MANUAL

FIRE-FIGHTING AGENTS

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DESIGN AND ENGINEERING PRACTICE

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1. INTRODUCTION

1.1 SCOPE

This manual provides information and, where applicable, gives minimum requirements for the various types of fire fighting agents, which should be used for the design and engineering of fire protection and related facilities for application in onshore oil and gas processing and petrochemical installations, storage facilities, jetties, terminals, loading and unloading facilities.

Although primarily intended for new construction, the requirements of this manual can also be applied for existing plants when the evaluation of safety audits indicates the need for improvements to fire protection systems. When modifications and extensions to existing plants are envisaged, fire protection shall always be considered and existing facilities improved where necessary. In addition the updating of fire-fighting training grounds is strongly recommended when they no longer provide the facilities for the required level of training.

Foams which suppress toxic vapours are not covered in this manual.

For matters not covered in this manual, the code of the 'National Fire Protection Association' (NFPA) shall be consulted.

1.2 DISTRIBUTION, APPLICABILITY and REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIPM, the distribution of this manual is confined to companies forming part of or managed by the Royal Dutch/Shell Group, and to contractors and when applicable, manufacturers/suppliers nominated by them.

This manual is intended to be used by contractors and Group companies for the selection of fire fighting agents.

This manual is intended for use in oil refineries, chemical plants, gas plants and where applicable, in marketing, exploration and production locations and new ventures.

National and/or local regulations may exist in which some of the requirements are more stringent than in this manual. The contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects.

In all cases the contractor shall inform Principal of any deviation from the requirements of this manual which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the authorities concerned with the object of obtaining agreement to follow this manual as closely as possible.

1.3 CROSS REFERENCES

Where cross-references are made, the number of the referenced section or sub-section is shown in brackets.

All publications referred to in this manual are listed in (3.).

1.4 DEFINITIONS

For the purpose of this manual, the following definitions shall hold:

Shall and **Should** - the word 'shall' is to be understood as mandatory and the word 'should' as strongly recommended to comply with the requirements of this manual.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include a consultant or a contractor authorised to act for the Principal.

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction and commissioning for the project. The Principal may sometimes undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

1.5 TERMINOLOGY

AFFF (Aqueous Film Forming Foam) Concentrate - A synthetic foam concentrate containing fluorocarbon surfactants that influence the physical properties of the foam solution so that it can float and spread across the surface of a hydrocarbon fuel.

"Alcohol Resistant" Foam Concentrate (ARFC) - A specially formulated foam for use on water miscible fuels, such as alcohols and other polar solvents.

Application Rate - The rate at which solution should be applied on a fire. This is normally expressed in terms of a solution flow in dm^3/min. per square metre.

Burnback Resistance - The ability of a foam blanket to resist direct flame contact such as would be evident in a partially extinguished (petroleum) fire.

Critical Application Rate - The lowest application rate at which a foam will extinguish a fire under laboratory conditions.

Critical Shear Stress - A measure of the stiffness of a foam.

Drainage Time - The rate at which foam solution liquid drains from an expanded foam (i.e. a measure of the foam's stability and an indication of the foam's viscosity). It is normally expressed as "25% Drainage Time" ("Quarter-Life"), which is the time (minutes) required to drain 25% of the solution liquid contained in the foam sample.

Dry Chemical Powder (DCP) - A powder composed of small particles, with an approximate size band between 20 and 100 micron, usually of sodium bicarbonate, potassium bicarbonate, urea based potassium bicarbonate, potassium chloride, or monoammonium phosphate with added particulate material supplemented by special treatment to provide resistance to packing, resistance to moisture (caking) and to provide the proper flow capabilities.

Dry Chemical Powder System - A supply system of dry chemical powder which can be automatically or manually activated to discharge through a distribution system onto or into the protected hazard by means of (hand) nozzles or monitors.

Expansion - The ratio of the volume of the expanded foam formed to the volume of the foam solution used to generate that foam. Expansion can be categorised further into low, medium or high expansion. There are no rigourous definitions of these terms but generally they can be taken as follows:

- Low expansion - Up to 20 to 1,
- Medium expansion - Between 20 and 100 to 1,
- High expansion - Between 100 and 1000 to 1.

Fluoroprotein Foam (FP) - A protein based foam with additional selected fluorinated surfactants which are loosely bonded to the protein to provide the foam with fuel resistance properties.

Foam (Finished foam, expanded foam) - The product of mixing air with the foam solution homogeneously.

Foam branchpipe - A hand-held air aspirating foam nozzle.

Foam concentrate (Liquid) - The medium which is added to water to make a foam solution. This solution mixed with air will form the expanded foam. Foam concentrates can be purchased for mixing with water into solutions of 2, 3, 4, 5 and 6 percent by volume. Foam concentrate is also called **foam agent**.

Foam generator - The device in which air is mixed with foam solution to form foam. Suitable for back pressures of maximum 0.5 bar.

Foam premix - A liquid (foam solution) in which foam concentrate and water are already mixed in the correct ratio; thus ready for immediate use in the appropriate foam generator.

Foam solution - The liquid formed when foam concentrate is mixed with water. This solution, mixed with air, gives a (fire-fighting) foam.

Fuel resistance - The ability of foam to restrict fuel penetration between expanded air bubbles, thus withstanding foam breakdown by fuel.

Fuel tolerance - The ability of a foam to withstand fuel pick-up so that the air-filled foam bubble will not become saturated with fuel and thus supports flames.

Heat resistance - The ability of foam to withstand the effects of exposure to heat through radiation or contact with a hot surface.

High Back Pressure Foam Generator (HBPG) - The device, used in selected foam applications, in which air is mixed with foam solution. The max. allowable backpressure is expressed as a percentage of the generator's inlet pressure. Min. inlet pressure 7 bar.

Inductor - A type of jet mixer operated by fire water, in which the foam concentrate, by means of suction, is entrained with firewater thereby forming foam solution. Only at specified flow is an inductor able to deliver foam solution of the required concentration. Typical inductor pressure loss is 30 percent of the inlet pressure.

Knockdown - The ability of an agent to extinguish a fire.

Manned Area/Room - A space which will be normally occupied 24 hours per day or can be reached by people within 10 minutes.

Monitor - A device, normally either portable, fixed, trailer-mounted or truck-installed, to which a large throughput nozzle is attached to allow the operator to direct the fire fighting agent as required.

Multipurpose Dry Chemical Powder - Usually ammonium phosphate-based. Effective on fires involving both ordinary combustibles, such as wood or paper, and fires involving flammable liquids.

Non-aspirated foam - A foam solution, discharged through a nozzle, in which no air is entrained intentionally.

Pick-up rate - The percentage at which foam concentrate is proportioned into the water flow. Normally this is either 3% or 6%, but may differ for certain types of fire, or type of foam concentrate or depends on the viscosity of the concentrate.

Proportioner - The device in which foam concentrate and water are mixed to form a solution. It is suitable for varying flow rates, e.g. between 10 - 100 percent, with a pressure loss of 10 percent of the inlet pressure.

Protein Foam Concentrate - A concentrated solution of hydrolysed protein to which chemicals are added to obtain vapour suppression, freezing point depression and other desirable characteristics.

