DESIGN AND PROTECTION OF PRESSURE SYSTEMS TO WITHSTAND SEVERE FIRES

T A Roberts*, I Buckland**, L C Shirvill***, B J Lowesmith**** and P Salater*****
*Health and Safety Laboratory, Buxton, Derbyshire SK17 9JN
**Technology Division, Health and Safety Executive, Merseyside L20 3QZ
***Shell Global Solutions, P.O. Box 1, Chester CH1 3SH
****Advantica Technologies, Loughborough, Leicestershire LE11 3GR
*****Norsk Hydro ASA, Stabekk, 0246 Oslo, Norway

Mitigation of the impact of severe fires on hydrocarbon processing plant is critical to minimising the risk to personnel, reducing damage and limiting capital loss. It is recognised that current experimental data and the associated model validation are mainly confined to the response of vessels containing Liquefied Petroleum Gas. Models for predicting the behaviour of vessels containing multi-component fluids (with or without emergency depressurisation) under severe fire loads exist. However, relatively little validation has been performed.

Currently, industry tends to use the American Petroleum Institute's Recommended Practices 520 and 521 for the design of pressure relieving systems to withstand fire conditions but these are only applicable to some of the less severe, hydrocarbon pool-fire scenarios. Under the auspices of the Institute of Petroleum and with the support of the Health and Safety Executive, interim guidelines have recently been published. They are intended to assist design and process engineers concerned with large, essentially fully enveloping pool fires and jet-fire impingement on pressure vessels and their associated pipework. The guidelines are intended for use primarily for designing new facilities and specifically deal with fires that are more severe than the open pool fires currently covered by API guidance.

This paper considers the guidance in the API recommended practice and the new Institute of Petroleum guidelines and compares the approaches with data from hydrocarbon pool and jet-fire trials on filled propane vessels.

KEYWORDS: Pool fires, jet fires, heat transfer, fire protection, pressure relief, emergency depressurisation, pressure vessels.

INTRODUCTION

Pressure systems are either designed to withstand the highest expected pressure or fitted with means of preventing over-pressurisation. During normal operations, protection of pressurised systems is provided by appropriately sized pressure relieving devices, typically pressure relief valves (PRV) and/or bursting discs, which are designed to automatically limit the maximum pressure within the systems. Process plant, especially that offshore, is usually fitted with an emergency depressurisation (EDP) system, in addition to a PRV, in order to reduce the risk and consequences of failure. In an emergency, the EDP system allows intentional and controlled discharge of the contents of the process plant into the flare or vent facilities.

Whilst PRVs are designed to prevent failure of pressurised systems due to over-pressurisation, it is recognised that the load-carrying capacity of pressure systems will be significantly compromised by exposure to fire. This occurs as a consequence of reduction of the strength of the vessels and pipe-work with increasing temperature. In general, there will be critical temperatures where, for example, vessels will fail, valves will cease to function adequately and/or flange connections will loosen. Pressure systems can also fail due to the increasing pressure exerted by their contents as these to rise in temperature and if the relief system is inadequate. Hence, the ability of pressure relieving and depressurisation systems to safeguard pressurised systems in a fire is critically dependent upon the assumptions made about the type and size of the threatening fire.

Currently, industry tends to use American Petroleum Institute's Recommended Practices 520[1] and 521[2] for the specification of pressure relieving systems to enable pressurised plant to withstand fire conditions. However, these are restricted to some of the less severe hydrocarbon pool-fire scenarios. Under the auspices of the Institute of Petroleum, and with the support of the Health and Safety Executive, interim guidelines[3] have recently been published. They are intended to assist design and process engineers concerned with large, essentially fully enveloping pool fires and jet-fire impingement on pressure vessels and their associated pipework. The guidelines are intended for use primarily for designing new facilities and specifically deal with fires that are more severe than the limited sizes of open pool fires currently covered by API guidance.

