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Hydraulic fluid power — Fire-resistant (FR) fluids — Requirements and guidelines for use

Transmissions hydrauliques — Fluides difficilement inflammables — Exigences et principes directeurs pour leur utilisation

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 7745 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*, Subcommittee SC 4, *Classifications and specifications*.

This second edition cancels and replaces the first edition (ISO 7745:1989), which has been technically revised.

Introduction

In hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure within an enclosed circuit. The most widely used liquid for hydraulic power systems is mineral oil which has advantages of excellent lubricity, availability in a wide range of viscosities and reasonable cost.

While not readily ignited in bulk, mineral oil is nevertheless flammable, and the high pressures associated with hydraulic systems can lead to a release of fluid which is easily ignited. In circumstances where ignition is likely, such as in a steel mill, or where released fluid cannot be allowed to propagate a fire, as in a coal mine, an alternative, fire-resistant, fluid must be used. Fire-resistance and physical properties such as viscosity and lubricity vary widely among the several types of fluid available. It is important therefore to select a fire-resistant fluid to match its proposed application and the perceived hazards in use.

Hydraulic fluid power — Fire-resistant (FR) fluids — Requirements and guidelines for use

1 Scope

This International Standard specifies the operational characteristics for the various categories of fire-resistant fluids defined by ISO 6743-4. This International Standard details the factors to be considered when selecting a fluid from these categories for a proposed application.

This International Standard identifies difficulties which might arise from the use of such fluids and indicates how they may be minimized. Appropriate procedures are given for replacing one fluid with another from a different category. Health and safety aspects when handling and disposing of fire-resistant fluids are also covered.

This International Standard does not apply to fire-resistant fluids used in the hydraulic systems of commercial or military aircraft. The appropriate aviation standards are also usually applied where aircraft hydraulic fluids are filled into ground-based systems.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
fire-resistant hydraulic fluid
hydraulic fluid that is difficult to ignite and which shows little tendency to propagate flame

[ISO 5598:2008, definition 3.2.271]

3 Hydraulic systems — Fire hazards

3.1 General

Fluid pressures in hydraulic power systems range up to 40 000 kPa (400 bar) and more. It therefore follows that any lack of integrity in the construction of a system, resulting in a burst or even a small leak, can in many circumstances give rise to a serious fire hazard.

3.2 Fault conditions

Failure of piping (particularly at joints and fittings), valves or gaskets, and rupture of flexible hoses have been principal causes of fluid being released from a system. The period of highest risk of this type of failure is during the commissioning, or after the repair, of a hydraulic system.

The following fire hazards are directly related to the use of hydraulic fluid under fault conditions. In each case, a source of ignition as described in 3.3 is required to initiate combustion:

a) ignition of hydraulic fluids ejected under pressure from hydraulic systems, in the form of a jet, spray or fog;

b) ignition of combustible vapours produced by hydraulic fluid;

c) ignition of hydraulic fluid spilled during transport, or leaking from hydraulic systems, on to absorbent material such as lagging or dust, and the subsequent propagation of fire along the fluid-wet absorbent material;

d) ignition of a fluid stream or pool;

e) ignition of hydraulic fluid where fire resistance has been reduced by chemical or physical changes in the fluid caused by service operation.

EXAMPLE 1 Reduction of the fire resistance of a fluid by evaporation or separation of water from the fluid which relies upon water to confer fire resistance.

EXAMPLE 2 Ignition of fire-resistant fluid contaminated with more combustible substances such as mineral oil.

3.3 Sources of ignition

Sources of ignition include, but are not limited to, the following occurrences:

a) discharge of static electricity;

b) stray electric currents or discharges from malfunctioning electrical equipment leading to high surface temperatures or sparks;

c) friction between moving surfaces, either during normal operation (e.g. brakes) or under fault conditions, leading to high surface temperatures;

d) high surface temperatures due to the presence of hot molten materials or materials undergoing high temperature manufacturing operations;

e) sparks and open flames from manufacturing operations, such as cutting, welding and grinding;

f) acoustic and electromagnetic energy, such as ultrasonic and microwave radiation.

4 Hydraulic systems — General precautions

4.1 Assembly work

Assembly work shall be carried out and supervised by competent staff following good hydraulic practice. The highest risk of leaks is during commissioning of a new system after assembly or during re-commissioning after repair.

4.2 Pipework and hoses

Pipework and hoses shall be mounted and secured in such a way as to minimize the effect of vibration. Consideration shall be given to siting components and routing pipes and hoses to minimize the likelihood of physical damage, particularly chafing of hoses. Wherever possible, pipework should not be routed adjacent to other services, particularly high-voltage electrical supplies.

4.3 Seals and gaskets

Only materials compatible with the fluid shall be used. Failure of incompatible materials can result in the rapid loss of fluid in the form of jets or sprays, which significantly increases the risk of fire.