Semi-subsurface foam injection - The discharge of foam at the liquid surface in a tank by means of a foldable hose, through a rupture disc from an inlet near the bottom of the tank to avoid submerging foam in the liquid.

Subsurface foam injection - The discharge of foam into a tank near the tank bottom (above the free water layer), allowing the foam to travel through the product to the surface.

Synthetic Detergent ("Syndet") Foam Concentrate - A detergent-based foam concentrate that can be used for low, medium and high expansion, but offers relatively poor burnback and heat resistance at any expansion.

Universal foam concentrate - An alcohol-resistant foam concentrate that may be applied on hydrocarbons and water-miscible fuels.

Unmanned Area/Room - A space which is intended for unoccupied use and cannot be reached by personnel within 10 minutes.

Vapour suppression - The ability to suppress the formation of flammable vapours, thus minimizing the risk of re-ignition.

Water branch pipe - A hand-held water nozzle, with a typical application rate of 200-400 dm^3/min. at 7 bar.

1.6 ABBREVIATIONS

BS	British Standard
EN	European Norm
MESC	Material and Equipment Standards and Code
NFPA	National Fire Protection Association
UL	Underwriters Laboratories Incorporated.

2. FIRE-FIGHTING AGENTS

2.1 FOAM

2.1.1 General

Foam is medium which can be applied on a flat service to form a blanket. Foam is generally used for suppressing and extinguishing pool fires, and as such it is called fire fighting foam. However it can also be applied on non-ignited liquids to suppress vapour emission.

The currently used fire fighting foams are of the mechanical (physical), not chemical, foam type. Foam concentrate is added to water in small quantities (between 1 and 6 percent) to form a foam solution. This is mixed with air to form the final fire fighting foam. Thus (expanded) foam is an aggregate of air filled bubbles and a small percentage of foam solution.
Foams can be divided in three types: Low, medium and high expansion foam (Refer to 2.1.4).
Prevention of a fire may be achieved by applying a foam blanket to fuel spills, reducing the evaporation rate. Foam shall not be applied to water reactive products. Fire fighting foams are particularly suited for extinguishing fires in storage tanks. They are also used for spill fires, fires in process areas, at truck or rail car loading facilities and at jetties.

Commercially available fire fighting foams can be divided into two main groups:
- protein based foams,
- synthetic based foams.

Foam concentrates possessing components of both groups are available. See (2.1.6).

2.1.2 Functioning of foam

Foam, when applied continuously at the required foam application rate, establishes and maintains a sealing blanket over a burning or non-ignited material.
Foam can only function as a fire extinguishing medium when the vapour release from the liquid is reduced such that the vapour/air mixture becomes leaner than the Lower Flammable Limit (LFL) of the vapour.

Foam acts differently on non-ignited and ignited fuels depending on the nature of the fuel.

On a **non-ignited** pool of fuel distinction can be made between:
a) hydrocarbon liquid fuels,
b) refrigerated LNG,
c) refrigerated LPG/NGL.

a) Hydrocarbon liquid fuels

Foam reduces the formation of vapour by:
(1) Shielding the liquid surface from the air, thus reducing vapour pick-up.
(2) Forming an insulating layer between any radiation from the environment into the fuel, thus reducing evaporation due to heat ingress.
(3) Producing water (result of foam drainage), which will reduce the temperature of the fuel surface (and adjacent materials) when the liquid fuel is above the water temperature.

b) Refrigerated LNG
LNG vapour is warmed as it rises through a thick (minimum 1.5 m.) layer of foam. The resultant buoyancy of the vapour leads to reduced vapour concentrations down wind at grade level.
However water, resulting from foam drainage, will act as a heat source and it has the undesirable effect of increasing vaporisation.
If high expansion foam (refer to 2.1.4.3), with long drainage time (typically 15 minutes or more), is used the overall effect on down wind vapour concentration at grade level is favourable.

c) Refrigerated LPG/NGL
Pools of LPG/NGL will be at their (cold) atmospheric boiling point.

Water, resulting from foam drainage, would act as a heat source and it has the undesirable effect of increasing vaporisation. As LPG/NGL vapours remain heavier than air the down wind LPG/NGL concentrations would increase. Therefore foam shall not be applied on non-ignited pools of LPG/NGL.

On an **ignited** (burning) pool of fuel distinction shall be made between:

a) hydrocarbon liquid fuels,
b) refrigerated LNG, NGL and LPG.

a) Hydrocarbon liquid fuels

Foam reduces the formation of vapour and reduces the intensity of the fire by:

(1) Forming an insulating layer between the flames and the fuel, thus reducing the heat ingress, via the liquid surface, into the fuel; this results in a reduction of the flammable vapour release which in turn decreases the size of the fire.
(2) Producing water (result of foam drainage), which will reduce the temperature of the fuel surface (and adjacent materials) when the liquid fuel is above the water temperature.
(3) Water evaporation out of the foam, thus:

- keeping the temperature at the top of the foam layer to maximum 100 °C, which restricts heat ingress into the fuel:
- forming steam, lowering the (relative) concentration of fuel vapour which reduces the intensity of the fire, resulting in lower radiation levels.

b) Refrigerated LNG, NGL and LPG

Foam reduces the formation of vapour by forming an insulating layer between the flames and the fuel, thus reducing the heat ingress from the fire, via the liquid surface, into the refrigerated fuel. This results in a reduction of the flammable vapour release which in turn decreases the size of the fire. For this purpose a thick (approx. 1.5 metres) foam blanket is required.

Water, resulting from foam drainage, will act as a heat source which will cause some increase in vaporisation. Therefore special high expansion foams (refer to 2.1.4.3) shall be used, having long drainage times (typically 15 minutes or more), which limit free water resulting in minimum increase of vaporisation.

As long as the foam blanket is present it will result in a smaller fire size (no extinguishment will be achieved) with radiation levels reduced to 10 %.

2.1.3 Limitations

From the foregoing it can be concluded that not all types of fire fighting foams can be used for any type of fuel fire.

Foams are not effective in extinguishing fires involving jetting or falling fuels and flowing liquid fires.

From a release of pressurised LPG the formation of a liquid pool is unlikely, and anyhow its presence of very short duration, due to flashing of the liquid. Therefore the use of foam is not effective.

Foams have a limited throwing distance, due to their low density. Wind force and direction may influence this distance as well.

Because foams have conductive properties, they shall not be used on live electrical equipment unless specially approved. If the bulk temperature of the liquid is high (>100 °C) this will restrict the use of foam, and may even cause violent frothing or slop-over.

The water required for producing foam should not be contaminated with water miscible componants e.g. alcohols etc.

2.1.4 Expansion ratio of foam

Depending on the type of foam concentrate and the foam producing equipment used, the expansion ratio will vary widely. The expansion ratio is also governed by the nozzle pressure and impurities in the fire water. Generally the following terminology is used:

Low expansion foam : Up to 20 to 1,
Medium expansion foam: Between 20 and 100 to 1,
High expansion foam : Between 100 and 1000 to 1.

2.1.4.1 Low expansion foam

Low expansion foam is mostly used in the petrochemical industry. It has a good throwing range due to its density (typically: hand nozzles: max. 20 metres; monitors: over 30 metres) and good flowing properties (fluidity).
Its expansion ratio varies between 6 and 10 to 1 for over-the-top applications. For subsurface applications the expansion ratio varies between 3 and 4 to 1. Non-aspirated application has a ratio of 2 to 1.

