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A Case of Choice of Passive Fire Protection (PFP) in an Oil & Gas EPC Project

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The choice of the type of Passive Fire Protection (PFP) for the protection of structural steel or process vessels in Oil & Gas or petrochemical plants depends on a number of different factors. The most obvious are related to the performance of the PFP versus its cost, but in world-scale Engineering, Procurement & Construction (EPC) projects the choice of one PFP must also take into account problems related to availability of the material in the specific country of construction, logistics and issues related to shipment, construction schedule, contractual agreements in place. Moreover, the requirements to fireproof structural steel of process vessels are project specific as they usually derive from application of international standards (API 521, 1997; API 2218, 1999), legislation in the country where the plant will be constructed, guidelines from Oil&Gas International companies and from the final Client, Quantitative Risk Analysis (QRA) studies.

The present paper presents a case of five process vessels processing natural gas and required to be fireproofed after a QRA study. The paper summarizes the analysis of possible types of PFPs that were considered for the protection of the vessels and illustrates how, in the case under study, the choice of mineral fibres has proven the best compromise between required performance and costs, minimizing at the same time the impact on construction schedule and logistics.

1. Introduction

The case is presented of five process vessels processing natural gas, with no liquid hold up, required to be fireproofed against pressurized gas jet fire for a minimum of 15 minutes.

The paper illustrates the discussion on how such requirement – derived from a QRA study – has been addressed for the case under study.

Commercially available options (cementitious products, intumescent coatings, mineral fibres) are presented and their performances are discussed versus their impacts on the Project, with an eye to delivery and construction schedules, cost, legal and contractual requirements. The final choice of using mineral fibres as PFP for the case under study is then presented and analysed.

2. Protection of steel structures from fire

In order to protect structures against hydrocarbon fires in onshore petrochemical complexes, steel is fire proofed with passive fire protection products that have been fire tested to the appropriate standard.

Steel elements to be fireproofed generally include steel structures/piperacks, supports of equipment containing flammable, combustible or toxic chemicals and supports of major equipment, with the aim to avoid escalation of damages during a major fire accident onsite.

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In plants processing or storing large inventories of liquid hydrocarbons steel structures may be protected from heat radiation generated by pool fires. Pool fires can generate flame temperatures of above 1000 °C within 10 min of ignition with heat fluxes of about 150 kW/m^2 (EAPFP, 2009).
On the other hand, plants that handle pressurized gas or Liquefied Petroleum Gas (LPG) are likely to require protection of steel structures from jet fires, which represent challenging scenarios for structures. In fact, if flame temperatures are comparable to the case of pool fires, heat fluxes can reach up to 300 kW/m^2 (EAPFP, 2009) and a pressurized jet impinging on a steel structure can cause it to collapse rapidly due to its mechanical action.
Besides, active fire protections such as water spray systems may be considered as a good alternative to fireproofing materials (and are in fact suggested in standards such as API 521 (1997)) for protection against pool fires, while they are not very effective against a pressurized jet fire due to its momentum. In such cases even some passive fire protections are unfit to resist to mechanical damage.

3. Fireproofing materials: available options

Three distinct types of passive fire protection products are normally used in hydrocarbon-processing complexes:

- Cementitious products generally based on Portland cement plus lightweight aggregates.
- Intumescent coatings generally epoxy based, spray or hand applied.
- Blanket systems made from man-made fibres which use insulation as their primary fire protection mechanism.

3.1 Cementitious products

The excellent fire protection afforded by concrete has been demonstrated many times over 90 years of experience in the petrochemical industry. The general conclusion is that concrete/gunite provides a satisfactory protection of steel structures.
Cementitious materials protect the steel in two ways. Firstly, they contain trapped moisture, which in a fire situation will boil and keep the steel temperature around 100 °C until all the water has disappeared. Secondly, the high mass and low thermal conductivity of concrete make it very effective at reducing heat input to the underlying structure.
Thermal expansion and contraction of structural support columns may cause spalling, cracking and delamination of the concrete fireproofing; firewater cooling during fire scenarios may add to the spalling problem. However, in several cases no evidence of deep damage to the concrete is found, while wire reinforcement minimizes the loss of fractured material during a fire exposure.
Concrete is a relatively simple and well understood material that is readily available around the world and can be applied by the site workforce. Still, poor quality of the materials or inadequate attention during the placement on the steel structure may lead to well known problems of corrosion under fireproofing, cracking and spalling of the concrete, loss of adhesion of the concrete to the steel substrate which renders the concrete fireproofing more susceptible to explosive spalling during a fire exposure. Some process licensors tend to discourage the use of cementitious PFPs due to such problems related to corrosion under fireproofing.
The weight of concrete on structures has an impact on the design that must be evaluated. A two inch thickness of concrete weighs approximately 125-150 kg/m^2. Lightweight cementitious fireproofing materials weigh significantly less, typically 25-50 kg/m^2 (Schilling, 2007).
Such lightweight products – aggregates such as vermiculite, perlite, and diatomite – show a good fire resistance and generally less spalling than dense concrete. The more porous structure of lightweight cementitious fireproofing materials better enables water to escape. On the other hand, lightweight cementitious fireproofing materials are less durable than concrete, with lower resistance to physical abuse and a greater tendency for water absorption. Besides, vendors generally require a primer coating for corrosion protection of the steel substrate as well as a sealer coat to improve durability and resistance to weathering and moisture intrusion during everyday exposure in the plant.

