LIQUID SPILLAGE FIRES

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SYNOPSIS

The properties of liquid spillage fires, and the means of their detection, extinction and control are reviewed.

The risk of ignition of a spillage increases as its temperature approaches and exceeds its flash point, and one-dimensional spread of flame for small-scale spillages reaches a maximum rate at approximately the temperature at which the vapour cloud above the pool has the stoichiometric concentration. Large spillages generating large vapour clouds, can give very fast initial flame spread which may produce blast effects in a complex plant. The mists produced by high pressure discharge of liquids behave similarly to vapour clouds.

The rates of heating of structures over which burning liquid is flowing, or which are surrounded by flames from a pool fire, are similar. Under these conditions unprotected metals can fail very quickly. Data are presented on the design of suitable protective systems based on insulation or cooling by water spray.

Rapid detection of fires is best achieved by the use of radiation detectors, particularly if they can scan appropriate areas of the plant at risk. Established fires may be extinguished by water streams and sprays or by suitable types of foam, which are now available for most liquids. The above extinguishing agents, dry powder or halogenated vaporizing extinguishing agents may be used to extinguish spillage fires in their early stages.

Introduction

The accidental escape of flammable liquid from a process plant can result in a fire. Such spillage fires can cause secondary damage and losses far exceeding the cost of repair of the initial fault.

This paper discusses the types of spillage fire which could occur on an open site, and factors affecting the duration and development of the fire, and the zone in which fire damage could occur. The protection of exposed structures is also discussed, and some information is presented on fire detection and extinction.

The organization of fire cover and the arrangement of protective measures are not dealt with. These matters are largely dependent upon the nature of the plant and the materials handled, and probably need engineering specifically for each risk.

Types of Spillage Fire

1. POOL FIRES

Ignition. Three parameters are commonly used to define the ignitability of liquid fuels, *viz.*, the flash point, the fire point and the ignition temperature (auto-ignition, spontaneous-ignition temperature).

The flash point is the minimum temperature of a liquid fuel at which the atmosphere above the liquid fuel will ignite when traversed by a small ignition source; the fire point is the minimum temperature of a liquid fuel at which the fuel, when ignited as for the flash point, will continue to burn, and the ignition temperature is the minimum temperature of an environment in which the liquid fuel will ignite within a specified period of time, without the application of an ignition source. None of these values is specific, each depending upon many factors such as the size and material of the test apparatus, the rate of heating and the restraints imposed on the atmosphere above the fuel surface, and the amount of fuel.

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Flash points of liquid fuels measured in a closed cup, when the atmosphere above the fuel is enclosed until a small ignition source is introduced, are somewhat higher than, but approximate to, the temperature at which an enclosed atmosphere above the liquid surface will contain the concentration of fuel vapour for the lower explosive limit. Flash points measured in an open cup, in which the fuel surface is exposed to a free atmosphere, are higher than closed cup values, and present a more complicated picture because there will exist a decreasing concentration of fuel vapour at increasing distances from the fuel surface, brought about by diffusion of the fuel vapour from the liquid surface, and also convection gradients when the fuel temperature is greater than that of the general atmosphere, and air movements. However, consistent results are obtainable with standard apparatus operated in draught-free conditions, and also it has been shown that behaviour, under undisturbed conditions other than the draughts that exist in a closed laboratory, can be predicted assuming that the concentration of the diffusing fuel vapour is reduced to zero about 50 mm from the liquid surface.[1] Also, it has been shown recently that, whereas under still conditions the upper boundary of ignitability above a pool is at the lower explosive limit, when a wind is blowing across a pool whose temperature is above the flash point of a liquid, the upper boundary of ignitability above the pool is brought closer to the liquid surface to that level at which the flame speed is equal to the local gas velocity.[2] A method of calculating the boundary is presented, which shows good agreement with experiment.

The fire point of a liquid is measured in an open cup apparatus, and is clearly related to the open flash point, with the additional requirement that the heat transfer to the liquid surface must be sufficient to vaporize enough fuel to maintain a flame after ignition.[3] The fire point is usually only a few degrees higher than the open cup flash point.

The ignition temperature of a liquid fuel is commonly measured in a glass flask maintained at the appropriate temperature, into which a small volume of the liquid is introduced, see for example British Standard 4056 : 1966, "*Method of test for ignition temperature of gases and vapours*". However, liquid fuels may be ignited by contact with a
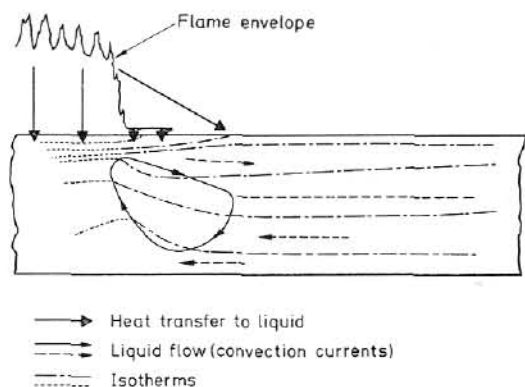
Fig. 1.—*Spread of flame on liquid*