2.1.4.2 Medium expansion foam

Medium expansion foam has a limited throwing range (approximately 10 metres) due to its low density. However with properly designed equipment it is particularly suitable for fires in enclosed or contained locations such as pump rooms and engine rooms.

2.1.4.3 High expansion (hi-ex) foam

Hi-ex. foam is a synthetic foam, which has no throwing range due to its very low density. It travels over the fuel by gravity. With properly designed equipment it is suitable for fires in enclosed or contained locations such as buildings and warehouses.
By placing a high expansion foam generator at an opening into a confined space and to ensure that clean air (without smoke particles) is present at the point where air is sucked in, a fire can be brought under control without personnel having to enter a potentially hazardous space.
Hi-ex foam, with an expansion ratio of about 200-500 to 1 and with a long 25% drainage time (typically: at least 15 min.), is used to cover (non) ignited LNG pools, to minimise vaporization. It requires foam blankets between 1.5 and 2.0 metres thick. It reduces flame size by approximately 90 percent.
There is an indication that selected alcohol resistant type foam compound can be used as an hi-ex application in e.g. chemical warehouses.

2.1.5 Travel distance of foam

Travel distance is the ability of foam to flow over a liquid by gravity from the application point over a certain distance. Regardless of continuing foam supply, when the maximum travel distance is reached, foam has the property that it will not travel (spread) any further.
Travel distance is a function of surface properties, foam expansion ratio, static foam head and viscosity.

Foam spread dominates fire control time. Good quality foam will travel 12 to 15 metres.

2.1.6 Types of foam

In the following sections different types of foams are discussed, addressing: composition, purpose of the foam, application method and price ratio.

2.1.6.1 Protein foam

Protein foam is mainly manufactured from waste animal material (such as hooves, horns, skins, blood or fish) or soya beans. Metal salts (such as aluminium, zinc or magnesium) are added to act as the framework for the bubbles (reinforcement).

Protein foam is mainly used for oil spills and tank fires. Foam concentration is normally 3 percent; it is used as a low expansion foam (2.1.4.1).
However, protein foam is no longer recommended because of its poor fuel tolerance. For this reason it cannot be used for sub-surface application.

2.1.6.2 Fluoro protein foam

Fluoro protein foam is similar to protein foam, but has a fluorinated surfactant added. This gives the foam a higher fluidity, without losing the cohesiveness of the foam blanket, i.e. the foam spreads easier over a surface fire but the resulting blanket is still tough enough to seal objects protruding from the fire. It has an excellent fuel tolerance. It is therefore suitable for subsurface injection.
The foam concentrate is normally added to water as a 3 percent concentrate; though also 5 and 6 percent concentrates are available. Mixed with the appropriate amount of air it results in a low expansion foam (2.1.4.1).
For rim areas of floating roof tanks it should be applied with an expansion ratio varying between 3 and 4 to 1. This will provide better fluidity around metal obstructions.
It is about twice as expensive as protein foam but it has a far better performance.

2.1.6.3 Film forming fluoro protein foam

Film forming fluoro protein foam (FFFP) is essentially a mixture of fluoro protein foam and aqueous film forming foam (AFFF). As a "hybrid" product it does not necessarily combine most of the good properties of both individual fluoro protein foam and AFFF. FFFP has the same expansion ratio as fluoroprotein foam.
This type of foam is only available from specific sources.

2.1.6.4 Aqueous film forming foam

Aqueous film forming foam, AFFF (A-triple-F) is a synthetic, foaming liquid. This type of synthetic foam consists of fluorochemical and hydrocarbon surfactants, combined with high boiling point solvents. The foam forms an aqueous film on the fuel surface.The AFFF has the ability to create a film of solution that floats on top of non-polar flammable liquids. Its high fluidity results in rapid fire knock down. In non-aspirating applications the expansion ratio is typically between 2 and 4 to 1. The foam is used for shallow spill fires.
Normally the concentrate is added as a 3 percent concentrate to water. It is also available as a 1.0 percent foam concentrate. The latter concentrate has the same expansion ratio as a 3 percent concentrate. This is particularly attractive where there are weight/space restrictions, as the storage capacity is reduced to 33%.
AFFF concentrate is more expensive than fluoro protein type foams. Typically 2.5 times the price of fluoro protein foam of the same concentration.

2.1.6.5 Aqueous film forming foam, alcohol type concentrate (AFFF-AR)

This synthetic foam has water soluble polymers added to it. This foam in contact with a polar solvent forms a cohesive polymeric membrane between the foam and the water soluble fuel. This thick membrane protects the foam and its aqueous layer from breakdown by polar solvents. If the protective layer should become disrupted by agitation or wind, more of the layer is produced by means of a regenerative action known as "self healing".
Most of these foams are a versatile AFFF foam type for the protection of a wide range of Class B (i.e. flammable liquid) hazards. It is available as a, UL-listed, 6 percent concentration for polar solvents. The thick polymeric membrane may cause sewers to block.
This type of foam concentrate is a non-Newtonian, jelly type liquid. Behaviour as a Newtonian liquid is only guaranteed above certain minimum flow velocities. Therefore all foam proportioning equipment requires specific calibration. This will avoid proportioning rates in error of some 50% (e.g. at a 6% setting the proportioning rate may only be 3%). The foam concentrate shall not remain in permanent contact with mild steel as the presence of iron ions will create a polymer film. The resulting sludge may block filters, inductors etc.
AFFF-AR shall always be applied in a "gentle" manner, to avoid submersion, and to ensure that the already formed film is not disturbed and thus remains effective. This implies that AFFF-AR shall never be applied sub-surface; however it may be applied in a semi sub-surface application.

AFFF-AR can also be applied on non-water-miscible (non-polar) fuels (e.g. normal hydrocarbons), and as such it is called "Universal" type foam. Universal concentrate added as a 6% addition is suitable for fires containing polar solvents. It can also be used on non water miscible hydrocarbons, added as a 3% concentrate. On hydrocarbons it functions like AFFF foam.

Only Underwriters Laboratories Inc. (UL)-listed concentrates shall be used.

AFFF-AR, applied in medium and high expansion equipment for e.g. chemical warehouses, shall only be used after actual tests of concentrate, equipment and fuel have proven positive. (Test protocol to be agreed.)

Typical price: two times the price of fluoro protein foam of the same concentration.

2.1.6.6 Fluoro protein alcohol resistant foam

This foam type consists mainly of hydrolised proteins, glycol solvents, fluorosurfactants and polymers. Its resistance against water miscibility is achieved by the formation of a polymeric layer between the foam blanket and the liquid fuel.

This foam compound is used as a 6% concentrate with low expansion equipment on water miscible fuels.

Though currently not recommended the foam compound type can also be used on non water miscible fuels; for low expansion application a 3% concentrate is used, while for medium expansion a 6% concentrate is applied.

Typical price: approximately 1.5 times fluoro protein of the same concentration.

