reliance on electrical or other mechanical energy with these methods of foam concentrate introduction to the water stream
- Store the spare foam charge together with the main foam charge in a common foam concentrate tank, or two interconnected tanks, to avoid having to refill in case the fire rekindles or reoccurs in another fire area.
- Utilise a "membrane" type deluge control valve (Inbal or other) without any mechanical moving parts. In the case of the prototypical 400m^2 settler, NFPA 11 requires the installation of only 2 discharge outlets (foam chambers). In order to actually extinguish fire in this settler, a foam chamber needs to be installed at 1 meter intervals or less along the entire tank perimeter (= 80 chambers) to ensure that the foam blanket closes over the fire area before the foam itself is consumed by fire. In other words, the number of foam introduction points must be infinite
- Utilise a Continuous Linear Nozzle (CLN) having an infinite number of foam discharge points to deliver foam inside the settler and overcome the obstacles presented by fences and other structures. Alternatively, a sufficient number of foam discharge devices giving a foam pattern similar to a linear nozzle is acceptable where the settler cannot be physically entered to install a CLN, such as in the case of operating settlers that cannot be removed from service. This method requires approximately 12 discharge units (foam generators) per 400m^2 of liquid surface depending on the settler configuration.

- Ensure that foam discharges toward the wall of the settler (not toward the centre) to cool the wall and reduce failure time, especially in the case of fiberglass-constructed settlers and tanks. Hydraulic pressure will force the foam back toward the centre of the fire area and cause the foam blanket to close.

- Alternatively, a single ASME Section VIII, Division 1 pressure vessel can be charged with pre-made foam supplying the CLN. This is the most reliable and economic method of fire extinguishment in a settler or tank.

3.5.1 The Hierarchy of Effective Foam Fire Extinguishing Systems

System Type	Response	Reliability
Pre-charged foam pressure vessel + CLN (the system is inherently NMMP)	Extremely rapid	Extremely reliable
Gravity water supply + NMMP + CLN or equivalent	Very rapid	Very reliable
Pumped water supply + NMMP + CLN or equivalent	Rapid	Reliable
Conventional foam delivery system as per NFPA 11	History of failure to extinguish	Unreliable

Reliability is a function of the simplicity of a fire extinguishing system. A system that requires less maintenance is more likely to be functional during an emergency than another system that requires more maintenance and that may become neutralized over time.

The most challenging aspect of fire extinguishment inside settlers is to get the foam blanket to close over the liquid surface, in spite of any physical obstacles and the intense heat of the flame front (>50kW/m^2) that tends to vaporise and destroy the foam cells faster than the blanket can close. The foam blanket must close at a faster rate than the thermal radiation can reduce it.

The solution to the problem is to deliver the foam to the burning liquid surface by means of a continuous linear slotted nozzle (CLN) that spans the entire interior perimeter of the settler shell at the top of the wall, thereby providing an infinite number of foam injection points. In actual fire tests, this method of foam introduction has shown to close a foam blanket over the surface of the burning liquid at a faster rate than the heat and intensity of the fire can vaporize the foam, this being the reason that no foam system has extinguished a fire in large diameter tanks to date.

Using this method of foam introduction, fully involved surface fires in >25m Ø (500m^2 fire surface area) test tanks using both gasoline and kerosene were repeatedly extinguished in less than 2 minutes after detection.

3.6 Theory of Successful Foam Introduction

Traditional design standards for extinguishing fire in flammable and combustible liquid storage tanks are based on internationally recognized standards and recommendations (e.g., FM, NFPA, UL, BS, EN, GOST, DIN etc.).[14] These provide guidelines for the method of extinguishment, arrangement of components, and for the technical design parameters of a storage tank fire protection installation, either fixed or semi-fixed systems. Unfortunately, most fire protection design guidelines for settlers in SX follow these traditional standards and design formulae, ignoring the large sizes and special characteristics displayed by settlers and other process vessels containing organic.

In fact, most designers of SX plants do not follow the recognized national and private body of safety standards, since SX plants are considered to be comprised of 'process equipment', not hydrocarbon storage tanks and are therefore exempt from compliance with the national codes and standards. What would not be code compliant in a commercial petroleum products terminal tank farm becomes perfectly acceptable inside an SX plant. The plant's insurance underwriters are the only parties positioned to impose any safety standards, but only as a condition of purchasing insurance.

All of the current standards governing the design of foam fire suppression systems are collections of engineering data gleaned from experimentation and past incidents. Following these instructions and recommendations, one can successfully extinguish a fire in small size storage tanks having no impediments to foam flow across a still, unobstructed surface, and without any movement of liquid inside the vessel (inflow, outflow, turbulence, splashing).

These design standards and formulae were appropriate >50 years ago when only relatively small (<30m Ø) size tanks existed in industry and where process vessels such as settlers used in SX were a thing of the future. The traditional foam application intensity, the foam generating and introduction method (using foam generators and foam chambers located outside the tank shell) proved successful and appropriate for the time. As the size of storage tanks began to increase, however, and the internals of process vessels became more complex while their associated hazards remained poorly understood, none of the established standards addressed the need to modify the fire protection system design principles.

Very large storage tanks (>100m Ø) came into use in the petrochemical industry from the 1980's onwards, while SX in hydrometallurgy began to develop and expand as early as the 1950's, therefore new standards should have been adapted to the new conditions.