Heat transfer to liquid
Liquid flow (convection currents)
Isotherms

Channel width: 33 mm
Room temperature

Fig. 3.—*Effect of liquid depth on induction period*

sufficiently hot surface, although the temperature for ignition is usually somewhat higher than the ignition temperature determined in a flask.[4,5]

Spread of flame. The ignition and one-dimensional spread of flame across liquid surfaces has been studied by a number of workers.[2, 3, 6-16]

For liquefied gases and for liquids above their flash point, the rate of propagation of flame across the surface is similar to the flame speed in an equivalent vapour system in the absence of liquid.[6] If the temperature of the liquid is below its flash point, a continuous source of ignition, such as a wick flame, must supply sufficient heat firstly to vaporize and ignite the fuel close to the source, and secondly to allow the flame to spread.[3, 8] The heat transfer paths are shown diagrammatically in Fig. 1.

The flame spreading process has been divided into three phases: (*a*) induction, during which heat from the ignition source is transferred to the liquid locally, prior to the spread of flame; (*b*) transition, during which the flame starts travelling across the liquid, and (*c*) propagation, when the rate of flame advance is steady and independent of previous history.[8] The duration of the induction period depends upon the temperature of the liquid and its flash point (Fig. 2),
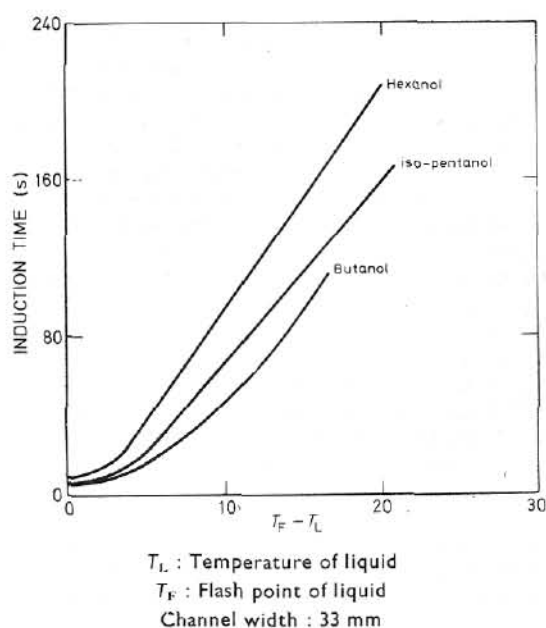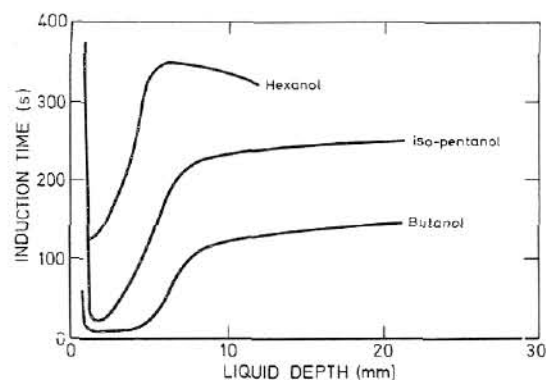
the depth of the liquid layer (Fig. 3), and to some extent on the size and materials of the ignition source. The transition period has not been studied in detail, but during this period, the rate of spread of flame accelerates to that during the propagation phase.[8, 11]

The rate of spread of flame during the propagation phase is dependent upon the temperature of the liquid (Fig. 4), becoming approximately constant at or above the temperature at which the stoichiometric concentration can be supported above the liquid surface. For depths above the minimum needed for flame propagation, about 1 mm (0·04 in), the rate of spread of flame increases with depth for liquids at
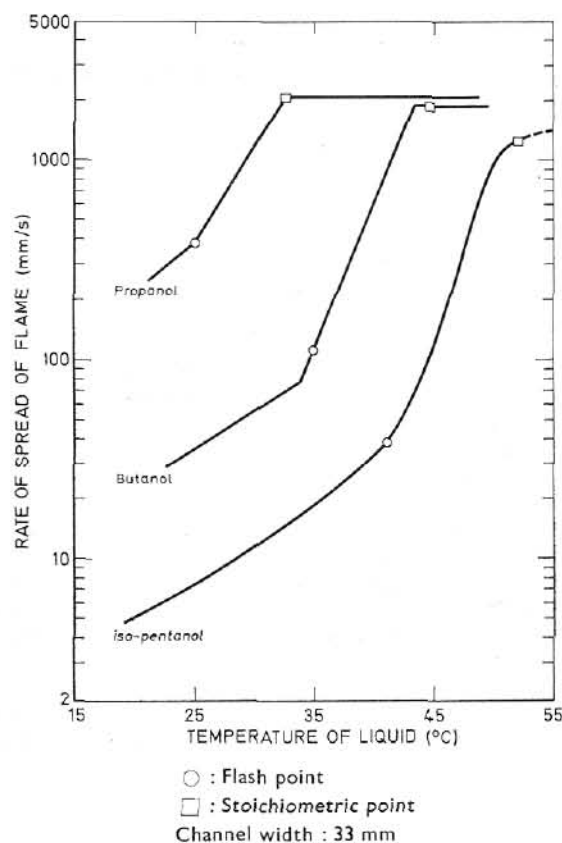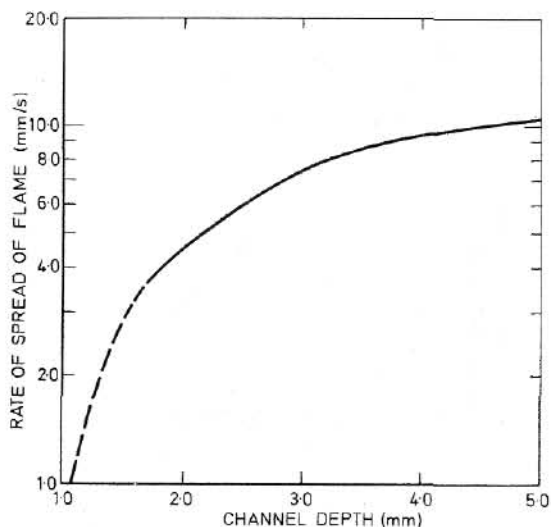