2.1.6.7 Synthetic detergent foam

Synthetic detergent foam is manufactured from chemical foaming agents with additional stabilisers (high boiling solvents). These foam concentrates have a high fluidity and are applied in solutions with a typical concentration of approximately 2 percent. These foam concentrates can be used to produce low, medium and high expansion foam.

The ordinary type has poor burnback resistance and poor fuel resistance and therefore this foam has limited extinguishing properties. It is used for extinguishing fires in buildings, warehouses, etc.

Special Hi-ex foams with a typical expansion ratio of 200-500:1 can be used for covering LNG spills However, before this foam is selected for this purpose advice from the principal should be sought.

Typical price: approximately 0.5 times fluoro protein foam of the same concentration.

2.1.7 Application rate of foam

To be effective, foam must be applied at a rate greater than the "critical application rate" which is the minimum recommended application rate that has been found by laboratory tests to be the most practical in terms of speed of control of the fire and the amount of agent required. A typical minimum recommended application rate for effective control of non-water-miscible fuel fires is 4-6 $dm^3/min/m^2$ fuel area.

Increasing foam application over the minimum recommended rate generally reduces the time required for extinguishment. Rates greatly exceeding recommended minima, waste foam supplies with no appreciable shorter extinguishing time advantage. If the application rate is lower than the recommended minimum, extinguishment may not be reached.

The relation between extinguishing time and application rate depends on fuel, foam type and method of application. For hydrocarbon products a standardised application rate is used. Polar solvents and chemicals require individually confirmed application rates to be obtained from the foam concentrate supplier.

The actual generated application rate is influenced by losses during throw. These losses can be in the order of 50 to 100%. This phenomenon should be considered when engineering fire fighting systems.

When foam is used it requires constant supply until:

- the fire is extinguished and the liquid is cooled down to below its flash point,

or

- the liquid has totally evaporated or has been transferred (pumped) to another container (tank).

For the application of (low expansion) foam the following aspects shall be adhered to:

- Plunging of foam into fuel should be avoided to reduce: free area of evaporation and breaking the foam blanket. Preferably foam shall be applied against a vertical "wall" or by spreading the foam from the application point.
- Recommended pressure ranges should be observed for all foam making equipment. Foam quality generally deteriorates outside these pressure ranges.

2.1.8 Properties of foam

2.1.8.1 Physical properties

Like all liquids, foam concentrates can be characterised by their physical properties, e.g.: specific gravity, pH, total solids, viscosity, and the minimum use temperature. These absolute values are used in engineering foam systems. These values may change over time, and their trend may adversely affect the properties described in this section.

2.1.8.2 Fuel tolerance

Good foam exhibits a high fuel tolerance; minimising fuel pick-up prevents the foam from emitting fuel vapours and supporting the fire. Fuel tolerance is vital for sub-surface and forceful surface applications. Foam can pick up fuel by two mechanisms:

- low interfacial tension can cause it to mix with the fuel (common with detergent based solutions),
- the combination of surface and interfacial values may cause fuel to spread over the foam bubbles. This is a common problem with protein foams.

2.1.8.3 Burnback resistance

The burnback resistance depends on the chemical make up of the foam concentrate. Protein based foams leave behind a charred residue which delays their destruction by the fire. Synthetic foams, in general, have a poor burnback resistance.

2.1.8.4 Heat resistance

The degree of heat resistance determines to a certain extent the ability to form an effective seal against hot obstacles protruding through the foam blanket.

2.1.8.5 Drainage time

With time, foam bubbles will collapse, depending upon surface tension characteristics, and foam solution will drop out of the foam. This will cause a considerable reduction of the effective thickness of the aerated foam blanket. Drainage time usually improves with expansion and viscosity. Obviously, long drainage time is a desirable feature for cold/refrigerated fuels. With film forming foams, a controlled drainage rate is required in order to maintain a well spread film. Sometimes the "50%" drainage time is used for commercial reasons. However typical minimum 25% drainage times for various types of foam are:

Fluoro Protein	using the UL-162 test method and a cylinder of1000 cc with a height of 352 mm: 8 minutes,
AFFF	using the UL-162 test method and a cylinder of 1000 cc with a height of 352 mm: 5 minutes,
High Expansion	(for standard applications): using a 200 litre container with a height of about 1 metre : 10 minutes,
High Expansion	(for LNG applications) : using a 200 litre container with a height of about 1 metre : 15 minutes.

2.1.8.6 Critical shear stress

A foam having a high critical shear stress will be stiff and not flow over a burning fuel surface as readily as one with a low critical shear stress and therefore it will not exhibit such good fire knockdown properties.

2.1.8.7 Shelf life

Shelf life is the foam concentrate manufacturer`s guaranteed time during which a particular foam concentrate will perform as specified, if applied correctly. Shelf life differs to each manufacturer: it should be at least 5 years under the storage conditions at the particular location. Foam concentrate can deteriorate in storage, due to e.g. sludging, oxidation, high storage temperature, loss of stability, dilution, evaporation or contamination. To assist in maintaining and extending shelf life, measures shall be taken to minimize contact of foam concentrate and air, e.g. storage tanks shall be equipped with domes. High temperatures can be avoided by installing a sun roof. During regular training exercises foam shall be checked for a possible change in performance using a fire tray. In addition stocks shall be checked annually by returning a sample to the supplier or preferably to an independent laboratory. See section (10.2). (A test kit is commercially available.)

2.1.8.8 Performance and quality

The performance of a foam is influenced by the aforementioned properties. Some of these properties counteract each other. The effectiveness of a good foam blanket in a fire situation will depend upon the type of fuel, quality, quantity and pressure of the fire fighting water, the foam making equipment and the foam concentrate. In order to achieve a good extinguishment there are six qualities that a foam must exhibit:

- Cohesion; must be such that the foam bubbles cling together and form a tough cohesive blanket,
- Vapour Suppression; the foam must be capable of suppressing flammable vapours and so minimise the risk of re-ignition,
- Stability/Water Retention; it must have the ability to retain water in order to perform its cooling function,
- Heat Resistance; the foam must be able to resist the destructive effects of heat radiated from any remaining fire or hot objects. In addition, it must be able to form an effective seal against any hot metal surface such as a storage tank wall,
- Flowability; in order to extinguish a fire rapidly the foam must flow freely around any obstructions present in the fire. This property is, of course, particularly important when dealing with crash fire situations; typically at loading stations where personnel may be present,
- Fuel Tolerance; a good foam exhibits a high fuel tolerance.

2.1.9 Compatibility

2.1.9.1 Foam concentrates

Different types of foam concentrate shall not be mixed.
Different makes of the same type foam concentrate or foam solution (premix) shall not be mixed in common storage facilities, unless both manufacturers guarantee the good performance of their foam concentrate when mixed together.
Equally if the concentrates are not compatible, resulting solutions shall not be mixed.

2.1.9.2 Finished foam types

Different makes of the same type of (finished) foams can be used simultaneously on the same fire.

2.1.9.3 Foam and dry chemical powder

Foams have to be tested and specified for their compatibility with dry chemical powder, and vice versa. Some dry chemical powders will destroy the finished foam, e.g. when the last flames are treated with dry chemical powder.