Now that these larger petroleum products storage tanks are aging, the industry is experiencing full surface fires. The success rate for extinguishing fires in these large size tanks is disappointingly low. This low success rate is a result of the existing extinguishing design standards not keeping pace with the increased tank sizes. Fortunately, research and advances in fire extinguishing technology addressing the challenge of fire in larger diameter tanks can be applied equally to settlers and tanks in SX. The science has simply not kept up with the times.

In the case of solvent extraction plants, not even the basic tenets of separation and containment dictated by the national fire codes are uniformly applied. The odds for the occurrence of large asset losses and full plant fires are exacerbated by the antiquated and inadequate formulae used for extinguishment. Consequently, industry losses run into the hundreds of millions of dollars without a change in approach to the problem. Insurance companies paid out the losses, owners continue in the same way.

3.6.1 The Reason for the Low Success Rate

Considering the NFPA 11 and similar formulae from the standpoint of practical extinguishing, a false doctrinal approach is encountered. The NFPA 11 formula is rooted in using the very same (constant) foam solution application intensity, regardless of the size of the protected vessel. This formula implies that if the fire surface is doubled the foam solution application rate does not have to be increased. The flow rate simply has to be increased linearly with the increased burning surface. This is a pure proportional response to the fire, but it does not work.

In order to successfully extinguish fire is large tanks and settlers, a progressive response to the fire condition is needed. The key to successful extinguishment is to increase the foam application rate, ignoring the standard design formulae.

This discussion offers an overview of the theory and practice of Progressive Response.

Three basic parameters to be considered in view of the new theory are:

- The foam solution application rate
- The foam introduction method
- The arrangement of the foam supply.

3.6.2 Foam Solution Application Rate

The NFPA 11 formula recommends a constant foam solution application rate (usually 4.2 litre/minute/square meter) for full surface kerosene fires (FM Global recommends 6.1 litre/minute/square meter), regardless of the size of the protected vessel. The total foam solution flow rate (litres per minute) needed for the foam attack is calculated by the multiplication of the fire surface (m^2) and the foam solution application rate (litre/minute/m^2). The longer distance the foam has to travel and the longer period of time the foam is exposed to the thermal effects of the fire have not been taken into account. In an actual tank fire, the fire vaporizes the foam faster than a foam blanket can close over the liquid surface. This is always the case in tank fires greater than 30m Ø (700m^2). In the case of settlers and other process vessels of square or rectangular footprint and having internal obstacles, the surface area limitation is greatly reduced. The foam simply does not reach the fire.

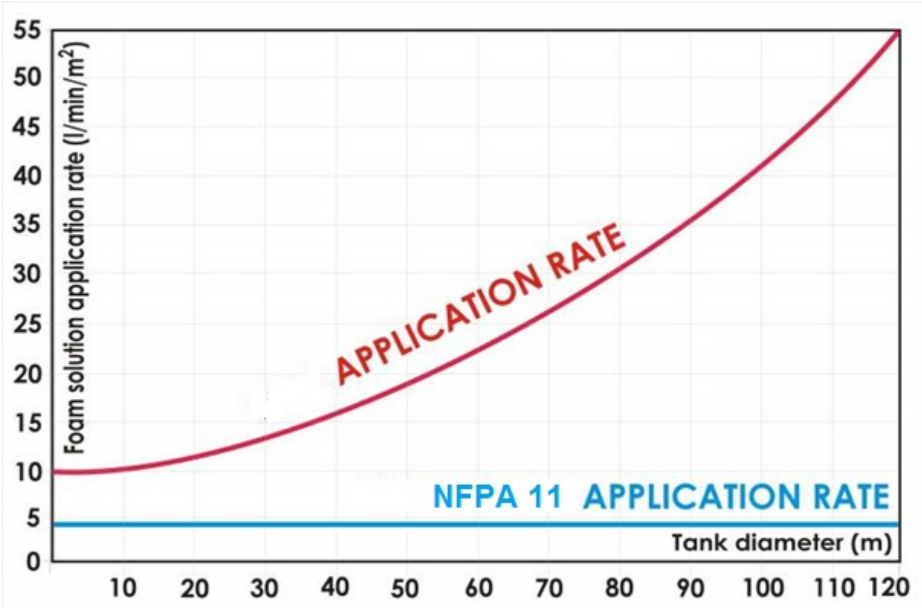

Figure 3.6.2 Foam Solution Application Rate versus Tank Diameter

From the traditional viewpoint, the foam solution application rate is in linear function with the diameter (constant) and the total foam solution flow rate in square function with the diameter of the tank. If the surface of the fire is doubled, the flow rate shall also be doubled. The standards recommend different standard values of foam solution application rate for rim seal fire protection, for dike area protection, and for monitor application. The burning material (polar or a-polar solvents) has also to be considered. All of these recommended values are independent of the fire size.

The larger the tank is, or the more obstacles the foam needs to overcome to reach the fire front, the longer time the foam has to travel until it reaches the centre of the burning vessel and closes to achieve coverage of the entire surface with a foam blanket that seals the burning surface against further oxidation. Longer travel simply means that the foam is exposed for a longer period to the heat of the flames. Foam is damaged by drying, thermal decomposition, thermal updraft, and other factors. The heat flux is also increased to some extent by the size of the fire. Hardening the non-moistened surface of the foam will cause slower movement, thus resulting in higher foam losses.

These effects must be compensated by a higher application rate, otherwise the foam blanket will never close and the fire cannot be extinguished. This is, in fact, what industry research, such as the Brandforsk Project 513-021, Swedish National Testing & Research Institute study of tank fire incidents from 1951-2003, has shown.