3.2 Intumescent coatings

Intumescent coatings have been a commercial reality since the 1960’s. When exposed to sufficient heat, intumescent coatings expand to form a thick, insulating carbonaceous char. The protection of the steel substrate ultimately relies on the thermal insulating capability of the char and the ability of the char to remain adherent and physically intact.

Intumescent coatings are very light products, their weight being within the range 5-25 kg/m^2 (Schilling, 2007).

Intumescent coatings are exceedingly complex coating materials that need to perform all of the functions that other exterior weathering coatings do (adhesion, hardness, toughness, corrosion resistance, etc.) and then, when exposed to sufficient heat, they need to transform and expand to form a thick, insulating, carbonaceous char. Such transformation involves a number of chemical reactions – acid release, char formation, and gas generation – that need to occur in a well coordinated fashion.

Intumescent coatings are generically similar but complex proprietary products can be very different for what concerns requirement for primers or reinforcements, weathering and chemical resistance, temperature of activation, which may range from 150 °C down to 65 °C (Schilling, 2007), natural limits on applied thickness and on the shapes of the steel structures to be protected (typically, longitudinal fissures develop on pipes because the coatings do not intumesce in the tangential direction, or fissures may develop at flange edges of I-beams).

One main problem with intumescent coatings is related to severe corrosion of the steel substrate that has been sometimes reported beneath apparently intact coating. In some cases the problem has been tied to hot weather coating applications where chlorinated solvents were used to thin the coating material. It's been argued that some of the chlorinated solvent remains trapped in the thick coating and the chlorinated solvent may later degrade to give hydrochloric acid.

The second consideration is that intumescent coatings – like other organic paints and coatings – may degrade with prolonged outdoor weathering and exposure to slightly elevated temperatures. The intumescent capability may be degraded to show delamination, softening, blistering and other signs of deterioration by prolonged outdoor weathering or exposure to elevated temperatures. In some cases, samples of aged coating being heated in a furnace may show no intumescent reaction but simply burn and disintegrate.

3.3 Thermal Insulation as Fireproofing

Such type of fireproofing are capable to protect by insulating the steel substrate from the heat of a fire and so thermal insulation systems can provide a dual role of thermal insulation as well as of passive fire protection.

Insulation materials for low temperature service – e.g. polyurethane foam – typically do not have good fire resistance, since they are quickly destroyed by the heat of a fire. They can be supplied with flame retardant additives to improve fire resistance (generally organo-phosphorous compounds and/or halogenated organic compounds) but such additives produce toxic fumes and produce over time corrosive components that may promote severe corrosion under insulation, typically on cold tanks (e.g., LPG).

Mineral wool and cellular glass have many unique properties. In particular, they are lightweight, dimensionally stable, essentially impermeable to moisture, and they are non-combustible (ASTM E136, 2011) with a flame spread rating of 5 (ASTM E84, 2011) and no smoke production. The absence of chemical binders also ensures there are no major issues of corrosion of the steel substrate and no toxic fume emission during a fire, which is a useful contribution to overall safety.

Besides, they show a good resistance to weathering or ageing. In sum, cellular glass and mineral fibres are ideal insulation materials for hot/cold service and – if properly designed – they can also provide the role of fireproofing.

Aluminium jacketing is common for thermal insulation systems but it cannot be used for fireproofing since Aluminium melts at about 660 °C (1220 °F).

Stainless steel jacketing is generally employed to obtain fire resistance. But there are additional details if one wants to achieve fire resistance with cellular glass:

• A minimum of two layers of cellular glass, each two inches (50 mm) thick for a total minimum thickness of four inches (100 mm).
• The individual layers are staggered so there are no through-thickness seams.
• Each layer needs to be mechanically fastened and supported with stainless steel bands or clips.