T_L : Temperature of liquid
T_F : Flash point of liquid
Channel width : 33 mm

Fig. 2.—*Effect of temperature of liquid on induction period*

○ : Flash point
□ : *Stoichiometric point*
Channel width : 33 mm

Fig. 4.—*Effect of liquid temperature on rate of spread of flame*

iso-pentanol at 22·5°C
Channel width : 33 mm

Fig. 5.—Effect of depth of liquid on rate of flame spread

Channel width : 33 mm
Room temperature
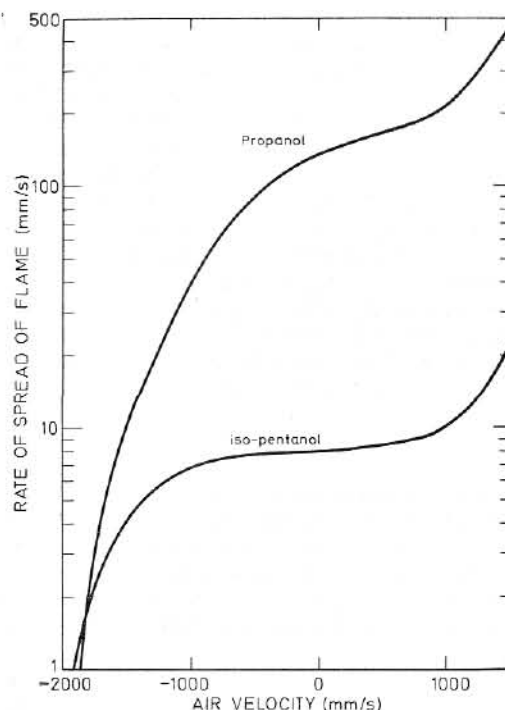
Fig. 7.—Effect of flow of air on flame spread

initial temperatures below their flash point (Fig. 5), but the depth has negligible effect if the temperature of the liquid is above its flash point. The rate of spread of flame also increases with the width of the channel (Fig. 6), up to a certain width after which it becomes essentially constant.[8, 12] Models have been constructed which account at least qualitatively for the observed flame spread in channels,[6, 10, 14] and may be used to predict behaviour in appropriate real situations.

The effect of movement of air above the liquid and of liquid within a channel has been studied in the laboratory.[9] Spread of flame for propanol and iso-pentanol was halted at a counter-current wind speed of 200 cm/s (6.6 ft/s) (Fig. 7); there was a marked reduction in the rate of increase of the rate of spread of flame at around zero flame speed, after which the rate of increase again increased. This effect has been attributed to the difference between ambient temperature and the flash point for the two liquids. Movement of the liquid produces different effects. The rate of spread of flame and speed of movement of liquid were additive for concurrent

movement, but in counter-current flow, the rate of spread of flame relative to the liquid increased (Fig. 8), and under the conditions of test, the flame was not swept back by the flow of liquid.