3.6.3 Shortening the Extinguishing Time

An increased application rate consequently shortens the extinguishing time.

The traditional diagram of the function of extinguishing time versus foam solution application rate is well established in the fire protection literature.

The critical intensity value and phenomena is the most interesting and important part of this diagram. The traditional view of tank fire extinguishing does not consider the critical foam application intensity as it depends on the size of fire.

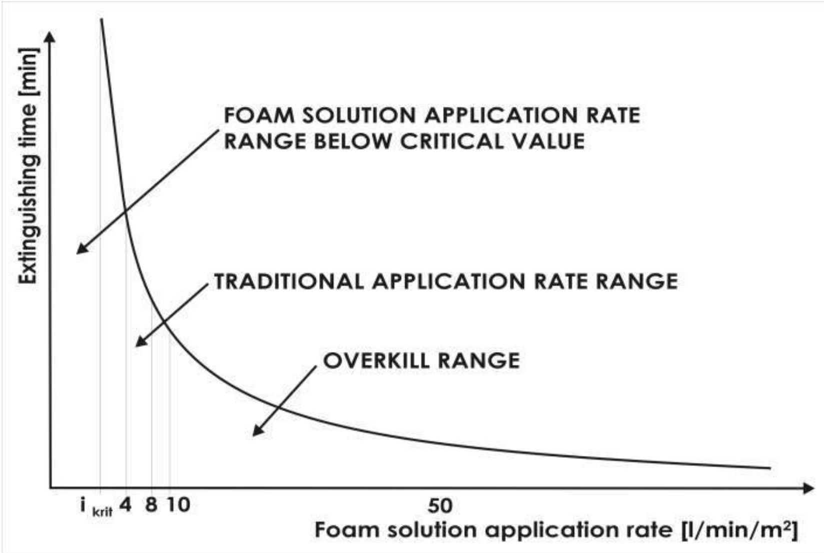

Figure 3.6.3.1 Traditional extinguishing time versus foam solution application rate.

From a traditional viewpoint, this diagram applies to all tank diameters. In other words, the critical foam solution application rate (i_{crit} ,the abscissa of this hyperbola) is constant, not depending on the tank diameter or the surface area of the burning liquid in the tank. In practice, the traditional extinguishing time-foam solution application rate diagram is found to be valid only for the smaller (<30m diameter) tank sizes.[3]

The critical foam solution application rate expressed in Figure 3.6.3.1 is not a constant value, but instead, it changes in accordance with the size of the fire surface.

From thus new viewpoint, every fire surface has its own curve (see Figure 3.6.3.2) The different characteristics and features of various foams are not considered here, for easier discussion of the phenomena. Obviously, foam quality is a function of the type of foam (low, medium or high expansion), method of dosing, the method or air entrainment, and water pressures used in delivery. Most important in terms of fire extinguishing, however, is the foam solution application rate.

When drawing a summarizing diagram, one arrives at a series of curves. Looking at this series, the curves seem to be very similar to the known traditional one, but they move in the direction of the higher application rates, parallel to themselves. This way, a three dimensional surface is formed; the third parameter on the “Z” axis is the diameter of the tank or equivalent settler surface. Figure 3.6.3.2 shows the projection of some curves on the “Z” axis to the plane X-Y, belonging to diameter 10, 20, 30, 40 and 50 meters. A 20m x 20m settler, for instance, would fall on the 23m-diameter curve.

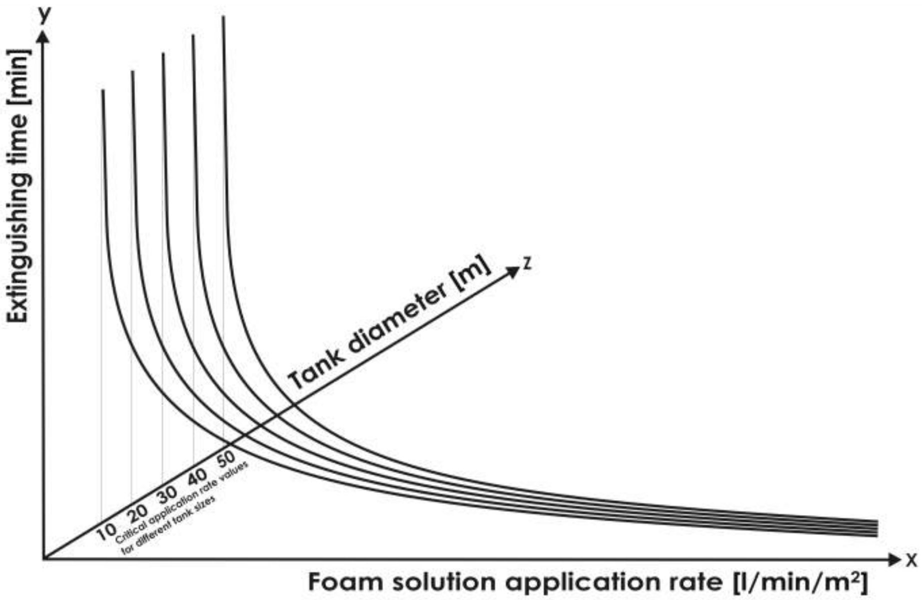

Figure 3.6.3.2 The critical application rate changes with the diameter of the tank.