2.1.10 Quantity of foam concentrate required

To determine the maximum required amount of foam concentrate, fire plans shall be made. The largest credible fire scenario which may be expected dictates the amount of foam concentrate to be available. Though the largest credible fire scenario may last less than one hour the stock quantity should allow for foam application being maintained for one hour. In addition, a spare stock of the same amount should be kept unless it is assured that such an amount will be available within 60 minutes.

2.1.11 Storage of foam concentrate

2.1.11.1 General

Foam concentrate shall be stored in a dedicated storage tank, manufactured of a suitable material; or in manufacturer's non-metallic drums. The manufacturer of the foam concentrate shall be consulted for suitable foam concentrate resistant material.
Following materials are recommended for:

Fluoro Protein (slightly corrosive):	Glass-Fibre Reinforced Polyester or Carbon Steel with an internal amine cured epoxy paint coating.
AFFF (corrosive):	Glass-Fibre Reinforced Polyester or Stainless Steel, type AISI 316L or agreed alternative.
Alcohol Resistant:	Glass-Fibre Reinforced Polyester or stainless steel type AISI 316L or agreed alternative (Polymer film will form when in contact with mild steel).

2.1.11.2 Foam sampling

Annually at least one bottom sample of foam concentrate shall be examined and tested (to determine specific gravity, pH and viscosity at 20°C) to verify the quality of the foam concentrate and the produced foam. The following collection schemes for foam concentrate samples can be used:

Collect one sample - bottom only (mandatory)

Collect two samples - one top, one bottom

Collect three samples - one top, one bottom, one middle (preferably)

Collect one sample - after recirculating contents

Care shall be taken with bottom samples: taking in consideration sediments, such as layers of dirt and degradation products. When samples contain rust or scale, the contaminated concentrate shall be drained and filtered. Samples of about one litre shall be representative of the bulk stock and they shall be sealed in clean non-metallic containers, accompanied by a label stating type and history.

2.1.12 Specification, testing and procurement of foam

2.1.12.1 Standards

Standardization organizations which deal with the quality of foam are:
National Fire Protection Association - NFPA,

Underwriters Laboratories Inc. - UL,

Factory Mutual - FM,

Their specifications and standards include requirements for foam concentrate and foam quality.
The UL-162 test correlates to realistic fires in the oil and chemical industry and is SIPM's preferred test method.

2.1.12.2 Testing

Independent testing authorities, such as Underwriters Laboratories Inc. (UL) are the customers' guarantee that the foam concentrate manufacturer has demonstrated, through extensive fire testing and evaluations, that the product complies with the rigid requirements and specifications of the testing authority.
In addition a UL-listed manufacturing source will be checked at regular intervals to confirm the quality of product and manufacturing process in the factory. Any deviation from these standards can lead to the foam concentrate manufacturer being removed from the approval listings.

Foam types and/or applications not covered in the UL standards shall be tested to an agreed protocol before acceptance by the principal.

2.1.12.3 Procurement

To obtain a high quality foam concentrate stock, fully UL-162 approved or listed foam concentrates are recommended for purchase. The requisition shall describe that a certification document is required stating that the particular batch conforms to UL listing. Additionally, the requisition should stipulate that a condensed UL test is to be performed on samples, taken from the manufactured batch, at the moment of delivery. This test shall determine the following values: pH (acidity), viscosity, 25 percent drainage time and specific gravity. Condensed test to be performed by manufacturer, and results to be forwarded to purchaser.
The foam concentrate manufacturer or supplier shall guarantee that the foam concentrates are biodegradable and non-toxic. For this purpose manufacturers shall supply data on chemical oxygen demand and biological oxygen demand.
It is recommended to include a "return" clause in any purchase order to dispose of redundant/deteriorated foam concentrate stock.

2.1.13 Safety and environmental effects of foam concentrates

Manufacturer's Material Safety Sheets for each foam concentrate type shall be available. The manufacturer shall confirm that the product meets the legal requirements of the country of destination.

Normally the various types of foam concentrates are complex mixtures. Foam concentrates can contain phosphates, mercury or other materials identified as contaminants or pollutants. Protein based foams may contain added freezing point depressants and organic and inorganic stabilisers. Synthetic foams may contain freezing point depressants and, in some cases, a surface-active fluorocarbon.

2.2 DRY CHEMICAL POWDER

2.2.1 Fire classification

Dry chemical powders are divided depending on the types of fires for which they are suitable. Fires are classified into groups in accordance with the flammable materials involved:

American (UL-711) class	Material involved	European (EN-2) class
A	Wood, paper, rubber (glowing embers)	A
B	Liquids like petroleum products, varnish, lacquer thinners, etc.	B
B	Vapours and gases	C
C	Energized electrical equipment	None
D	Metals like magnesium, sodium, titanium, potassium, lithium, zirconium	D

In order to avoid misunderstanding the UL-711 classification is followed in this publication.

2.2.2 Functioning of powder

The detailed mechanisms by which dry chemical agents extinguish fires have not been completely determined. However, it is generally accepted that the primary extinguishing mechanisms include:

- interruption of the chain reaction sequence in chemical reactions,
- reduction of liquid fuel evaporation rates by reduction of flame radiation at the liquid surface,
- inert effects due to reduction of oxygen concentration within the active fire zone.

Secondary extinguishing mechanisms may include:

- heat absorption effects (particularly at high dry chemical concentrations),
- cooling effects, due to the formation of water vapour by the pyrolysis processes, in the flame. (This reduces the heat radiated back into the product on fire.)
- additional inert effects due to the formation of carbon dioxide by the pyrolysis of the dry chemical,
- fire retardant effects due to surface coatings.

The effectiveness of the chemical reaction mechanisms differs with each chemical agent and is believed to be the primary reason for the differences in overall effectiveness of the different agents at critical extinguishing flow rates. The physical mechanisms, such as reduction of oxygen concentrations, are significantly influenced by dry chemical concentrations in the flame zone as well as the dry chemical agent physical properties.

2.2.3 Advantages and limitations of powder

Dry chemical powders give an instantaneous extinguishment of the flames of a fire. The agent gives very rapid fire control and it is particular useful against running flammable liquid fires, which foam cannot readily extinguish. Dry chemical powders are highly efficient in extinguishing fires, provided they can reach all areas of the fire without interruption.

The use of dry chemical agents shall not be considered satisfactory protection for the following:

- chemicals containing their own oxygen supply, such as cellulose nitrate.
- combustible metals such as sodium, potassium, magnesium, titanium, and zirconium.
- deep seated fires in ordinary combustibles where the dry powder cannot reach the point of combustion.

Although dry chemical powders are electrically non-conductive, they should preferably not be used for instrumentation and electrical equipment, due to the corrosion after being exposed to moisture. Their use in fixed installations requires specialist's designs. They shall be designed according to NFPA and the manufacturer's specifications. Dry chemical powders do not cover and cool oil surfaces.

Dry chemical powders have limitations in extinguishing performance. Therefore the appropriate powder shall be used for a particular fire (see 2.2.4).

Dry chemical powders do not cool the product on fire. After extinguishment a flash fire may occur instantly; this can only be avoided by cooling with water.

2.2.4 Types of dry chemical powder

The common dry chemical powders are listed below. These materials are treated to gain proper flow capabilities and to provide resistance against packing and moisture absorption (caking). The type of dry chemical powder used as one of the factors determining the fire extinguishing rating as described in UL-711 and EN 3-1.