This paper considers the approaches in the API Recommended Practice 521[2] and the new Institute of Petroleum guidelines[3] and compares the approaches using data from kerosene pool-fire trials and flashing-liquid propane jet-fire trials on filled, horizontal, cylindrical propane vessels. A brief consideration of EDP systems is also given.

MANAGEMENT OF FIRE HAZARDS

Safe operation does not rely solely on the protection afforded by relief and depressurising systems. Indeed, pressure relief and depressurising systems are safeguard measures that only come into play when other measures aimed at preventing fires have failed. Good design (for example, careful use of flanged connections), elimination of potential ignition sources (e.g. hazardous area classification and permit-to-work procedures; such as for hot work), and early fire detection and response (in the unlikely event that ignition does occur) all play a role.

As shown later, pressure relief and depressurisation do not guarantee that vessels will not fail in a fire, particularly a severe fire. In principle, depressurisation and fire protection can prevent vessels from failing, but in practice the adequacy of these measures must be judged in the context of the likelihood and consequences of vessel failure. For example, a higher level of safeguards will be required on a manned offshore facility or onshore installation with offsite populations in close proximity, than on a small vessel in a remote location.

It is now common practice to carry out a fire risk analysis where measures taken to reduce the risk of a fire occurring, and the effectiveness of mitigation measures should a fire occur, are all included. Depending on the nature and size of the facility, the fire risk analysis may range from a simple assessment through to a fully quantified risk assessment (QRA). For offshore facilities, this would be part of the Fire and Explosion Strategy (FES) outlined in ISO 13702[4]. For onshore installations, this would be incorporated in the process safety management system for the plant and, where applicable, form part of the safety report or demonstration of safe operation to the competent or regulatory authority.

CURRENT INDUSTRY PRACTICE

A survey (under the auspices of the Institute of Petroleum (IP)), of a world-wide range (circa 160 organisations) of operators/owners, consultants and design contractors, indicated that there was no consistent approach or consensus on what criteria to use to design against the risk of severe fires. The main conclusions from the responses and information received were:

(a) There is little consistency in the design methodology used, even within a single company;
(b) Some said they had limited in-house expertise and engaged a specialist design contractor; and
(c) Some applied API RP 521 and assumed that by designing to that code, there was no additional risk.

There appeared to be no industry-preferred methodology and this has been taken as being the justification for preparing interim IP guidelines.

Whilst the recommendations and equations in API RP 521 are generally applicable to a refinery or chemical plant, they were never intended to cover all fire scenarios, especially those that may foreseeably occur on offshore installations. The scope and application does not apply to very large enveloping pool fires or impinging jet fires. Hence, should process plant fitted with protective systems designed to API RP 521 or a similar standard be exposed to severe fires, such systems may be insufficient to prevent failure of the vessel before the inventory has been safely removed. Should the vessel contain a hazardous inventory (usually flammable hydrocarbons), the consequences of failure will be compounded with potentially catastrophic results and escalation of the event.

AMERICAN PETROLEUM INSTITUTE RECOMMENDED PRACTICE 521

As indicated above, industry has traditionally used the American Petroleum Institute's Recommended Practice 521[2] when designing pressure vessels to withstand the effects of fire. When a pressure vessel containing liquid and vapour hydrocarbons is heated by fire, there are two main considerations:

(1) Heat will be transferred to the contents thereby increasing the pressure.
(2) The vessel wall not in contact with liquid may be heated to a point where the vessel fails.

HEAT TRANSFER TO THE CONTENTS

The basic formulae given in API 521 for the heat absorbed by the contents of a vessel engulfed in fire is:

$$Q = 43.2\ F\ A^{0.82} \text{ (with adequate drainage)} \qquad (1)$$

$$Q = 71.0\ F\ A^{0.82} \text{ (without adequate drainage)} \qquad (2)$$

where Q is the heat absorbed (kW), A is the effective wetted surface area of vessel (m^2) and F is an environment factor.