The controlling factors in the measurements of rate of spread of flame across liquid surfaces reported above are that the liquid was not agitated, flame propagation was one-dimensional and the channels were narrow. The resultant

Liquid temperature : 23°C

Fig. 6.—Effect of channel width on spread of flame
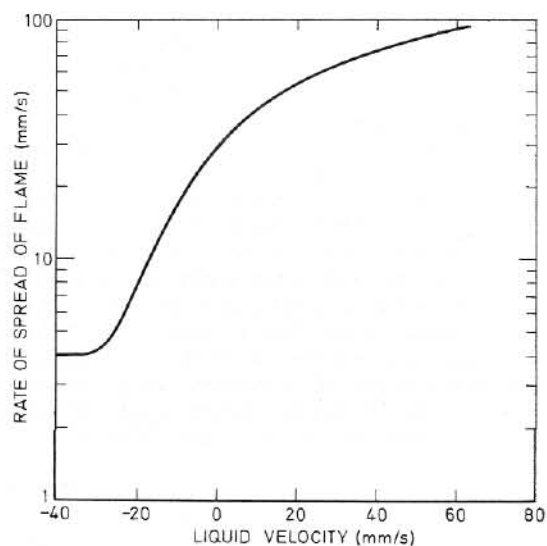
Butanol at room temperature
Channel width : 33 mm

Fig. 8.—Effect of flow of liquid on flame spread

rates of spread of flame were about 2 m/s (6·6 ft/s) in the steady, propagation phase.[9] These factors are unlikely to apply during a spillage from industrial plant. Although spillage could occur in a duct or channel, the width could be much greater, but probably most spillages would result in the formation of pools. If such a pool were ignited after it had come to rest and disturbance of the vapour above the liquid had ceased, flame propagation would be two-dimensional and could be relatively slow, particularly if the height of the vapour above the liquid at or exceeding the stoichiometric concentration was small.

Much more severe conditions could arise if a liquid at a temperature above its flash point and under pressure were suddenly released, for example, by pipe fracture or gasket failure. Under these conditions the liquid could be discharged upwards or from an elevated position, to form a rapidly growing pool on the ground and to generate a large volume of turbulent vapour/air mixture above the pool. On ignition, flame would propagate rapidly through the turbulent cloud, at velocities probably of the order of tens of metres per second. The liquid would then ignite from the base of the burning cloud, giving a correspondingly high rate of spread of flame. If liquid continued to escape from a high level, a running fire could become established (see below).

Under these conditions, a rapidly expanding ball of fire would first be seen, followed by the flaming of the liquid on the ground and probably at the point of escape. The flames from the escaped and escaping liquid would be expected to be at first relatively small in height, and much smaller than the initiating three-dimensional vapour flame, and then to increase to the maximum steady-state height as the temperature of the liquid rose, this height being governed by the area of the pool (see below). There is evidence to suggest that a massive escape of this kind, producing large volumes of turbulent vapour/air mixture, particularly with any additional turbulence created during flame propagation by elements of the plant, might well result in structural damage to the plant due to blast.[17]

Rate of burning. The rate of burning of a pool fire is controlled by the purity and volatility of the liquid, the emissivity of the flame, the flame temperature, and the dimensions of the pool.[3, 6, 12, 15, 18-21]

Some liquids containing a number of components of differing volatility form a hot zone at the top of the liquid while burning, the depth of which increases at a rate faster than the rate of burning.[21, 22] The hot zone arises from the preferential burning of the lighter components, which results in an increase of density of the remaining components to a value greater than that of the original fuel, in spite of density reduction due to heating by the flame. The convective circulation of the denser residual fuel, coupled with the diffusive transfer of lighter constituents from the unaffected fuel below, forms a zone of hot fuel, relatively sharply separated from the cool lower layers in the pool, which increases in depths as combustion proceeds. Hot zone formation is often followed by a " boil-over " of the liquid fuel, in which large volumes of froth are produced, often overflowing the bounds of the burning liquid, and increasing the area of a fire. This phenomenon would be associated predominantly with fires in tanks, and boil-over is unlikely to occur in shallow spills in the absence of water.

Liquids of narrow boiling range burn without the creation of a hot zone. For pools of less than about 1 m (3 ft) in diameter, the rate of burning increases with increasing volatility of the liquid. The relation between boiling point and rate of burning for four liquids burning at the steady rate in pools 300 mm (1 ft) diameter is shown in Fig. 9. The data are drawn from two sources;[19, 20] the very good linearity
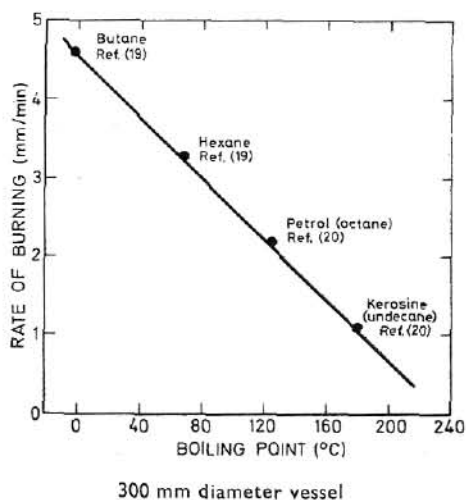
300 mm diameter vessel

Fig. 9.—*Effect of fuel volatility on rate of burning*

of the relation may be fortuitous, since the boiling points of kerosene and petrol have been assumed to be those of undecane and octane.