The larger and more irregular the fire surface, the more damage will be caused to the foam. Using the traditional formulae, with the higher foam losses over a certain size of the tanks (>30m Ø), the total foam flow will be consumed by the fire. The foam will never reach the middle of the liquid surface, therefore the extinguishing time becomes infinite. In other words, the fire cannot be extinguished. Historically, this has been the case for large diameter (>30m) hydrocarbon fires in tanks that were equipped with fixed foam systems.[3]

The explanation for the failure to extinguish is that the critical application rate failed to increase with the increase of the tank size. In the larger tank sizes, the critical foam application rate belonging to that size exceeds the application rate recommended by the traditional standards (NFPA 11 et al).

The critical foam application rate changes with the size of the storage tank. The larger the fire surface, the higher the critical intensity value will be. In other words, the application rate that is used successfully for small size tanks will be insufficient for larger size tanks.

Successful extinguishment is possible only above the critical intensity value that belongs to the given tank or vessel.

The real trend of the critical foam application rate versus tank diameter curve is unknown at this time. Extensive large volume fire tests in both round tanks and square/rectangular vessels would be required to determine the exact trend. The sole conclusion available now is that the derivate of the curve is positive. Full surface gasoline and kerosene fires in 500m² size tanks have been successfully extinguished according to this new formula in less than 2 minutes using 3% AFFF foam products. The experiment is repeatable.

These “Dynamic Tactical Rules” recommend always using a higher foam application rate than the critical application rate of the size of the burning tank.

3.6.4 Criteria of Extinguishing Time

The NFPA 11 calculation of the required quantity of foam concentrate is based on the multiplication of the fire surface (m²) times the foam solution application rate (liters per minute) times the recommended application duration (minutes).

In the case of Class II combustible liquids (kerosene-based organic), thirty (30) minutes of application time is required. For Class I liquids such as gasoline, fifty-five (55) minutes is required. The determination of duration is made according to the flash point of the stored flammable material. This does not make a lot of practical sense, since both kerosene and gasoline, once ignited, burn with more or less equal intensity and are extinguished according to the same tactical rules.

The extinguishing time is the period in minutes and seconds needed to form a foam blanket on the entire flammable liquid surface. When the foam closes, usually in the middle of the surface, the flames will be put out. When investigating the conditions of foam blanket closing, the Wall Effect must be considered as well.

The faster the velocity of the moving foam is, the shorter the extinguishing time will be.

The extinguishing time can be reduced by a drastic increase in the foam solution application rate. The explanation of this method is based on the rules of fluid dynamics included in the foam spread theory. The most important factor in foam spread is the foam front velocity as it moves across the surface of the burning liquid.

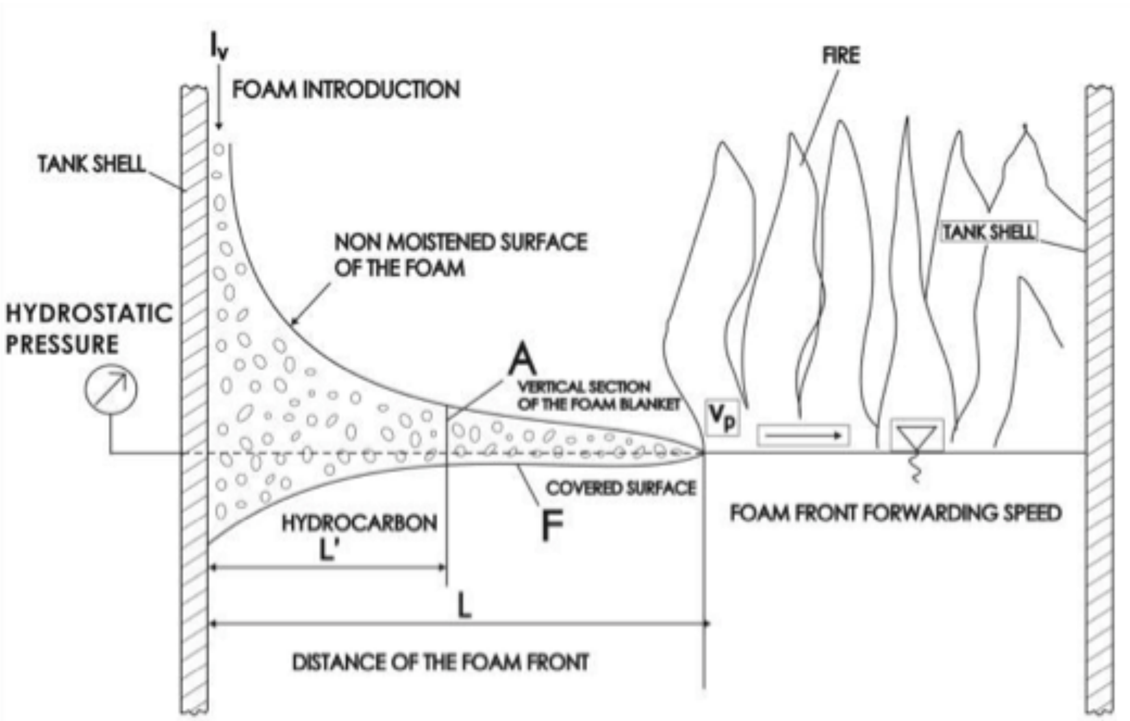

Figure 3.6.4.1 Driving force of the foam movement across the burning liquid surface.