The effective wetted area of the vessel is defined as the surface area of the vessel in contact with liquid up to a height of 7.62 m (25 ft) above ground level or other surface that could sustain a fire. Effective elevation is based on observations that wind and shape effects limit the contact of the fire with the vessel as the elevation increases. Some companies use larger values for the effective elevation. The philosophy of wetted area is that heat transferred to the liquid will eventually cause it to boil and produce more vapour, whereas heat transferred to the vapour phase will just cause vapour expansion. The environmental factor (F) is an attempt to correct the heat flow for the effect of insulation, water drenching and earth covering. The values used for F and limits of application give rise to most conflicts between codes (see Parry[5]).

HEAT TRANSFER TO THE UNWETTED SURFACE

Heat input from an open fire to the bare outside surface of an unwetted wall may, in time, be sufficient to heat the vessel wall to a temperature high enough to rupture the vessel. API RP 521 gives two illustrative figures. The first figure gives the average rate of heating of steel plates exposed to an open gasoline fire on one side. Observed data (mean temperature versus time) for plate 3.2 mm (1/8 inch) thick are given together with computations for plates 3.2 mm, 12.7 mm and 25.4 mm thick. The second figure illustrates the effect (rupture stress versus time at indicated temperature) of overheating steel (AST A 515, Grade 79).

INSTITUTE OF PETROLEUM INTERIM GUIDANCE

Scandpower Risk Management AS[6] have prepared a guideline for protection of pressurised systems exposed to fire for Statoil and Norsk Hydro. It is based on Norsk Hydro's internal guidance and is primarily concerned with the design of systems fitted with emergency depressuring systems (EDP), although much of the information given is also relevant to other systems. The guidance produced by the Institute of Petroleum (IP) draws heavily on this guideline in relation to EDP. However, the IP guidance[3] has a wider scope in that it is intended to also cover vessels, e.g. storage vessels, which are not normally fitted with EDP systems. The key components of the IP guidance are:

- An outline of the design process;
- fire types and thermal loading;
- Equipment response and failure prediction;
- Protective measures; and
- Areas of uncertainty, which might warrant further study.

The IP guidelines are intended to supplement the existing codes and should be used in conjunction with them. The main differences between the IP and API guidance are in relation to severe fires. These are considered as follows.

MEASURED HEAT FLUXES

Over the past 15 years, there has been a number of joint industry projects designed to generate data for the validation of models for predicting the response to open and confined severe hydrocarbon pool and jet fires. It is not the intention to review this data here but some of the key references are given as background information to the proposed values given later:

- Most of the experimental data prior to 1991 are summarised in reports produced as part of Phase 1 of the Blast and Fire Engineering Project for Topside Structures (Cowley and Johnson[7] and Cowley[8]).
- Data on free and impinging horizontal jet fires were obtained as part of two European Community (EC) projects viz. AA and JIVE. As part of project AA *(Two-phase releases for toxic and flammable substances: Thermal initiation, source terms and fire effects*), a programme of large-scale steady state ignited jet releases of natural gas and liquefied petroleum gas (LPG) was performed during the period 1988 – 1989. A total of 125 individual experimental data sets were prepared, including 68 experiments in which the fires impacted onto a cylindrical vessel or a pipe. Cowley and Pritchard[9] published some of the work in regard to the thermal impact on structures.
- The JIVE project[10] was concerned with the *Hazard consequences of jet fire interactions with vessels containing pressurised liquids*. Part of the project was concerned with taking 2 tonne propane tanks to failure[11] via a nominal 2 kg s^{-1} flashing liquid propane jet fire. Another part of the JIVE programme of work, performed by Davenport[12], involved measurement of the impact of the flames from the natural gas/butane mixtures on targets.
- In 1995, Gosse and Pritchard[13] studied the heat transfer from vertical natural gas jet fires impacting onto the underside of a flat 20 m by 20 m deck at flow rates up to 3 kg s^{-1}. The effects of exit pressure and orifice diameter, stand-off distance, partial confinement and wind speed were studied.
- Unconfined crude oil jet fires were studied in Phase 2 of the JIP on 'Blast and Fire Engineering of Topside Structures' (Selby and Burgan[14]) and in a subsequent JIP on releases of 'live' crude oil containing dissolved gas and water (Evans[15] et al.).
- A major experimental programme of large-scale compartment fires (Chamberlain[16]) was carried out by Shell research at SINTEF. 0.35 kg s^{-1} propane jet fires were burnt inside a 135 m^3 insulated steel compartment with reduced ventilation to simulate accidental fires in offshore modules. Further work on confined fires was performed in Phase 2 of the JIP on 'Blast and Fire Engineering of Topside Structures' (Selby and Burgan[14]), where a 415 m^3 insulated compartment was also used.