2.2.4.1 Sodium bicarbonate

This agent consist primarily of sodium bicarbonate and it is a basic dry chemical powder extinguishing agent. It consists of small particles which do not penetrate deeply into the fire. It is suitable for use on all types of hydrocarbon flammable liquid and gas fires (Class B) and also for fires involving energized electrical equipment (Class C). It is not recommended for Class A fires. A fire extinguisher rating of 60 (based on UL-711) is typical for 12 kg of sodium bicarbonate for class B and C fires.

2.2.4.2 Potassium bicarbonate

This agent consists primarily of potassium bicarbonate. It consists of larger particles which penetrate deeper into the fire. As a result it has a better UL rating than sodium bicarbonate. A UL-711 rating of 120 is typical for 12 kg of potassium bicarbonate for class B and C fires.
It is suitable for use on all types of flammable liquid and gas fires (Class B) and also for fires involving energized electrical equipment (Class C).

Generally dry chemical powders, based on salts of potassium, are not recommended for Class A fires.

2.2.4.3 Ammonium phosphate

This agent consists of a mixture of ammonium phosphate (min. 40%) and ammonium sulphate. Mono-ammonium phosphate powders, referred to as multi-purpose powders, are suitable for Class A,B and C fires. The agent, when heated, decomposes to form a molten residue which will adhere to heated surfaces. Therefore they are less appropriate for processing and storage facilities. On combustible solid surfaces (Class A), the molten residue excludes the oxygen necessary for propagation of the fire. As a result it has a good extinguishing effect in Class A fires.

2.2.4.4 Urea-based potassium bicarbonate

This material is denser than sodium bicarbonate. Due to the resulting improved throw, urea-based potassium bicarbonate has a better fire penetration capability in all types of flammable liquid and gas fires (Class B) and also in fires involving energized electrical equipment (Class C). As a result the fire extinguishing rating is better than of potassium bicarbonate. Urea-based potassium bicarbonate particles have a larger volume than potassium bicarbonate particles. The filling ratio of urea-based potassium bicarbonate to potassium bicarbonate is 0.7. A nominal 12 kg portable extinguisher filled with 8 kg urea-based potassium bicarbonate has the same extinguishing rating for B,C fires as when filled with 12 kg potassium bicarbonate. Though more expensive, urea-based potassium bicarbonate is the most powerful dry chemical powder on a weight basis and therefore the preferred powder for use in our installations.

The urea-based dry chemical powders are not recommended for the extinguishment of Class A fires.

2.2.4.5 Special powders for chemical or metal fires

These dry chemical powders are generally based on sodium chloride, graphite or sodium bicarbonate. Standard types of dry chemical powders should not be used to extinguish chemical or metal type fires because in most cases there is danger of increasing the intensity of the fire due to chemical reaction between some extinguishing agents and the burning chemical or metal. When using special powders for chemical or metal fires, special safety equipment, including breathing apparatus, may be required to protect operators.
With these special powders care should be taken to use the appropriate type of dry chemical powder for the particular type of fire.

2.2.5 Application rate

Dry chemical powder is used to achieve fast extinguishment of any fire which may occur in the protected area.

Specification for the application rate of dry chemical powders is a function of:

- the flow characteristics of the particular dry chemical powder,

and - the equipment used in the system.

The following minimum application rates for dry chemical powders can be used for guidance:

- sodium bicarbonate : 1.1 kg.s^{-1} m^{-2}.
- potassium bicarbonate : 1.1 kg.s^{-1} m^{-2}
- urea-based potassium bicarbonate : 0.8 kg.s^{-1} m^{-2}.
- ammonium phosphate : 1.6 kg.s^{-1} m^{-2}.

Typical discharge time is at least 30 seconds.

Performance rating of an extinguisher is typically expressed as a fire area which can be extinguished under test conditions e.g. a UL 711 rating of 60 indicates an area of 14 m^2

2.2.6 Properties of powder

2.2.6.1 Flowability

In this context flowability is the ability of the dry chemical powder to pass through piping systems (incl. hoses, fittings and nozzles) without blocking of the extinguishing system.

2.2.6.2 Hygroscopic behaviour

Dry chemical powder has the tendency to absorb moisture; this is called hygroscopic behaviour. Most powders have a silicon coating which may resist absorption. When the moisture content is too high, the dry chemical powder will cake. The moisture content shall not exceed 0.2%.

2.2.6.3 Resistance to packing

Resistance to packing of the dry chemical powder particles is important when the dry chemical powder is stored in sacks or in fire-fighting vehicles. The storage of sacks shall not exceed a height of 1.2 metre. The silicon coating, which is on most powders, may be broken by crushing; this will cause the extinguishing performance of the dry chemical powder to deteriorate.
In portable, wheeled, mobile and fixed systems powders may be subject to vibration. Therefore provisions shall be made to fluidize the powder upon pressurisation.

2.2.6.4 Particle size

The particle size of dry chemical powders is important to its extinguishing performance. The smaller the particle size, the greater the relative particle surface and the lighter the particle. The lighter the particle the lesser the throwing capacity. Particles smaller than 14 µm are too light for sufficient throwing capacity.

2.2.7 Compatibility

2.2.7.1 Compatibility of powder types

Dry chemical powders shall not be mixed. Mixtures of certain dry chemicals may generate dangerous pressures and the mixtures may form lumps. When dry chemical powders of the ABC type (ammonium phosphate) are mixed with dry chemical powders of the BC type (potassium or sodium bicarbonate), ammonia and carbon dioxide gases will be released.

2.2.7.2 Compatibility of powder and foam

Dry chemical powders shall only be used with foam when the manufacturer of the dry chemical powder provides proof, by an independent testing authority, that the powder is compatible with the particular foam type. Generally, silicone-coated dry chemical powders are compatible with foam.

2.2.8 Quantity required

To determine the amount of readily available dry chemical powder, fire plans shall be established. The largest credible fire hazard, which may be expected, dictates the amount of dry chemical powder to be available for immediate use. A 100 percent spare capacity shall be kept in stock.

2.2.9 Storage of powder

2.2.9.1 Storage conditions

Stocks of dry chemical powder shall be stored in a continuously dry area. Dry chemical powders are unaffected by temperature extremes. Dry chemical powder shall be shipped/stored in containers which will prevent the entrance of moisture. For stacking see (2.2.6.3).

2.2.9.2 Periodic inspection

At regular time intervals, dry chemical powder stocks should be inspected for flowability and caking. They shall be laboratory-tested in accordance with UL-299. Powder contained in portable, wheeled and mobile units shall be checked regularly to ensure the powder is still free-flowing.

2.2.10 Specification, testing and procurement of powder

2.2.10.1 Standards

Neither Royal Dutch /"Shell" Group nor Oil Industry specifications are available to specify dry chemical powder.

Available USA specifications are:

Federal spec. O-D-1407 for potassium bicarbonate
and Federal spec. O-F-371B for sodium bicarbonate.

Specifications for other dry chemical powders require Principal's approval.

2.2.10.2 Testing

Independent testing authorities, such as Underwriters Laboratories Inc. (UL) are the customer's assurance that the manufacturer of Dry Chemical Powder (systems) has demonstrated through extensive fire testing and evaluations, that the product complies to the rigid requirements and specifications of the testing authority.