For pools of larger diameter, extraneous heat losses are less and the contribution of radiation to heat transfer to the liquid is greater, and the rates of burning of liquids, particularly hydrocarbons, become similar.[3, 6, 23] The effect of the emissivity of flames from 300 mm diameter pools on the rate of burning of three fuels of similar volatility is shown in Fig. 10.[20] As the diameter of a pool fire increases above about one metre, the flame becomes turbulent and hence thicker, and the emissivity of the flame approaches unity. Rasbash *et al*[20] have given the flame temperatures of kerosine, petrol, benzene and ethanol as 990°, 1030°, 920°, and 1220°C when determined by the Schmidt method, and 1210°, 1250°, 1190°, and 1290°C when determined for the edge of the flame by the two-colour method. It would thus seem reasonable to adopt a figure of about 1100°C as the flame temperature for most liquid fuels. The similarity in flame temperature and emissivity for fuel spillages of large area would indicate a similarity in heat transfer to the liquid surface. The rate of burning would then depend inversely on the heat of vaporization of the liquid.

Spalding,[24] in the study of convective heat transfer to liquid surfaces has derived an equation in which the rate of burning is proportional to the $\frac{3}{4}$ power of a transfer
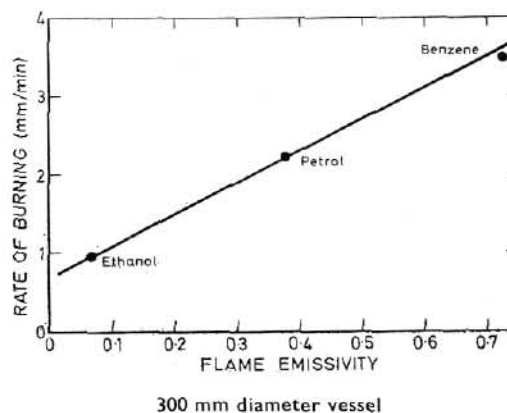
300 mm diameter vessel

Fig. 10.—*Relation between flame emissivity and maximum rate of burning*

Slope of line : 0·87
UDMH : Unsymmetrical-dimethylhydrazine
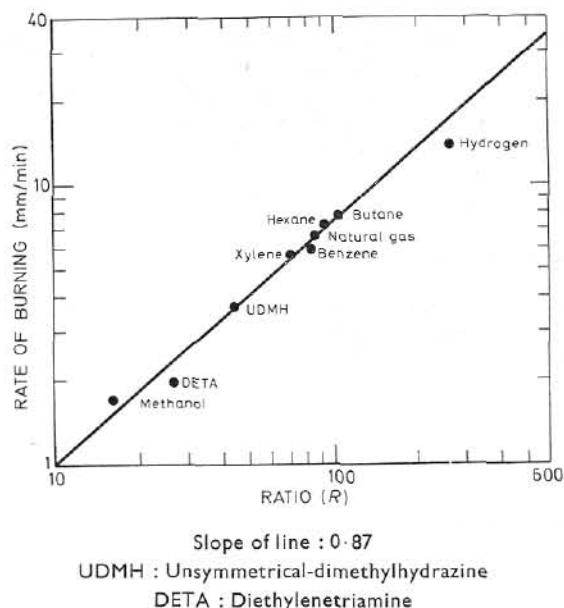DETA : Diethylenetriamine

Fig. 11.—*Relation between rate of burning and ratio (R)*

number B, in the numerator of which the principal term is the heat of combustion of the liquid, the denominator being the heat transfer to the liquid surface sufficient to vaporize unit mass of fuel. Under steady burning conditions the denominator is equal to the heat of vaporization of the liquid.[25] A logarithmic plot of experimental values for the rates of burning of liquid fuels for a wide range in pools of about 1 m diameter against the ratio, R, of the heat of combustion and the heat of vaporization has been produced (Fig. 11) and gives the exponent of R as about 0·9,[3] but the same results plotted linearly result in the rate of burning equal to $0·076R$ mm/min ($0·003R$ in/min), except for liquid hydrogen.[19]

Blinov and Khudiakov[6] have made a significant contribution to the study of pool fires, as they have examined fires in pools of diameters from 3·7 mm (0·145 in) to 22·9 m (75 ft). An analysis of these results by Hottel[15] has indicated the effect of diameter on rate of burning and flame size (Fig. 12),
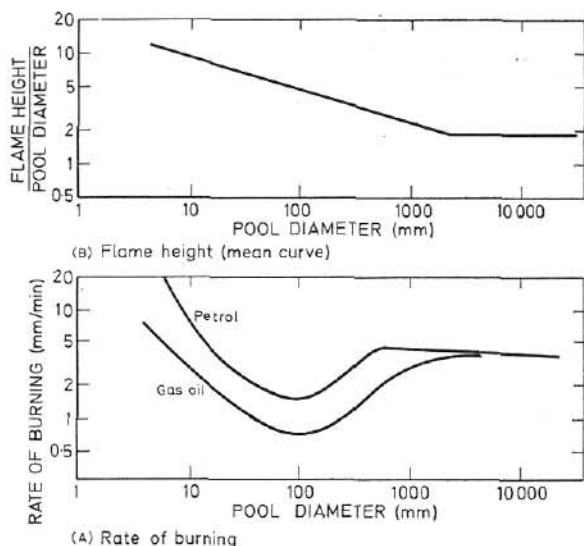
which indicates there are three regimes: (i) diameters below 100 mm (4 in), in which the rate of burning decreases with increasing diameter, (ii) between 100 mm and 1 m, in which the rate of burning increases with increasing diameter, and (iii) above 1 m, in which the rate of burning is constant, the results suggesting that the rate is the same for fuels of widely different volatility.