The data from these trials have been used to derive the values proposed later.

HEAT LOADS FROM JET AND POOL FIRES

In order to calculate the heat up of vessels or pipe-work subjected to fire, it is necessary to quantify and understand the thermal load imposed by fires. This thermal load is a combination of convection from the hot combustion products passing over the object surface and radiation emitted by the flame to the object surface. In reality, this is a very complex event and the following issues are relevant:

- The relative proportions of radiative and convective load from a flame will vary depending on the fuel type and location of the object within the flame;
- The total heat loads will vary depending on the fuel type, the size and shape of the object and the location of the object within the fire;

- The heat loads will vary over the surface of the object; and
- The heat absorbed by the object will vary with time.

In most cases, it can be assumed that the flame and the object surface are diffuse grey bodies and that the ambient temperature of the surroundings is low compared to the flame temperature. Using these assumptions, in simple terms for a fully engulfing fire, the heat flux absorbed by the object can be expressed as:

$$Q_{ABS}\,(kWm^{-2}) = Q_{RAD} + Q_{CONV} = \varepsilon_s\,\sigma\,(\varepsilon_f\,T_f^4 - T_s^4) + h\,(T_f - T_s) \qquad (3)$$

where ε_f, ε_s are the flame and surface emissivities respectively, σ is the Stefan Boltzmann constant (5.6697×10^{-11} $kWm^{-2}K^{-4}$), T_f , T_s are the flame and object surface temperatures (K) respectively, and h is the convective heat transfer coefficient ($kWm^{-2}K^{-1}$).

It is important to note that the thermal loading absorbed by an object in a fire as described by equation (3) will reduce as the object heats up. As can be seen, if the object heats up, T_s will increase whilst T_f is likely to remain much the same, resulting in reduced Q_{ABS}. The important parameters (likely to be unchanging in a steady state fire) are thus T_f and ε_f for radiative loading, and T_f and h for convective loading. Generally speaking, it is these parameters that need to be specified together with ε_s (which may change with temperature) for calculation of the response of an actual section of pipe-work or vessel subjected to fire impact. Therefore, these are the parameters specified in Table 1 for different fire scenarios.

However, researchers most often quote heat flux loadings from fires to objects in kilowatts per square metre, for example, as in the results[14] of the Blast and Fire Engineering Project, Phase 2 and the interim guidance notes issued[17] after Phase I of that project. Without other information such as T_f and ε_f this may be of little value. Furthermore, in experiments designed to assess thermal loading from flames to objects, the "load" actually measured is that absorbed by instruments situated on the object surface, not the surface itself. Typically, calorimeters are used to measure the total heat load and sometimes radiometers are deployed to measure the radiative component. During the experiment, the instrument is deliberately maintained at a constant known temperature. In the Institute of Petroleum Interim Guidance[3], advice is given on how some of the above factors can be simplified for calculation purposes and on the interpretation of heat flux measurements.

PROPOSED VALUES

As mentioned above, different fire types will result in different heat fluxes, for example:

- High pressure releases of fuel, with a significant gas content, will tend to produce a high convective flux.
- Pool fires and jet fires of liquid fuels tend to have a low convective flux.
- Higher hydrocarbons tend to produce more radiative flames.
- Fires in enclosed spaces can result in higher flame temperatures and hence fluxes through restricted heat losses (they can also result in lower values if the air supply rate is too low).
- Very large fires can produce higher flame temperatures and hence fluxes.