When the incoming foam immerses in the hydrocarbon liquid, it displaces an equivalent volume of the hydrocarbon in order to be able to float on the hydrocarbon surface. The depth of the immersion is in linear function with the difference in density of the foam and the hydrocarbon liquid and with the flow rate of the foam while flowing down the inside surface of the tank shell.

This immersion creates a hydrostatic pressure at the original meeting point of the liquid surface and the tank shell. This pressure is pushing the foam away from the shell; this is the driving force of the movement. The velocity of the movement is proportional to the hydrostatic pressure and therefore to the foam flow rate.

Instead of the total foam flow rate that is used during the fire extinguishing procedure, it is easier to explain the situation by the introduction of the idea of the Specific Foam Application Rate, which is the foam flow rate produced per each meter of the perimeter of the tank or settler.

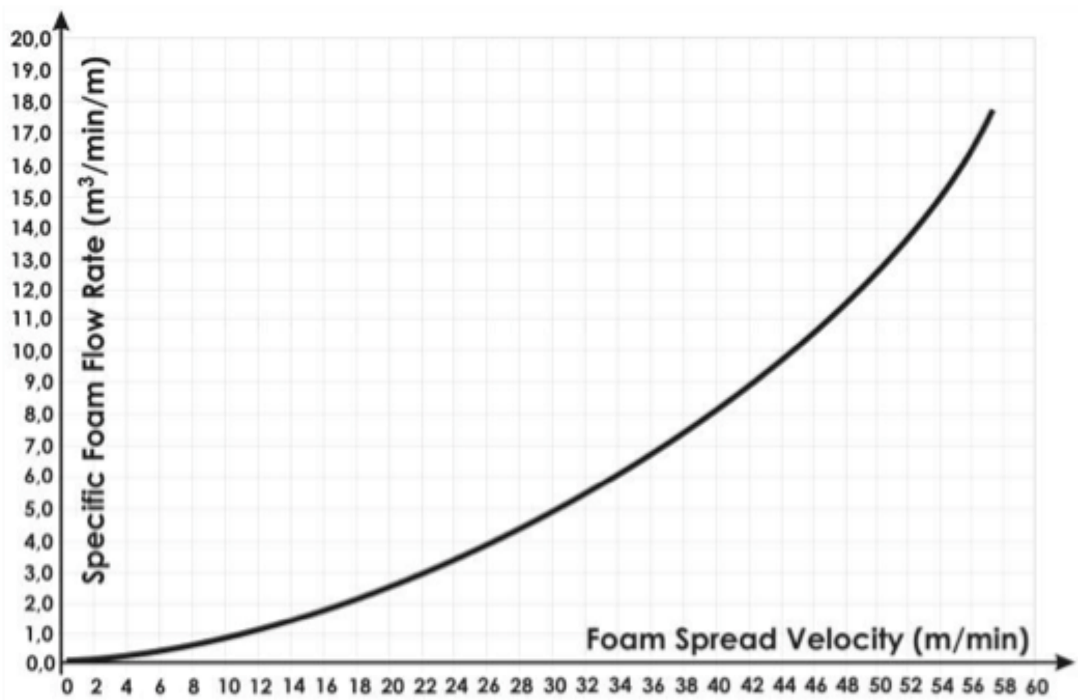

Figure 3.6.4.2 The Function of Foam Spread Velocity & the Specific Foam Flow Rate.

<u>A "one-minute" fire extinguishing criteria can actually be achieved</u> in any size of tank, when using the appropriate specific foam flow rate (foam solution application rate) as shown in Figure 3.6.4.2. In the case of settlers containing obstructions, a fudge factor should be used.

In the case of actual (as opposed to theoretical) fire fighting, a thick and stable foam blanket is needed to prevent re-ignition by hot elements of the storage tank. This is especially important in settlers constructed of wood and FRP materials where a deep-seated fire in these structural elements can contribute to re-ignition. Re-ignition-safe foam blanket thickness forming is therefore a must. The larger the tank or settler is, the thicker the foam blanket has to be. The effect of side-wind and turbulences need to be taken into account, especially in open and semi-open settlers (Figures 2.2.2.1 & 2.2.2.2).