• A polymeric adhesive needs to be used to glue the blocks of glass together and to provide a final surface coating.

4. The case study

We present the case of five process vessels used for removal of excess Mercaptans from a stream of natural gas; the Mercaptan removal occurs by adsorption on molecular sieve beds. Three out of five vessels work in adsorption, one is in regeneration, one is in cooling. The time sequence is such that adsorption phase lasts for 18 hours while regeneration and cooling phases last for 6 hours each.

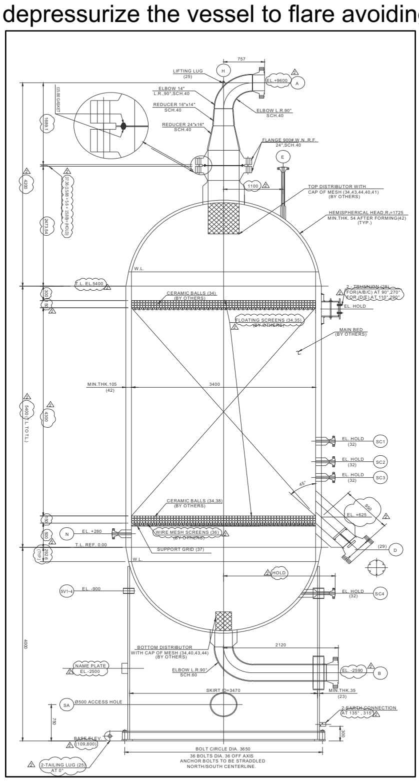
An excerpt from the mechanical drawings of one vertical vessel is shown in Figure1.

Operating temperature and pressure during adsorption phase are respectively 35 °C and 65 bar. The regeneration process occurs at operating temperature of 300 °C and operating pressure of indicatively 22 bar.

The original design of the vessels included thermal insulation for Personnel Protection for Health & Safety reasons during the regeneration phase when internal temperature reaches 300 °C. Such thermal insulation was aimed at keeping the outside skin temperature of the vessels at a maximum 60 °C and consisted of an 80 mm-thick layer of mineral wool with a density of 70 kg/m^2 and an external 1 mm Aluminium coating.

In normal operating conditions no liquid HC is expected within the process vessels, since the natural gas stream is dehydrated and separated from its condensable fraction prior to flowing through the five process vessels. According to the project general specifications agreed with the Client no fire proofing was originally considered for protection against pool fire based on API 521 (1997) and API 2218 (1999) standards.

The requirement for fireproofing of the bodies of the five vessels derived from a QRA. The case was analyzed of a jet fire originated from one vessel and impinging on another vessel. The layout (see Figure 2) is such that heat radiations of 80-100 kW/m^2 could be reached on the vessel skin. Operating conditions during adsorption phase are such that the blow-down system would be sufficient to depressurize the vessel to flare avoiding catastrophic damages to the body of the vessel itself.



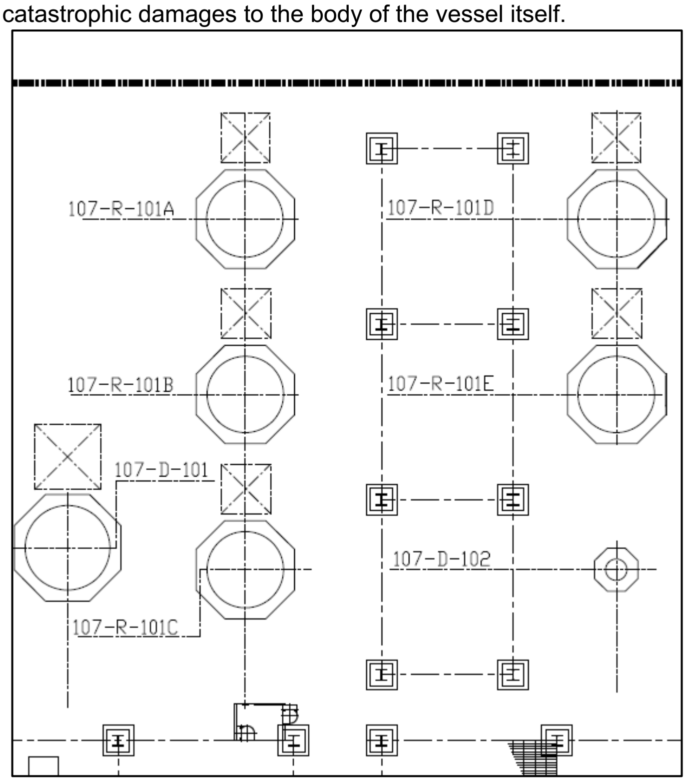


Figure 1: Mechanical sketch of one vessel   *Figure 2: Layout of the five vessels (107-R-101A/E)*

However, a jet fire impinging on one vessel during regeneration phase would be a critical scenario, mainly due to the high operating temperature of the vessel skin. In such a case the portion of vessel impinged by the jet could start degrading its properties of mechanical resistance well before the 15 minutes needed for the blow-down system to reduce significantly the internal pressure of the vessel, leading the vessel to possible collapse. Therefore the fireproofing was requested to protect the vessels against jet fire for a minimum of 15 min.