Table 1. Typical parameters for pool and jet fires

Fire type	Open pool fires	Severe or confined pool fires	Open jet fires[c]	Confined jet fires
Total incident flux[a] (kWm^{-2})	50–150	100–250	100–400	150–400
Radiative flux[a] (kWm^{-2})	50–150	100–230	50–250	100–300
Convective flux (kWm^{-2})	0	0–20	50–150	50–100
Emissivity[b] of flame ε_f	0.7–0.9	0.8–0.9	0.5–0.9	0.8–0.9
Temperature of flame, T_f(K)	1000–1400	1200–1450	1200–1500	1200–1600
Heat transfer coefficient, h ($kWm^{-2}K^{-1}$)	0	0–0.02	0.04–0.17	0.04–0.11

Notes: a) Radiative (and total) flux does not take account of emissivity of surface of object (that is, quoted values are equivalent to $\varepsilon_s = 1$).

b) Emissivity is influenced primarily by fuel type and size of the fire. Higher hydrocarbons characteristically have higher emissivities. Large fires will also tend to produce more luminous flames due to soot production and again this will tend to lead to higher values of emissivity. The values presented relate primarily to hydrocarbons and values outside this range may apply for other fuels, especially if cleaner, essentially soot-free flames are observed.

c) Mixed fuel jet fires with both high velocity gas and a higher hydrocarbon liquid fuel tend to produce the highest heat fluxes, producing both high radiative and convective components. The lowest overall fluxes are expected from pressurised liquid releases of higher hydrocarbons ($\geq C_5$).

Hence, a wide spectrum of fires can be produced with differing heat fluxes depending on various parameters. Typical heat fluxes produced by hydrocarbon pool and jet fires may vary as shown in Figure 1, depending on the confinement and severity of the fire. For simplicity, the following four categories of fire are proposed in the IP Interim Guidelines for consideration in the design process:

- Open pool fires
- Large or confined pool fires
- Open jet fires
- Confined jet fires

The heat fluxes measured in experiments (see MEASURED HEAT FLUXES above) are closely related to the initial incident heat flux experienced by an object. Hence, Table 1 presents values of heat flux (total, radiative and convective) typical of those initially expected from a fire to an object. The radiative flux given represents $\sigma\, \varepsilon_f\, T_f^4$ and the convective flux given represents h $(T_f - T_s)$ when T_s is low (nominally ambient). The table presents ranges of values - emphasising the point illustrated in Figure 1 that fire types are widely varying.

In experiments where direct measurement of heat flux is made, the reported heat flux is the incident heat flux. However, in experiments where the heat flux is calculated from the rise in temperature of the contents the reported heat flux is the absorbed heat flux.

COMPARISON WITH DATA FROM FIRE TRIALS ON PROPANE VESSELS

A comparison, of the heat transfer predictions from the IP guidance and the pressure relief requirements of API, is made with experimental observations from hydrocarbon pool fire and flashing liquid jet-fire trials on filled propane vessels.

EXPERIMENTAL TRIALS

The Health and Safety Laboratory has performed two sets of fire trials on filled propane tanks. Moodie[18] et al. conducted trials to determine the behaviour of a 5 tonne horizontal cylindrical LPG tank engulfed in kerosene pool fires (Figure 2). Five tests were carried out with commercial propane fill levels from 22% to 72%. The kerosene and vessel were contained in a 3.8 m by 6.8 m bund. In fire durations from 11.6 minutes (22% fill) to 31.0 minutes (72%) fill, the peak heat fluxes, corrected for the absorptivity (assumed to be 0.8) of the pipe calorimeters used, was 105 kWm^{-2} (incident heat flux). It was stated that the engulfing fires were fully established within 3 minutes of ignition with heat fluxes of 100 kWm^{-2}.