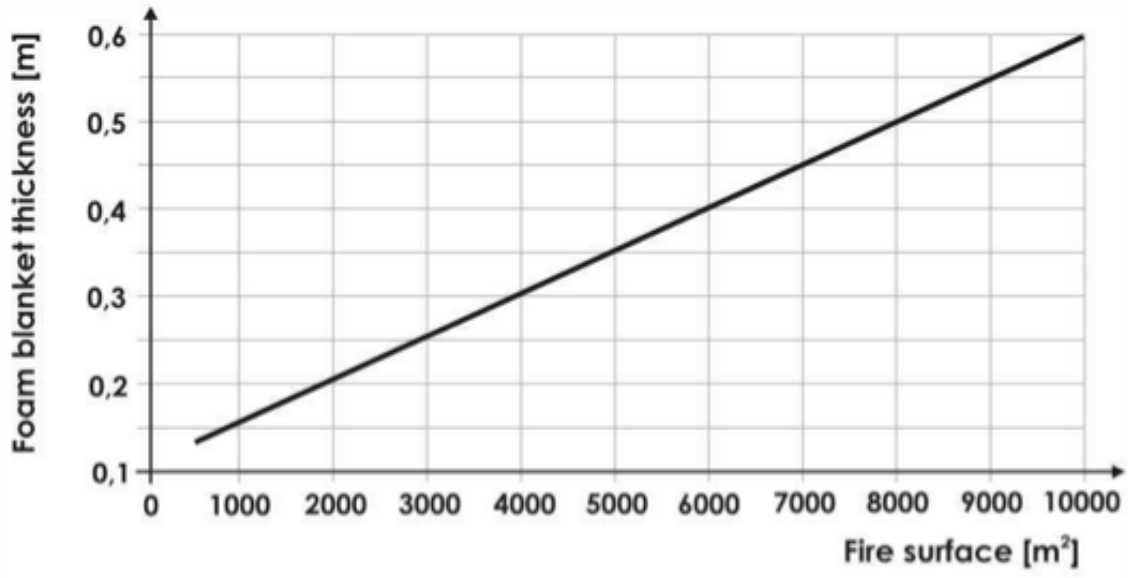

Figure 3.6.4.3 Foam Blanket Thickness Requirement versus Fire Surface

The extremely high foam spread velocity and the fast extinguishment results in very low foam losses. In spite of the high flow rates, the total volume of the foam concentrate needed to extinguish the fire is considerably less than in the traditional foam application methods, since the foam losses are reduced while the extinguishment time is shortened.

3.6.5 Designing the Foam Delivery System

The increased foam flow rate requires a change in the calculation of the foam delivery system.

By the traditional methods, foam chambers have to be installed every 24 meters along the circumference, regardless of the size and diameter of the tank. The function of the tank diameter and its circumference is linear: $K = D * \pi$. In other words, if the diameter of the tank increases to double, we must design the installation for two times the number of foam chambers.

The performance of the foam chambers is limited for fabrication reasons, therefore the total foam solution flow rate is also limited. This linear foam inlet point pitch along the perimeter of the tank fulfils only the foam solution application rate requirements of the traditional (e.g. NFPA 11 based) formulae.

For larger tank sizes these formulae are insufficient to provide the necessary higher foam flow rate needed to actually extinguish fire as the new tactical rules have shown.

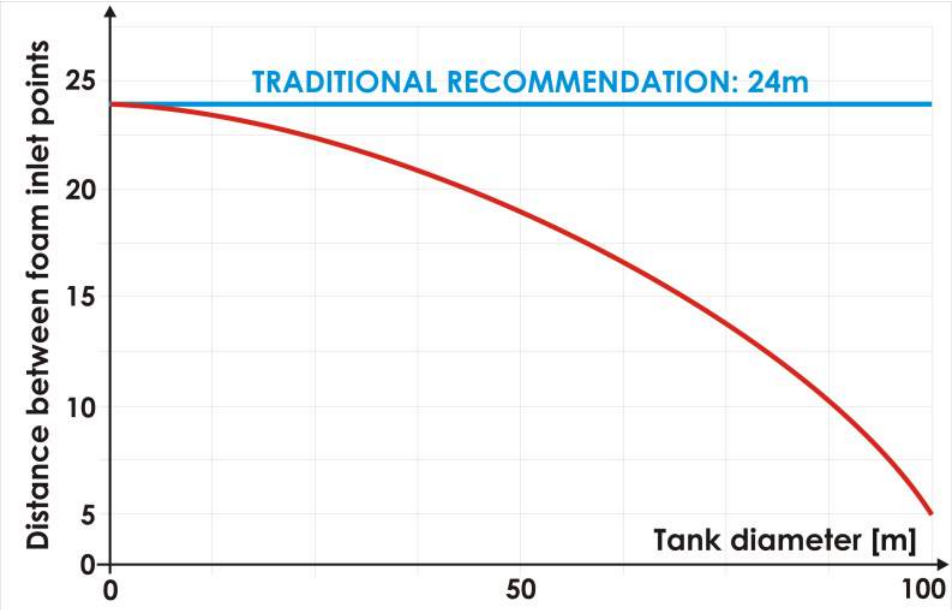

Figure 3.6.5.1 The function of the distance between the foam chambers and the tank diameter by traditional standards and by the new theory.

Excessive velocities in foam introduction can be prevented by the increased total cross section of the foam outlet. One method to create larger cross sections in the foam outlet is the increase of the number of the foam inlet points. Figure 3.6.5.1 shows the necessary distance between the foam chambers if each of them is providing 2500 litres/minute foam solution flow. As the surface area of the fire increases, the distance between foam discharge points diminishes; in other words, the number of discharge points becomes infinite.

This realization leads to the need for a continuously slotted ring nozzle, or its operational equivalent, that covers the entire circumference of the fire area, rather than a small number of isolated discharge points from which the foam blanket can never close.

3.6.6 The Continuous Linear Nozzle (CLN)

The CLN is simply a slotted pipe that provides the equivalent to an infinite number of foam injection points around the top rim of the tank or settler. The length of the CLN is roughly equivalent to the perimeter of the protected vessel. The CLN discharges a solid stream of foam against the wall of the vessel to cool it at the same time that the foam blanket begins to form over the fire surface in much the same way that the aperture of a camera lens uniformly closes to reduce the amount of light admitted to the interior of the mechanism. In closing, the foam blanket exponentially reduces the fire's capacity to destroy the foam. The flame front is reduced at an increasing rate as the foam blanket closes over the fire area. The fire is extinguished every time.

There are two basic ways to produce foam solution for the CLN or its equivalent.

- Use of a conventional water supply, foam concentrate proportioning equipment, and foam solution distribution piping network with high back pressure type foam makers in the feed risers to the CLN mounted inside the protected vessel.