It should be noted that systems with a high inventory of hydrocarbon gases and no liquid hold-up are more critical in scenarios like the one under study: the presence of internal liquid that can vaporize may perhaps make depressurizing times longer but on the other hand may provide cooling to the steel vessel skin helping preserving its mechanical resilience.

The request for protection of the bodies of such process vessels came from QRA/Client's request. The extra protections considered in API521 (1997) section 3.15 were discussed and finally the use of fireproofing was chosen as appropriate for the scenario under study.

5. Selection of the type of PFP

The request for fire-proofing of the five vessels came in a relatively advanced stage of the engineering activities, with the five vessels already under manufacturing. Even though it was still possible to make amendments to engineering specifications and data sheets forwarded to the equipment Vendor, certainly it was important to consider the impact of such amendments on the schedule of delivery of the vessels to site. It should be specified that the vessels were being manufactured in the Far East and they needed to be shipped to the site in the Gulf region. Of course, the economic impact of such amendments was certainly to be taken in due consideration.

Cementitious materials could combine relatively low extra cost and easy application on site and needed only proper supports to be welded in the workshop prior to shipping. Gunite could be sprayed on site and would not require specifically trained personnel to perform the job. Also, the material was available and easy to be procured in the country of construction. On the other hand, the choice of cementitious materials and the large areas of the vessel shells did pose a problem related to the extra weight on the supports of the vessels. Moreover, the future plant will be constructed in an aggressive marine environment and therefore possible corrosion under the cementitious fireproofing is a main concern.

The option of intumescent coatings was investigated and enquiries were made with a few Vendors, a couple of which could deliver in the country of construction and were already qualified by the Client. Major concerns about this type of PFP were raised regarding the cost, the applicability of the material in the aggressive marine environment of the Gulf region. Besides, the issues of durability and resistance to ageing and weathering were issued by the partners of the EPC consortium. One more doubt regarded the times of delivery of the intumescent coating required and whether those would delay the construction schedule on site.

The final choice was a mineral fibre coating. The original requirement of 80 mm rock wool with Aluminium coating had to be increased to a 140 mm thick layer with stainless steel external coating. The 140 mm thickness is reached using two individual layers that are staggered so there are no through-thickness seams.

For vessels already required to be thermally insulated the option of ceramic fibre fire protection was considered the most practicable. In this case the impact on engineering activities is minimized, no new material needs to be provided and applied, with small impact on the procurement side, on logistics or shipment.

The application of the new insulating material on site certainly requires specific application procedures to be followed, especially if the Vendor is asked to provide performance guarantees against an approved test (BS 476, 1987, ASTM E1529, 2010, UL 1709, 2011). On the other hand, the product is a well known material that can be handled by the site workforce, with assistance from the Vendor. Therefore the vessels can be fabricated in workshop as per original design and with no need to alter the original schedule, then shipped to site and erected. The ceramic fibre layer can then be applied on site by EPC contractor, following Vendor's recommendations. Therefore the impact on application schedule and costs can be optimized.

The system performance is certified by internationally recognized bodies such as Lloyd's register.
The need for a thicker layer of ceramic fibre may not be critical on the budget, while the need for a 0.7 mm stainless steel instead of a 1 mm Aluminium external coating may impact on cost, depending on the price of the materials at the moment of the purchase.
The choice of mineral fibre PFP does not pose any extra impact or issue from the point of view of adhesion to steel structure, hardness, toughness, resistance to ageing and weathering or corrosion resistance, etc).
The original design of the five vessels needed to undergo small modifications to adapt the supports/rings to the new thickness of the insulation layer.

6. Conclusions

The choice of the type of PFP depends very much on the specific requirements and constraints of an Oil&Gas EPC project.
Technical performance naturally represents the first criteria of choice, which needs to be balanced against the impact on engineering, procurement and construction activities. To this extent, the same technical requirement agreed in the month 1 or in the month 15 of the schedule will have completely different impacts on the overall project.
As a conclusion, in the case under study the choice of mineral fibres has proven the best compromise between required performance and costs, minimizing at the same time the impact on construction schedule and logistics.

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