Roberts and Beckett[19] performed four trials on 2 tonne horizontal, cylindrical LPG tanks engulfed in nominal 2 kgs^{-1} flashing-liquid propane jet fires (Figure 3). Tanks with fill levels from 20% to 85% were heated in a jet fire until they failed (within 5 minutes). A target of similar shape and size to the LPG tanks was fitted with pipe calorimeters at 90^o intervals and the mean incident heat fluxes found to be in the range 180 to 200 kWm^{-2}.

COMPARISON WITH PROPOSED VALUES

The Shell HEATUP model[20] was used to derive the parameters, given as ranges in Table 1, for the:

- kerosene pool fire trial on the 72% full tank (typical of an open pool fire of the type referred to in API RP 521); and
- flashing-liquid propane jet fire on the 85% full tank (typical of an open jet fire with a higher-hydrocarbon, more-radiative, fuel).

The values are compared with the ranges of values proposed in the previous section in Table 2. The values used in the HEATUP code gave a good representation of the wall temperatures, pressures and time to failure for the jet-fire impinged vessels. All values used are within the ranges specified in Table 1.

Table 2. Comparison of data derived from lpg tank trials

Fire type	Kerosene pool fire		Open jet fire	
	HEATUP*	Table 1	HEATUP*	Table 1
Total incident flux (kWm^{-2})	75	50–150	170	100–400
Radiative flux (kWm^{-2})	75	50–150	120	50–250
Convective flux (kWm^{-2})	0	0	50	50–150
Emissivity of flame ε_f	0.9	0.7–0.9	0.6	0.5–0.9
Temperature of flame, T_f (K)	1070	1000–1400	1370	1200–1500
Heat transfer coefficient, h ($kWm^{-2}K^{-1}$)	0	0	0.05	0.04–0.17

*ε_s assumed to be 0.65 for the modeling

RELIEF PERFORMANCE

API RP 521 defines a pressure-relieving system as an arrangement of a pressure-relieving device, piping and a means of disposal intended for the safe relief, conveyance and disposal of fluids in a vapour, liquid or gaseous state. A relieving system may consist of only one pressure relief valve or rupture disk, either with or without discharge pipe, on a single vessel or line. A more complex system may involve many pressure-relieving devices manifolded into common headers to terminal disposal equipment. In this section, the API PRV requirements are compared with the PRVs actually used and the level of protection provided in the trials.

The pressure relief valve requirements were sized in accordance with the requirements of API RP 520 and API RP521, which covers calculation of the required pressure relief area for the rate of vapour generation determined. The results are compared with the characteristics of the pressure relief valves actually used in Table 3.

Clearly, the trial conditions are such that drainage for any spilt fuel is inadequate. However, this was taken into account in sizing the installed safety valves, which were adequate in accordance with API RP 520/521 recommendations for such a scenario in both cases. In the 72% fill pool-fire trial, the PRVs opened (14.3 barg) at about the set pressure and the pressure in the vessel did not exceed this throughout the trial confirming the adequacy of the API recommendations. In the case of the 85% fill jet-fire trial, the PRV opened at 18.3 barg (set pressure 17.2 barg), cycled open and shut twice and then remained open until catastrophic tank failure at 24.4 barg. Hence, a PRV sized to API 520/521 cannot be assumed to be capable of keeping the pressure to the set pressure when subjected to a jet fire of the nature used in the trials. This suggests that the combination of heat flux and wetted surface area recommended in API 521 is inadequate for sizing PRVs in a severe fire situation.

Table 3. Comparison of api prv requirements with those used

Parameter	5 tonne tank in pool fire		2 tonne tank in jet fire	
	Adequate drainage	Inadequate drainage	Adequate drainage	Inadequate drainage
Maximum fill level	0.72	0.72	0.85	0.85
Wetted surface area (m^2)	25.7	25.7	15.3	15.3
Heat transfer rate (kW)	577	948	404	664
Vaporisation rate (kgs^{-1})	2.00	3.29	1.51	2.48
Safety valve set pressure (barg)	14.3	14.3	17.2	17.2
API required effective flow area (mm^2)	463	761	296	486
Installed effective flow area (mm^2)	887	887	619	619

Note: Effective flow area is the product of the actual safety valve flow area and its coefficient of discharge.