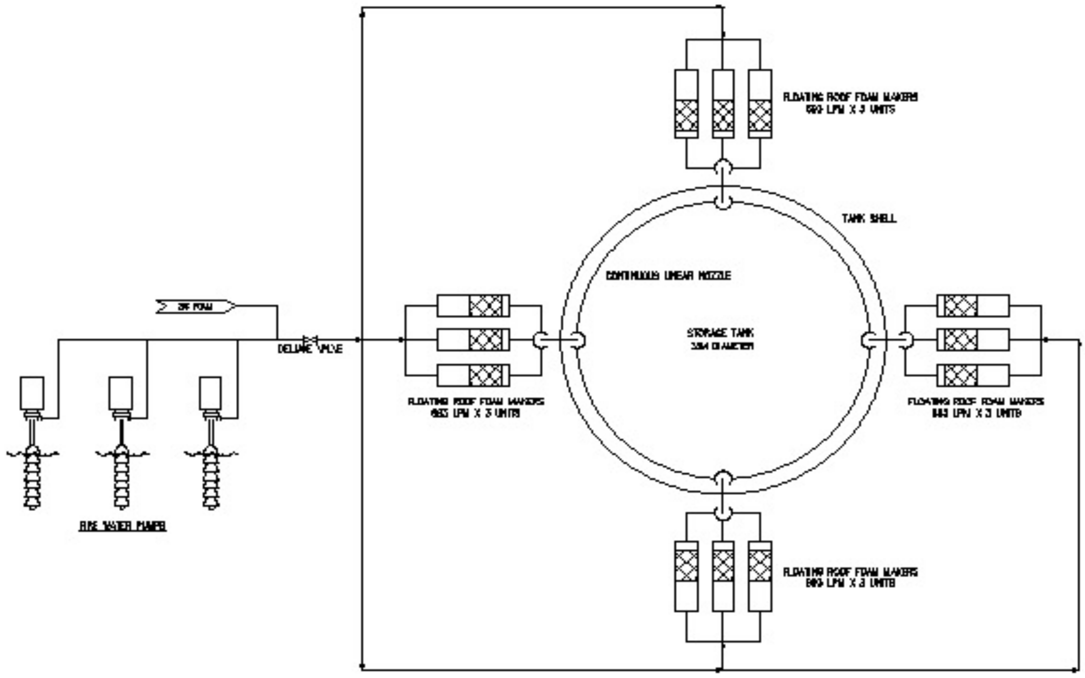

Figure 3.6.6.1 Conventional water supply, high backpressure foam makers and CLN mounted in a circular storage tank.

- Use of an ASME Section VIII, Division 1 pressure vessel containing pre-made foam and a simple membrane-type deluge valve releasing foam directly to the CLN.

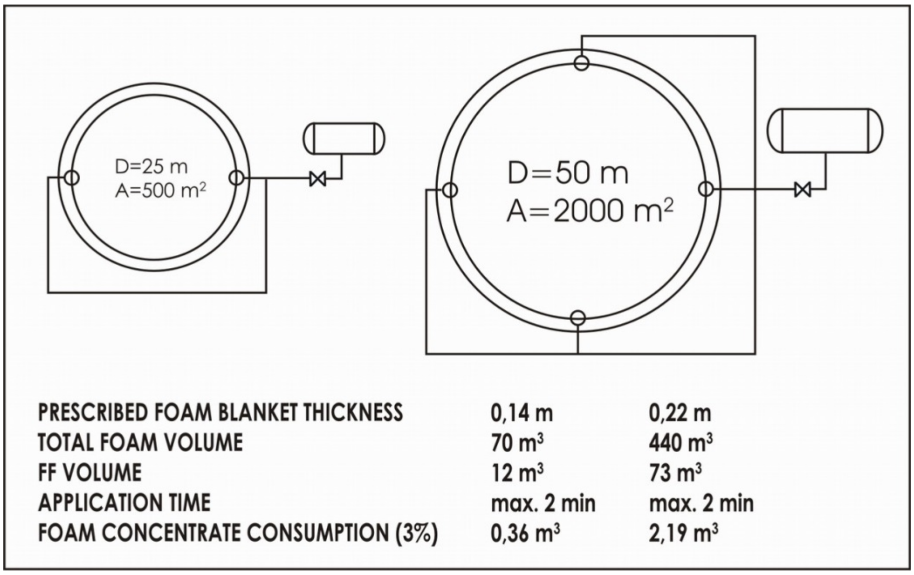

Figure 3.6.6.2 Pressure vessels with pre-made foam and CLN mounted in circular storage tanks.

3.6.7 System Installation

For new settler construction, the installation of the CLN is straightforward in any type settler and poses no constructability issues. Because it is composed of a slotted stainless steel pipe whose inlet is sealed by a replaceable silicone rupture disk, acid/organic misting has no effect on maintenance or performance. The CLN cannot clog or malfunction in any way.

In the case of existing settlers that cannot be taken out of operation, installation of the CLN in open settler designs (Figures 2.2.2.1 & 3.6.7.1)) is similar to new construction and without serious constructability issues. Where settlers are fully enclosed, likewise there are no installation problems so long as the enclosure can be entered by the pipefitters.

Figure 3.6.7.1 The CLN can be easily retrofitted to this typical enclosed settler.

For operating settlers that cannot be entered (Figures 2.2.2.2 & 2.2.2.4), the principle is applied through the use of a series of vertically mounted, high capacity foam lances with discharge adaptor that mimics the discharge pattern of the CLN. The lances are inserted through penetrations in the settler roof and discharge directly against the interior wall of the settler.