The height of flame is also dependent on the size of pool (Fig. 12). For many hydrocarbon fuels, burning at the steady rate in pools of diameter greater than 1 m, the flame height is about two diameters. This height occurs for combustion in the absence of strong winds or vorticity; if some vorticity is generated, the flames could be substantially elongated.[26, 27] This could well occur in plant, where structures could confuse wind orientation. In the absence of vorticity, the length of flame is not altered appreciably by wind, but the flame is deflected to leeward; also, the rate of burning from pools of small diameter is increased up to that of large pools, but is little affected for large pools.[19, 28]

The ullage of a pool has little effect on the rate of burning of pools of liquids whose flames are of low emissivity such as ethanol, and remain close to the surface of the liquid, heat transfer to the liquid taking place primarily by conduction and convection. However, for pools of liquids giving flames of high emissivity, so that radiation accounts for a large proportion of the heat transfer to the liquid, the zone of unburnt vapour between the liquid and the flame is large, and the flame tends to be supported above the ullage, thus reducing the contribution of radiation to heat transfer to the liquid, the rate of burning reducing with increasing ullage.[28–30] However, because a wall retaining the spillage can act as a bluff body, and secure and stabilize the flame, the rate of burning can increase with wind speed, because of the reduction in the distance separating liquid and flame brought about by turbulence.[29]

The above mentioned characteristics of pool fires indicate the ways in which spillage fires may be prevented, controlled or extinguished. If the temperature of the spillage is below its flash point, ignition can be prevented by ensuring no contact with hot surfaces. If ignition occurs, extinction can be achieved by the rapid cooling of the liquid and of hot surfaces in its path, or by covering with foam. However, if the temperature of an ignited spillage is above its boiling point, the whole of the spillage would be flaming; the decision whether to extinguish or to allow controlled burning to continue depends largely on whether the flash point of the liquid is above or well below ambient temperature (*e.g.* liquefied petroleum gases).

2. RUNNING FIRES

Liquid escaping from a rupture or leaking joint can pour over parts of the plant. If such a running spillage becomes ignited, the wetted surfaces can become enveloped in flame, resulting in a rapid rise in the temperature of the surfaces. Temperatures attained by steel surfaces over which flaming fuel was flowing are shown in Fig. 13; the rate of rise in temperature of a steel stanchion standing in a pool of burning petrol, and of a steel stanchion subjected to the furnace test, British Standard 476 : Part 1 : 1953, are included for comparison.[31–33] The rates of rise of temperature for the steel exposed to running fires and pool fires are similar, up to the time when the petrol pool was consumed, and differ little between the different hydrocarbon fuels. However, the mean rate of rise for the condition of test, 230°C/min, is about three times that for steel exposed to the standard furnace test, and the critical temperature for structural steel, 550°C, was reached in about 2 to 3 min, about a fifth of the time taken in the standard furnace test.
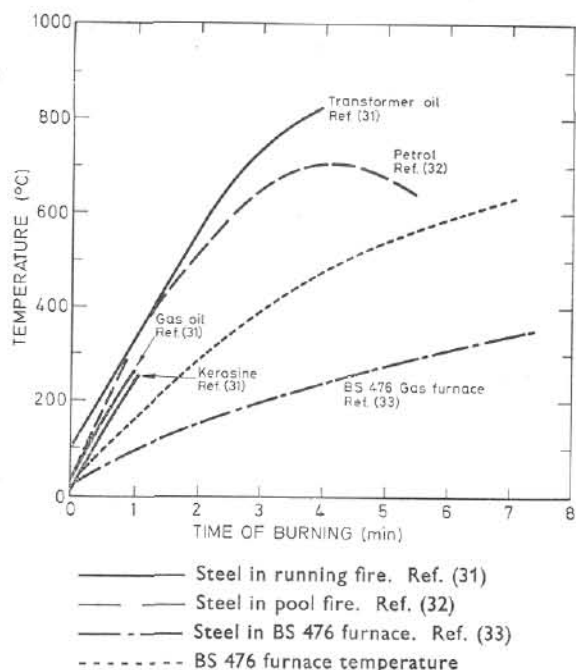

(B) Flame height (mean curve)

(A) Rate of burning

Fig. 12.—*Rate of burning and flame height of hydrocarbon fuels*

Fig. 13.—*Temperature of exposed steel in liquid fuel, running and pool fires*

———— Steel in running fire. Ref. (31)
— ·— Steel in pool fire. Ref. (32)
— · —· Steel in BS 476 furnace. Ref. (33)
- - - - - - - BS 476 furnace temperature