The pool fire trials were not designed to take the vessel to failure. All the vapour space wall temperatures behaved similarly, increasing rapidly once the fire had become established, but rising less rapidly once venting commenced. In individual tests, large temperature differences (440°C to 610°C for 58% fill) existed at any one time, both across the tank and from end to end. The peak rates of temperature rise (from ambient to 400°C) was roughly 1.25 Ks^{-1} for a vessel with a wall thickness of 12 mm. Figure 1 in API RP 521 suggests a heating rate of 1.75 Ks^{-1} i.e. it is conservative compared to this test. However, for the jet-fire trials, the heating rate with a wall thickness of 7 mm was 7 Ks^{-1}. Interpolation of the plots in API RP 521 suggests a heating rate of around 4 Ks^{-1} i.e. a gasoline fire is much less severe than a jet fire. All the LPG vessels failed catastrophically in the jet fires within 5 minutes, at pressures from 16.5 barg to 24.4 barg and at maximum dry wall temperatures from 704°C to 870°C.

EMERGENCY DEPRESSURISATION

As indicated in the Introduction, API RP 521 is also used for the design of emergency depressuring (EDP) systems. API RP 521 defines a vapour depressurising system as a protective arrangement of valves and piping intended to provide for rapid reduction of pressure in equipment by releasing vapours. The actuation of the system may be automatic or manual. In general, emergency depressuring systems are usually fitted to all offshore, and most onshore, process vessels. However, they are not usually fitted to storage vessels as it is not practicable to remove the large inventories involved. All types of vessel are normally fitted with pressure relieving systems.

For vapour depressurising, API 521 recommends *"reducing the equipment pressure from initial conditions to a level equivalent to 50 per cent of the vessel's design pressure within approximately 15 minutes. This criterion is based on the vessel wall temperature versus stress to rupture and applies generally to vessels with wall thicknesses of approximately 25 mm or more. Vessels with thinner walls require a somewhat greater depressuring rate. The required depressuring rate will depend on the metallurgy of the vessel, the thickness and initial temperature of the vessel wall, and the rate of heat input from the fire." "Where fire is controlling, it may be appropriate to limit the application of vapour depressuring to facilities that operate at 17.24 barg and above, where the size of the equipment and volume of the contents are significant. An alternative is to provide depressuring on all equipment that processes light hydrocarbons, and set the depressured rate to achieve 6.9 barg or 50 per cent of the vessel design pressure, whichever is lower, in 15 minutes. The reduced operating pressure is intended to permit somewhat more rapid control in situations in which the source of a fire is the leakage of flammable materials from the equipment to be depressured."*

In the severe fires identified, EDP may not guarantee vessel protection if designed to API 521 because the heat transfer to the contents and dry wall will be higher than assumed. In a review by Roberts[21] et al., an analysis of an example pressure vessel was performed in order to demonstrate the likely thermal and mechanical response of pressurised equipment to a severe fire. It indicated that guidance was required on the behaviour of vessels and their contents in severe fires.

Scandpower Risk Management AS[6] have prepared a guideline for protection of pressurised systems exposed to fire for Statoil and Norsk Hydro. It is based on Norsk Hydro's internal guidance and is primarily concerned with the design of systems fitted with emergency depressuring systems although much of the information given is also relevant to other systems. The guideline reflects the Statoil and Norsk Hydro design philosophy which focuses on fast depressurisation with maximum use of the flare capacity, rather than use of passive fire protection to mitigate the consequences of the fire. It suggests, as a starting point, that for severe fires there should be a pressure reduction to 7 bar within 8 minutes i.e. nearly twice as fast as recommended by API. The guidance produced by the Institute of Petroleum (IP) draws heavily on the Scandpower guideline in relation to EDP.