Figure 3.6.7.2 Foam discharge devices that mimic the performance of the CLN, mounted inside a fully enclosed settler. 50mm diameter feed pipes (not shown) to

each lance connect to a 100mm diameter ring main installed around the outside wall of settler. The devices comprise an open pipe discharging against a simple screen for air entrainment and produce a medium expansion foam ratio of approximately 20:1. There are 16 devices mounted in this 20m x 20m settler. Note the deflector that directs foam toward the wall of the settler and eliminates turbulence caused by foam flow impinging on the liquid surface. The result is a gentle, uniform blanket spreading across the liquid surface at the same time that the wall of the settler is cooled above the liquid surface, thereby contributing to vessel stability.

3.6.8 Bench Testing the Foam Discharge Device (CLN Equivalent)

The device used in the test is the SABO SE-SME series foam lance, modified to carry a custom designed deflector plate that mimics the performance of the CLN. A mounting plate is attached as shown in Figure 3.6.7.2. The device shown in Figure 3.6.8.1 is without the deflector and mounting plate shown in Figure 3.6.7.2.

The medium expansion foam produced in the test was analysed by SABO and FM Global and found acceptable.

Figure 3.6.8.1 SABO SE-SME foam discharge device mounted horizontally.

Figure 3.6.8.2 Expanded foam produced by the simultaneous operation of 2 devices for several minutes duration. The estimated time to fill the entire interior space of each protected settler (400m^3) is <2 minutes.

Discharge Device	:	SABO SE-SME
Foam Concentrate	:	PLUREX M 3% AFFF
Proportioner	:	FireDos FD-8000/3-PPS-SW turbine
Line Pressure	:	900-1000 kPa

Three (3) foam samples were taken for analysis:

Sample No.	Flow Rate (LPM)	%
1	6001	3.2
2	6320	3.4
3	4410	3.4

3.6.9 CLN Test References

Experimental evidence supporting this new theoretical approach to fire extinguishing includes:

- Several references for installations built to these rules of design.
- Live fire tests on 500m² surface area atmospheric storage tank model, extinguishing a gasoline fire in less than one minute after a 2-minute pre-burn

period, using the CLN and pre-made foam supplied from an ASME Section VIII Division 1 pressure vessel.

- Successful extinguishment of diesel (kerosene) fires in tanks up to 500m² in less than 1 minute using a pumped system and high back pressure foam makers with the CLN
- Tests are repeatable with consistent results
- The mean size for settlers used in SX plants in hydrometallurgy is 400m².

A 2-minute pre-burn time. 21 seconds after actuation. 43 seconds after actuation.

Figure 3.6.8.1 Performance of the CLN in a 500m^2 diameter fully involved gasoline fire.

FOOTNOTES

1 Using Principles of Inherent Safety, Larry Moore, P.E., Factory Mutual Engineering

2 Thermal Radiation Assessment, Kinsevere Copper SX Plant, Protec Group, 2015

3 Brandforsk Project 513-021, Swedish National Testing & Research Institute, Tank Fires Review of Fire Incidents 1951-2003

4 Center for Chemical Process Safety Guidelines Series, AIChE

5 Directive of 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC.

6 Inherently Safer Plants, An Update, T.A. Kletz, Proceedings of the 24th Annual Loss Prevention Symposium, San Diego, CA August, 1990, American Institute of Chemical Engineers

7 Olympic Dam, Western Mining Corporation, 2001

8 Minera Cobre Las Cruces, Spain, 2013

9 Developments in Flammable Liquid Tanks Fire Protection, Robert Zalosh, 2007

10 IEC EN 61508, Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems

11 Protec Group recorded 120 faults in a master fire alarm controller located in an SX plant process control room in 2011. The system was replaced and the new master panel outputs interlocked with the SX plant DCS. If the new system reports fire, an orderly process shutdown is automatically initiated. Operators cannot abort the shutdown until the fire system is reset.

12 Novota Engineering (Protec Group), Settler Radiation Assessment, 2012.

13 SFPE Handbook of Fire Protection Engineering, Society of Fire Protection Engineers, Quincy, Mass. 3rd Edition, 2002, p. 2-303 to 2-306.

14 Flammable Liquids are defined as liquids having closed cup flash points below 100°F (37°C) and vapor pressures not exceeding 40 psi (276 kPa) (2.76 bar) at 100°F (37°C). Flammable liquids are referred to as Class 1 liquids.

Class IA liquids - flash points below 73°F (22.8°C) and boiling points below 100°F (37.8°C).
Class IB liquids - flash points below 73°F (22.8°C) and boiling points at or above 100°F (37.8°C).
Class IC liquids - flash points at or above 73°F (22.8°C) and below 100°F (37.8°C).

Combustible Liquids are defined as liquids having closed cup flash points at or above 100°F (37°C). Combustible liquids are referred to as Class II or Class III liquids.

Class II liquids - flash points at or above 100°F (37.8°C) and below 140°F (60°C).
Class IIIA liquids - flash points at or above 140°F (60°C) and below 200°F (93.4°C). c.
Class IIIB liquids - flash points at or above 200°F (93.4°C).

Ignitable Liquid is any liquid or mixture that will burn. A liquid will burn if it has a measurable fire point.

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PROTEC GROUP is a project-based team of professional engineers and technologists specializing in fire protection for high value/high risk properties, particularly SX/EW plants, petroleum products facilities, and mining operations worldwide.

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