Few studies have been made of the effect of wind on running fires. Some tests at the Fire Research Station on an array of steel tubes have shown that the total radiation from flames increased as wind speed increased up to about 2 m/s (6·6 ft/s), but decreased thereafter.[31] The effect could be due to an improvement in heat transfer to the tubes from the flames brought about by their deflection and increased vaporization of fuel as wind speed increased up to a critical level, above which the reduction in flame thickness and luminosity increased the cooling of the tubes by transfer to the air stream, and reduced transfer from the less luminous and smaller flames. The critical wind speed would be expected to be specific for the fuel, its rate of flow, and the array over which the running fire occurred. The same programme of tests showed that the rate of rise of temperature of the steel decreased as wind speed increased over the range examined, 1–4 m/s (3–13 ft/s). The rise in temperature of structures exposed to such fires may be estimated, provided reliable heat transfer data are available.[31]

3. SPRAY FIRES

Escape of liquid from a fracture or leak in plant containing liquid under pressure can produce a spray discharge. A spray containing small droplets behaves similarly to a gaseous discharge. Only small sources of ignition are required to ignite suspensions at temperatures substantially below the flash point of the liquid,[32,34] and the lower limit concentration is similar to that of a gaseous fuel, about 50 mg/l (0·05 oz/ft³) in air. The presence of a spray discharge can therefore increase the risk of fire for flammable liquids, by generating a readily ignitable cloud above the spillage.

Protection of Plant from the Effects of Fire

A spillage fire can result in the structural failure of unprotected plant, or other catastrophic damage, in a very short time. Because of the complexity and large throughput of modern plant, a fire can result in large financial losses,

due to the need for extremely costly repairs and heavy additional losses through down-time. It is therefore of major importance to ensure the integrity of plant and plant control systems by reducing the duration of any fire to a minimum and ensuring, by suitable insulation and other means, the preservation of both structures and systems.

A paper[35] has been published on the calculation of the degree of insulation required to restrict the rise in temperature of the protected elements to the appropriate level. These calculations are based on the assumption that the surface of the insulation soon attains flame temperature. The following equation is derived for the calulation of the protection afforded by insulation to unit length of protected element:

$$\frac{\theta_s}{\theta_f} = 1 - \exp\left(-t/RC\right)$$

where:

θ_s = the temperature of the protected surface, presumed to undergo no further heat loss.

θ_f = the temperature of the flame, which can be taken as 1100°C for most fuels.

t = the time for which the protected system is exposed to flame.

$C = Mc_s + 0·5A\rho c_t d$.

$R = d/KA$.

M = the mass of the protected material.

c_s = the specific heat of the protected material.

A = the area through which heat flows.

ρ = the density of the insulating material.

c_t = the specific heat of the insulating material.

d = the thickness of the insulating material.

K = the thermal conductivity of the insulation material.

A plot of θ_s/θ_f against t/RC (Fig. 14), may be used for the calculation of the appropriate thickness of the insulating material, chosen for the conditions of use, for the estimated duration of burning of a spillage. The original paper gives further data on the calculation of protection for specific risks.

Although it is likely that some parts of plant requiring protection may extract heat from the protected surface, e.g., because their contents may be flowing, it would probably be as well to err on the safe side, and assume, as above, that no further heat loss occurs from the protected surface.

It may well be that some surfaces which may be exposed to flames from a spillage cannot be protected by fixed insulation, because of weight or other considerations affecting their
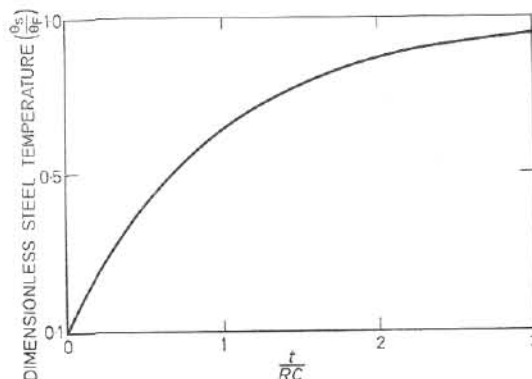

Fig. 14.—*Relation between steel temperature and insulation parameter*

stability or operation. Under these circumstances, application of water to the surfaces to be protected, either from sparge pipe, spray jets or hose stream can prevent a rise in temperature to critical levels. Assuming heat transfer from flames to the surface of $17 \, W/cm^2$ (54 000 Btu/ft² hr), this amount of heat could be removed by the uniform application of water at a rate of between 0·07 and 0·5 l/m^2 s (0·1 and 0·6 gal/ft² min), dependent upon whether the water is fully vaporized, or heated to boiling point. The rate usually adopted for this purpose is 0·16 l/m^2 s (0·2 gal/ft² min).[36] For such a system to be fully effective, it is essential that all exposed surfaces are wetted uniformly by the applied water. Any channelling of water due to dirt or oil, or deflection of the water flowing over the risk, can result in the presence of large areas of unprotected surface. Very large quantities of water will be required for these purposes, and adequate reservoirs and hydrant systems should be installed.

