

Fire Precautions

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CHARACTERISATION OF PASSIVE FIRE PROTECTION (PFP) MATERIALS AGAINST JET-FIRE IMPINGEMENT

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Summary

This DIN provides a summary of the main findings arising from recently completed research to study the performance of PFP materials as a means of protecting LPG tanks against jet-fire impingement.

Project Objectives

The principle areas of work were:

- (i) review of the current methods used to characterise the fire performance of PFP materials;
- (ii) development of a standard method to evaluate the performance of PFP materials against jet-fire impingement;
- (iii) validation of the standard test method developed against a realistic jet-fire impingement on a PFP coated LPG tank.

Main Findings

- (i) Review of current test methods.

The majority of existing methods used to characterise the fire performance of PFP materials model a cellulosic fire; for example the BS476 Part 20 furnace test. When used on vessels containing flammable liquids and gases, occasionally a hydrocarbon pool fire has been used to provide a more realistic measure of the PFP materials performance. For example earlier work carried out at HSL, Buxton in the 1980s used this method.

However on an LPG storage facility a jet-fire is the more likely incident scenario. Experiments have shown such fires to be significantly more challenging than pool fires. This is due to the high localised heat flux, typically about 200kW/m² compared to about 100kW/m² from a pool fire, and the mechanical erosive effects of the jet.

On the basis of heat flux alone, a vessel in a pool fire can be expected to fail after about 10 to 12 minutes fire engulfment. Under jet-fire impingement failure can occur within 5 minutes.

The review concluded that a jet-fire test is needed to characterise the performance of PFP coatings on vessels containing pressurised flammable liquids and gases, such as LPG tanks.

(ii) Development of standard test.

Tests may be carried out on LPG tanks. Whilst these have the benefit of directly indicating the PFP materials fire performance, there are various drawbacks with such an approach.

The tests are expensive. Each validation trial carried out in the course of this work cost about £60k. This compares to circa £10k for the standard (reduced-scale) jet-fire test developed.

The tests on LPG tanks need to be aborted before the PFP material fails, whereas in the standard test the material can be taken to failure. (Allowing a tank to BLEVE will clearly involve significant extra expenditure to cover the cost of the tank and additional safety measures will be required.)

The tests are also only of limited application, namely to an LPG tank. Whereas the standard test can be potentially applied to a wider range of uses. Provided of course that the appropriate validation trials are carried out.

Coincidentally with DST's (then THSD's) desire for a realistic and cost-effective test of a PFP materials fire performance to be developed, OSD had a similar requirement. This arising from the Cullen Report of "the public inquiry into the Piper Alpha disaster". Recommendation 52 requiring OSD to work with industry to develop a test method reflective of the high heat fluxes and pertinent characteristics of a jet-fire.

Recognising that there could be considerable overlap in the onshore and offshore requirements of any test-developed, OSD and DST agreed to collaborate on this. To take the work forward the Jet-Fire Test working Group was formed. As well as representation from HSE, there were also members from the Norwegian Petroleum Directorate, Lloyds Register, Industry representing the user of PFP materials and other international test houses.

As a consequence of the work of this group a reduced scale jet-fire test procedure has been developed. Full details of the test and test protocol have been published as an HSE - Offshore Technology Report - OTI 95 634 "Jet-Fire Resistance Test of PFP Materials".

The test employs a 0.3kg/s propane vapour sonic velocity jet which impinges on a 1.5m square target coated with the PFP material, 1m away. The principal characteristic of the test set-up is that complete fire engulfment of the test specimen results, giving the most onerous heat flux conditions. The actual target used is chosen on the basis of the item of plant to be protected; ie panel; planar steelwork; structural steelwork and tube/pipe. The planar steelwork test is held to be representative of an LPG vessel.

The performance of the PFP material is assessed from the temperature measurement from the array of thermocouples fixed to the rear of the target.

(iii) Validation of the standard test method against a full scale test.