In addition, a UL-listed manufacturing source will be checked at regular intervals to confirm production quality in the factory. Any deviation from UL standards can lead to the manufacturer being removed from the UL approval list.

When witnessing manufacturers' tests, the Dry Chemical Powder shall be applied with standard equipment, i.e. with mass-produced equipment which is generally available to the customer.

2.2.10.3 Procurement

To obtain a high quality Dry Chemical Powder, only fully (e.g. UL) approved or listed Dry Chemical Powder from reliable and reputable Dry Chemical Powder system manufacturers are recommended for purchase. The requisition shall specify that a certification document is required stating that the particular batch is suitable for the intended system. Only Dry Chemical Powder with a test certificate (e.g. UL-299, Part 47: "Extinguishing agent test"), shall be accepted. Such tests shall be performed by suitable, independent testing laboratories.

2.2.11 Powder systems

2.2.11.1 General description

Upon manual or automatic activation dry chemical powder systems release a pre-determined quantity of dry chemical powder through a distribution system onto or into the protected area.

2.2.11.2 Safety aspects

Discharges of large amounts of dry chemical powder may create a hazard to personnel, such as reduced visibility and temporary breathing difficulty. In total and local application systems where there is a possibility that personnel may be exposed to a dry chemical discharge, suitable safety measures shall be provided to ensure prompt evacuation of such locations.

2.3 HALON COMPOUNDS

2.3.1 General

Halons are bromo- (chloro-) fluorocarbons. Halon 1301 is a colourless, odourless, electrically non-conductive gas. Halon 1211 is a colourless, faintly sweet-smelling, electrically non-conductive vapourizing liquid. They are both effective media for extinguishing fires and have become widely used because they are the only known agents that do not cause agent damage to the protected area.

There has been increasing concern in recent years that the emission of halons into the atmosphere results in the depletion of the earth's protective layer of stratospheric ozone.
The Royal Dutch /"Shell" Group supports international efforts to phase out Halon 1211 and 1301, which are listed in the Montreal Protocol.

For this reason, halons are **not recommended** as a fire fighting agent.
HALONS SHALL BE USED ONLY WHEN IT IS CONSIDERED ESSENTIAL AND ALTERNATIVES ARE NOT SUITABLE.
General guidance on Halon is provided below.

2.3.2 Functioning

The chemical mechanism by which halon extinguishes a fire is based on a chemical reaction affecting the progress of the fire "anti-catalytically". Finely-distributed halon interrupts the radical chain and branching reactions which maintain combustion; even small amounts of halon rapidly produce these breakdown reactions. The extinguishing effect due to cooling or dilution of oxygen or fuel vapour concentration is minor.
Halons are only effective at temperatures above 482 °C. Halon has a very good extinguishing performance compared with other types of fire fighting agents.

2.3.3 Restrictions

Halon is not suitable for deep seated or smoldering fires where the temperature does not exceed 482 °C.

2.3.4 Types of Halon and their applications

2.3.4.1 Halon 1211 - BCF (bromochlorodifluoromethane)

Halon 1211 (BCF) is a halogenated chlorofluorinated carbon, with the chemical formula $CBrClF_2$.

It is mostly used in portable fire extinguishers and local application fire protection systems, such as floating roof seals and gas turbine/compressor units.
Due to its boiling point of minus 4 °C and vapour pressure of 2.7 bar (ga) at a temperature of 21 °C, it can be discharged in a directional manner, i.e. "thrown" at the target. Liquid particles penetrate deep into the fire before evaporation.
The fundamental purpose of a local application system is to reach and hold the required concentration for the required time around the hazard.

2.3.4.2 Halon 1301 - BTM (bromotrifluoromethane)

Halon 1301 (BTM) is a halogenated fluorinated carbon, with the chemical formula $CBrF_3$.

It is mostly used in total flooding fire protection systems, for the protection of computer rooms, telephone exchange rooms, and rooms where special, critical and highly valuable applications are installed. Due to its boiling point of minus 58 °C and a high vapour pressure of 14.7 bar (ga) at a temperature of 21 °C, it can be discharged rapidly and it mixes readily with air. The fundamental purpose of a total flooding system is to create and maintain the required extinguishing concentration for the required time in the protected enclosed hazard area.

2.3.5 Physical properties of Halon

The properties of halon shall be in accordance with MESC Specification 96.13.10/001.

2.3.6 Health and environmental aspects

The discharge of Halon 1301 or Halon 1211 to extinguish a fire may create a hazard to personnel; particularly chlorides, hydrogen chlorides, fluorochlorides and phosgene that result from exposure of the agent to fire or hot surfaces.
Halons have a very low toxicity and they are normally not harmful to personnel; as a result exposure to halon is generally of less concern. However any unnecessary personnel exposure to high concentrations (e.g. near nozzles) should be avoided. Personnel shall evacuate an area before any discharge from a fixed halon system. For this purpose an appropriate warning system shall be installed. Other potential hazards to personnel are noise, turbulence and, for Halon 1301, cold temperature near nozzles.

The environmental effect of ozone layer depletion is less severe with Halon 1211 than with Halon 1301.

2.3.7 Quantity required

In fixed systems the minimum design requirement for extinguishment by Halon is 5 percent of the total volume of the protected enclosure for class A, B and C fires (For typical information refer to NFPA 12A for Halon 1301 and NFPA 12B for Halon 1211). To ensure minimum necessary quantities of Halon, the protected enclosure shall be designed air tight. Moreover, upon Halon system activation, any ventilation system shall shutdown and dampers shall be closed.

2.3.8 Storage

Halon is stored in transportable containers up to 130 litres, which shall be made according to the required codes as dictated by country of destination (See MESC 96.13.10/001).

2.4 CARBON DIOXIDE

Carbon dioxide is a colourless, odourless, electrically inert gas. It acts as a fire suppressor by reducing the oxygen-fuel ratio below the necessary concentration to support combustion. Particularly in enclosed areas, as a gas it will penetrate and spread to all parts of the hazard (e.g. gas turbine enclosure).

Carbon dioxide is a gas present in the air at an average concentration of about 0.03 percent by volume. Carbon dioxide gas has 1.5 times the density of air.

2.4.1 Advantages

Carbon dioxide is used as an inerting agent in specific hazards or equipment and in areas/enclosures, where an inert electrically non conductive medium is essential and where clean up of other agents presents a problem.

Some types of hazards and equipment that carbon dioxide gas may protect are electrical hazards, rotating equipment and electronic equipment, engines utilising gasoline and other flammable liquid fuels, unmanned computer rooms, ordinary combustibles such as paper, wood and textiles.

2.4.2 Restrictions

The discharge of liquid carbon dioxide can produce electrical charges which, under certain conditions, could create sparks. In addition, vaporizing carbon dioxide (atmospheric boiling point minus 79° C) may damage sensitive equipment through cold shock on direct impact.

2.4.3 Safety

Carbon dioxide cylinders shall not be exposed to direct sunlight as the vapour pressure rises sharply under rising temperature.

In enclosed areas the concentration of carbon dioxide as discharged from fire extinguishers may create serious hazards to personnel, such as suffocation and reduced visibility during and after the discharge period. A concentration of 30 percent is needed for fire extinguishing, while a 12 percent concentration creates a risk to personnel.