The protection of power cables and electronic and pneumatic control lines and systems is often of as much importance as the protection of other parts of a plant. These services are commonly grouped, so that their failure through fire at one part of a plant can lead to the loss of control and shut-down of much larger sections of the plant while costly and time-consuming replacement is made. However, the methods of protection discussed above are equally applicable to these systems, the critical temperature being that of failure of the insulation, tubing and so on. Protection can be afforded by boxing cables and control lines in fire resistant insulating boards, the box being capped with the same material. Further insulation where required could be obtained by surrounding the cables in the box with granular inert material, such as expanded vermiculite. Also mastics that have a resistance to fire and to weather can be used to coat cables directly, and there may be many sites where water sprays or curtains could be used to keep cables cool in a fire. It is of course important where electrical cables are so insulated to ensure that the power rating of cables is adequate to keep the operational temperatures rise within the accepted limits.

Fire Detection and Control

Damage resulting from liquid spillage would be minimized if spillages could be detected and discharge stopped before the liquid ignited. There are a number of devices available, whose operation is based on some property of the liquid or vapour (conductivity, infra-red absorption or heat of combustion, for example), which can detect such spillages and which may be coupled to alarm and control circuits.[37]

However, conditions and circumstances of operation can be expected to cause ignition of a spillage. To meet this threat, fire detectors are required. The ideal detector should detect and locate the fire instantly and also should inaugurate action to limit or stop the discharge of liquid and to extinguish or control burning. These requirements are perhaps impossible to achieve, but much may be done to approach this ideal.

Fire detectors are available operating by temperature rise, heat flow, smoke, ionization and radiation detection.[38] Of these, the only group which can detect fire rapidly and reliably on an outdoor site, without needing to be placed in the path of the flames or the products of combustion, are the radiation detectors. Devices operated by infra-red radiation are available, and others are in the course of development. False alarms from radiation detectors have been greatly reduced by making the detectors sensitive only over the narrow band of frequencies over which flames pulsate,[3, 6, 20] and their sensitivity is such that they can be made to detect flame at distances greater than 50 m (160 ft). An important

development has been the production of a detector capable of scanning over 360° horizontally, which also has a wide vertical angle of acceptance.[39] As the device " homes " on the detected fire, a minimum of two such detectors servo-coupled to a remote indicator would show the position of the fire on a complex and sparsely manned plant, and so permit rapid deployment of fire-fighting equipment and personnel.

Extinction of Fires

The action to be taken on the discovery of a spillage fire would depend on the means of extinction available and on the desirability of either control or extinction.[40] As most process plants involve flammable materials, fire preventive and protective measures should always be considered at the design stage of original plant and of any alterations.

Fires of highly volatile liquids present the most difficulties. Although it is possible to extinguish such fires by suitable application of most extinguishing agents, the risk of re-ignition from hot surfaces or incendiary sparks or flames is high. If a large cloud of flammable vapour which can be ignited were formed, there could be a fire or explosion more dangerous than the original fire. A burning or unignited spillage of volatile liquids must be covered quickly, and any igniting sources in the path of escaping vapours extinguished or cooled rapidly and the leakage stopped if this form of fire prevention or extinction is to be successful. If this degree of protection cannot be assured, it may well be desirable to permit or arrange for the controlled burning of the spillage at a slow rate accompanied by the cooling of any heated surface which could introduce additional hazards.

Recent developments in water-based foam compounds have made systems available which are capable of covering and if necessary extinguishing such spillages including those of water-miscible liquids which up to now have proved most difficult to cover economically.[41] If the speed of attack is such that rapid extinction can be achieved and the leakage stopped rapidly, agents such as the halogenated liquids,[42] inert gases[43] or their combination as a cryogenic slurry,[44] and dry powder,[42] can effect extinction. Such rapid extinction could permit an isolating valve to be reached and operated. The use of cryogenic slurries for the extinction of fires of volatile liquids could well reduce the temperature of the liquid, at least locally in the spillage, to below its flash point; this effect could be of great value in preventing re-ignition.

For liquids with flash points higher than ambient temperature, water possesses many advantages as an extinguishing agent, because of availability, low cost and high heat-removing potential.[25] The choice between the use of foam or spray would depend upon the properties of the liquid fuel and the nature of the confinement, if any, of the spillage.

The need for large reserves of water has been mentioned above. It is necessary to have large quantities of all extinguishing agents on site, either disposed strategically about the site or on vehicles, and preferably in bulk containers so as to reduce handling to a minimum.

Conclusions

Studies of the development and properties of fires of liquid spillages have done much to increase the understanding of fires and their dependence upon fuel properties. The task, of designing plant to minimize risk of damage from fire, and of selecting insulation systems for strategic sections of plant, providing appropriate systems for detection, and of deploying fire-fighting equipment and personnel to the best advantage, is thereby made easier.

Acknowledgments

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