For the full scale test, the target chosen was a 20% full 2 tonne LPG tank. The PFP coatings used were to the same specification as those used on the standard test. The jet-fire was mimicked as a 1.5kg/s flashing liquid propane jet, 4m from the tank. The flashing liquid release is considered typical of the type of release expected in an industrial accident, such as damage to a pipe carrying liquid LPG. The discharge rate and distance of the jet from the tank were chosen to effect complete fire engulfment of the tank. This being considered to produce the most onerous heat flux transfer to the tank.

In the test, temperature measurements were made from thermocouples located on the surface of the tank, above and below the liquid level, beneath the PFP coating. The pressure within the tank was also measured over the test period.

The tests demonstrated that the temperature of the tank in the vapour space was the critical parameter. Below the liquid level, whilst the temperature of the tank increased, it did so much more slowly than in the vapour space. The liquid LPG providing a substantial heat-sink. After 80 minutes the temperature of the tank remained at about 50°C below the liquid level, whereas above this in places it had reached 200°C.

The internal pressure increased steadily over 45 to 50 minutes until the PRV opened. This occurred at about its nominal set pressure of 17.6 bar g. Thereafter the pressure remained relatively constant, at about 3 bar below this.

By way of comparison, the PRV on an LPG tank without a PFP coating, when subjected to the same jet-fire, operated within 2 minutes.

The temperatures measured on the tank above the liquid level were found to be broadly comparable to those measured on planar steelwork in the reduced scale jet-fire test. The maximum temperatures measured on the tank were actually found to be a little higher than those on the planar steelwork. This is believed to be due to the reduced heat losses prevalent in the tank compared to the planar steelwork target. Further work is to continue on insulating the rear face of the planar steelwork to mirror the lower heat losses which occur on the tank.

However a reasonable conservative estimate can still be achieved by also considering the vertical web temperatures, which are higher than those measured on the tank. These along with the planar steelwork temperatures are measured if the structural steelwork target is tested. As such this target, at least in the interim, might be the most cost effective for a company to choose to have their PFP material tested.

The flashing jet used in the full scale test would appear to be less mechanically erosive than the sonic jet used in the reduced scale jet-fire test. In particular the sonic jet is seen to provide a more challenging examination of the reinforcing mesh's performance in keeping the PFP coating in place.

In conclusion the standard (reduced-scale) jet-fire test has been shown to give a reasonable indication of a PFP materials fire performance on an LPG tank.

CONCLUSIONS

PFP materials can be effective in protecting LPG tanks against the effects of fire, including the most challenging of jet-fire impingement.

The performance of PFP coatings against jet-fires can only be properly assessed by a test involving a jet-fire.

A full-scale test may be carried out. But a standard (reduced-scale) jet-fire test has been developed and shown to be a viable alternative. This test is more cost-effective and can be used to model a wider range of applications for PFP materials than a specific full-scale test.

The standard test provides a measure of the fire performance of the PFP material for a given thickness and reinforcing mesh in terms of a temperature-time profile for the protected metal target.

The data may be limited to cover only a specific period of fire exposure, or be extended to determine when the PFP material finally fails. It is important to note that the performance of PFP materials over a specific period of fire exposure cannot be accurately extrapolated. Therefore when using such data to determine the period of fire protection needed for an LPG tank, a suitable safety factor needs to be included.

For a LPG tank, the fire performance criterion of a PFP coating is essentially to prevent failure and BLEVE of the LPG tank. The length of time for which the PFP coating needs to remain effective against jet-fire impingement will depend on the incident scenario envisaged. HS/G34 recommends a minimum period of 60 minutes, but it is possible that certain incidents will require a longer period of protection to be provided, before they can be effectively brought under control.

The critical parameter in determining whether an LPG tank might BLEVE is the temperature of the tank shell in the vapour space. The actual critical temperature depends on the vessel design, including the type of steel used and thickness of the tank walls. It is for the tank owners to assess and be able to justify the maximum temperatures that plant can safely withstand without catastrophic failure.

From work carried out at HSL on the failure of LPG tanks designed to BS5500: 1976, 300°C has been determined to be a reasonable limiting critical temperature. Above this the steel strength starts to fall and the tank's integrity compromised.

REFERENCES

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