Other personnel hazards are noise and cold burn.

2.4.4 Storage

Carbon dioxide shall be stored in rechargeable containers designed to hold pressurised carbon dioxide in liquid form at atmospheric temperatures corresponding to a vapour pressure of 58.6 bar (ga) at 21 °C. Containers for transport purposes, up to 130 litres, shall be made according to required codes as stipulated by the country of destination (see MESC 96.13.10/001).

2.4.5 Carbon dioxide systems

Carbon dioxide extinguishing can be applied through the following methods:

- Portable/Wheeled Extinguishers,
- Total Flooding System,
- Local Application System,
- Standpipe System in combination with mobile supply.

Portable extinguishers shall conform to EN 3-1, 3-2, 3-4 and 3-5 inclusive, or UL-154. Carbon dioxide systems, for total flooding, local application or standpipes, shall be designed, commissioned and (performance) tested according recognised codes, such as NFPA-12. With regard to personnel safety adequate consideration shall be given to safety precautions for carbon dioxide systems.

2.5 STEAM

Steam extinguishes fire by exclusion of air or reduction of the oxygen content of the atmosphere in a manner similar to carbon dioxide or other inert gases.

Steam is generally used for fire fighting purposes in areas where it is readily available in large quantities such as furnaces. The advantage of using steam in fighting furnace fires is its lack of generating cold shock. Steam can be applied with the use of a steam lance in furnace crossover header boxes etc.

Sometimes steam rings are used around flanged connections, in e.g. hydrogen service.

Possible injury from burns to personnel should be considered when steam is used. The use of steam as a fire fighting agent has often been unsuccessful due to lack of understanding that it is preventing the supply of oxygen.

2.6 SAND

Sand can be applied on small surface fires. It can also be used for fire prevention: absorption, covering, directing of spills. At least 0.5 m^3 of sand shall be available:

- in process units,
- in hazardous areas (e.g. pump houses, valve manifolds) of storage facilities,
- at (un)loading stations.

Sand shall be stored in non-metallic containers equipped with a cover. In each container two scoops shall be readily available. Locations of the containers shall be shown in the fire fighting system's master plan. For new projects, containers, inclusive sand fills and scoops, shall form part of the project requirements.

2.7 WATER

2.7.1 General

Water is the most commonly used agent for:
- cooling adjacent equipment,
- controlling fires and vapour releases.

Water can be used for extinguishing certain fires. As such it is highly effective on fires of solid materials (class "A" fires) such as wood, paper, natural rubber etc.
In office buildings and warehouses water can be applied by means of fixed installed sprinkler systems.

Water can only be applied on fires of liquid materials if both the following conditions are met:
- the product, cooled down by the ambient water, has a high flash point,
- the bulk temperature of the liquid (on fire) is below 100 °C, thus avoiding steam "explosions". Above 100 °C water shall be applied intermittantly and with low application rate (typically: 2 $dm^3/min/m^2$) to avoid frothing.

For these applications fixed systems are normally not used; water is applied by mobile equipment.

Water shall be applied on the target in spray form to obtain effective cooling and to avoid splashing in case of a liquid fire. Water applied by a jet is only justified to cover long distances when the water will reach the target in droplets. For cooling purposes of equipment in an engulfed petrochemical fire a mininum design rate of 8.5 $dm^3/min/m^2$ equipment surface area or 20 $dm^3/min/m^2$ projected area is required for fixed installed systems.

Water is also used for curtain systems, which are applied as a heat barrier between a fire and the protected equipment. With a similar water curtain a non-ignited vapour cloud can be diverted and large volumes of induced air will reduce the (relative) vapour concentration downwind.

In most cases water is more economic than other fire fighting agents.

2.7.2 Use

At ambient temperature, water can be used for:
- cooling (protection against exposure to fire)
- producing foam to cool fuel surfaces and to extinguish pool fires,
- extinguishing fires of liquid hydrocarbons with a flash point above 38 °C up to flash points of 93 °C: NFPA Class II and IIIA,
- for directing pools of burning liquids,
- for dispersion of escaping gases and vapours,
- protection of personnel.

2.7.3 Heat absorption

The ability of water to cool hot surfaces is a function of its heat capacity, i.e. the heat required to raise its temperature to boiling point and to vaporise it into steam. The efficiency of heat transfer is proportional to the exposed water surface in contact with the heat source. In practice most cooling is achieved by directing water droplets onto a hot surface. Such droplets have a relatively large surface area. This implies that water should be applied as a spray in most cases.

2.7.4 Vaporization

When water is converted from liquid to vapour, its volume at atmospheric pressure increases about 1700 times. This large volume of water vapour (saturated steam) displaces an equal volume of air surrounding a fire, thus reducing the volume of air (oxygen) available to sustain combustion.

2.7.5 Restrictions

Water can increase corrosion rates particularly if it is salty or contaminated.

Since water is conductive, the use of water for electrical fires should be avoided. Factors influencing the likelihood of shock from live electrical equipment are:

- electrical loading (voltage and current),
- distance separating water application equipment and live electrical equipment,
- dispersion of the water stream or spray, i.e. the electrical conductivity of the water stream.

NFPA gives recommendations about safe distances between hose nozzles and electrical equipment at different voltages.

2.7.6 Compatibility

2.7.6.1 Water and foam

Water shall not be used where foam is applied since water spray will destroy foam bubbles and water will displace the foam from its desired locations, and a water jet will destroy the foam blanket.
Water may be used to cool down adjacent/nearby equipment, and simultaneously foam can be applied on a pool fire.

2.7.6.2 Water and powder

Water shall not be used together with powder as the powder extinguishing efficiency will be adversely affected. However, immediately after flames have been extinguished by powder, water shall be instantly applied to cool adjacent hot surfaces to avoid flash fires.

3. REFERENCES

In this manual reference is made to the following publications.

NOTE: Unless specifically designated by date, the latest issue of each publication shall be used (together with any amendments/supplements/revisions thereto).

SHELL STANDARDS

Material and Equipment Standards and Code - Fire Fighting Extinguishing Agents: Gases	MESC 96.13.10/001

AMERICAN STANDARDS

Low expansion foam and combined agents systems	NFPA 11
Carbon dioxide extinguishing systems	NFPA 12
Halon 1301 extinguishing systems	NFPA 12A
Halon 1211 extinguishing systems	NFPA 12B
Dry chemical extinguishing systems	NFPA 17

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Foam equipment and liquid concentrates	UL-162
Dry chemical fire extinguishers	UL-299
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U.S.A.

Fire extinguishing agent - Potassium bicarbonate dry chemical	O-D-1407
Fire extinguishing agent - Sodium bicarbonate dry chemical	O-F-371B

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EUROPEAN STANDARDS

Fire Classifications	EN 2
Fire fighting - Portable fire extinguishers, Part 1	EN 3-1

Fire fighting - Portable fire extinguishers, Part 2	EN 3-2
Fire fighting - Portable fire extinguishers, Part 4: Charges and minimum performances	EN 3-4
Fire fighting - Portable fire extinguishers, Part 5: Complementary requirements and tests	EN 3-5

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