DISCUSSION

The hydrocarbon pool-fire results suggest that guidance in API 521 works well for the design of systems to resist open hydrocarbon pool fires with incident heat fluxes up to about 100 kWm^{-2}. However, for the flashing liquid propane, jet fires with incident heat fluxes of the order of 180 kWm^{-2}, it appears inadequate. API RP 521 does not offer guidance on jet fires or confined fires but these are not excluded from the scope. As a consequence of this, there is a tendency for the user to follow the code's emergency depressurisation rates and related relief valve sizing recommendations without understanding the limitations in terms of the severity of the fire. This has been raised with API for consideration in their next revision of API RP 521.

The IP guidance allows the higher heat fluxes that occur in severe fires to be taken into account. It categorises the fires into usable data sets that provide the necessary heat transfer properties in order to evaluate the equipment response. It is recognised that in many situations a detailed structural response calculation is not required. However, when it is required, there are no fully validated models available to assist in these calculations as no fire trials have been performed on pressure vessels fitted with EDP systems.

CONCLUSIONS

The main conclusions are that:

- Application of API guidance can lead to a significant under estimation of heat load and hence under-size relief systems in severe fires, which can occur offshore and in some onshore situations.
- The IP guidance provides a more realistic assessment of potential heat loads.
- Validation of the new IP guidance against tests involving pressure vessels incorporating EDP systems is recommended.

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DISCLAIMER

The opinions and conclusions expressed in this paper are those of the authors and do not necessarily reflect the policy or views of the organisations involved.

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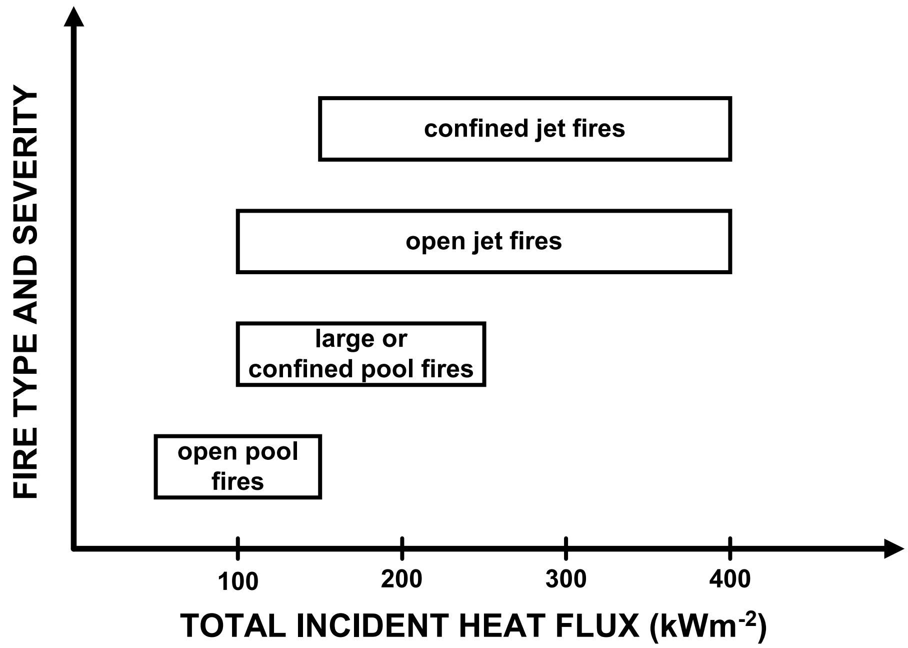

Figure 1. Illustrative heat fluxes for pool and jet fires

(Courtesy of HSL -see reference 18)

Figure 2. Kerosene pool fire trial (with flare from PRV)

(Courtesy of HSL- see reference 11)

Figure 3. Flashing liquid propane jet fire trial