4.4 High fluid temperatures

The operating temperature of a well-designed hydraulic system should not normally exceed 50 °C at the pump inlet. Higher operating temperatures shall be subject to careful consideration of the increased hazards and preferably with the written agreement of the fluid supplier. Operation at increased temperatures should be accompanied by more frequent monitoring of the fluid condition and properties.

High operating temperatures generally reduce fluid viscosity which can greatly increase the potential leakage rate and may render the system less efficient. Further, when water-based fire-resistant fluids are used in high temperature conditions, evaporation of water can lead to reduced fire resistance and other changes in fluid properties.

It is recommended that thermal shut-down devices be incorporated within the hydraulic reservoir, to operate in the event of high fluid temperatures occurring.

High temperatures also accelerate fluid degradation due to chemical changes. Prolonged exposure to excessive temperatures can promote instability in emulsion-type fluids, resulting in the separation of an oil-rich emulsion (cream) and free oil which is more flammable than the bulk of the fluid. Where installations require reservoir heating for cold start-up, the rating of the heater shall be limited to avoid thermal degradation of the fluid.

5 Requirements for fire-resistant fluids

5.1 General fluid requirements

5.1.1 General

To perform satisfactorily in a hydraulic system, a fire-resistant fluid shall have properties and characteristics which match the system requirements. Conversely if the perceived risk of fire limits the range of fluid types which can be used, the components of the hydraulic system shall be designed to perform adequately with the fire-resistant fluid selected.

5.1.2 Viscosity

The fluid shall be sufficiently viscous at all working temperatures to prevent unwanted leakage across working clearances wherever a pressure differential exists. Where the chosen fluid has a very low viscosity, system components shall be selected which are designed specifically for use with such fluids.

However, the functional fluid shall be of sufficiently low viscosity at all working temperatures to flow readily through the system and to accommodate rapid changes in velocity and pressure.

5.1.3 Lubrication

The fluid shall have sufficient viscosity and film strength to lubricate working parts effectively, under both hydrodynamic and boundary conditions, over the working temperature range. Where the chosen fluid has a very low viscosity, and adequate lubrication properties are not conferred by additives, system components shall be selected which operate satisfactorily with the fluid.

5.1.4 Compatibility

The fluid shall be compatible with the constructional materials used in the system and be non-corrosive. If necessary, the system or component manufacturer shall be contacted for guidance.

5.1.5 Chemical and thermal stability

The thermal, oxidative and hydrolytic stability of the fluid shall be sufficient to ensure the safe and reliable operation of the system. The service life of the fluid is closely related to the bulk operating temperature as well as the effectiveness of fluid maintenance and the successful control of contamination.

5.1.6 Air release and foaming

The fluid shall release entrained air readily and not produce stable foam.

5.1.7 Shear stability

The fluid shall be shear-stable, i.e. its viscosity shall not display a significant permanent change as a result of applied shear in the system.

5.2 Other fluid properties which may impact on system design

5.2.1 General

The following fluid characteristics shall be considered during the course of system design and fluid selection.

5.2.2 Filterability

The fluid shall be filterable at the rating of the finest filter in the system. The rating (fineness) of the system filters is determined by several factors, including type and condition of the fluid, component design, required component life and reliability.

5.2.3 Density

The density of some fire-resistant fluids is greater than that of mineral oil, which may lead to increased pressure drops in circuit components, and may impose restrictions on the design of the suction line of the pump.

5.2.4 Vapour pressure

The vapour pressure of some fire-resistant fluids, particularly those whose fire resistance is conferred by the presence of water, is much higher than that of mineral oil and varies with fluid temperature. The design of the system, particularly around the suction of the pump, shall minimize the risk of cavitation at the pump inlet. Other than very coarse strainers, filters in suction lines should be avoided, and ideally the pressure at the pump inlet should be greater than 100 kPa (1 bar) absolute.

6 Characteristics of fire-resistant hydraulic fluids and factors affecting their selection

6.1 General

6.1.1 Composition

Fluids used as fire-resistant hydraulic media obtain their fire resistance either from the presence of water, or from their chemical composition.

Water is readily available and completely non-flammable. However, it has a very low viscosity and poor lubrication properties and apart from the obvious temperature limitation, its use also gives rise to problems of erosion, cavitation, and corrosion. Nevertheless, technology is available permitting the use of pure water, or water with corrosion inhibitors added, as a hydraulic fluid. Most hydraulic applications, where fire resistance is a requirement, make use of formulated fluids which have performance advantages over pure water.

6.1.2 Classification of fire-resistant fluids

Table 1 is adapted from ISO 6743-4:1999, Table 1, and the tables of ISO 12922:1999, and gives the classification of fire-resistant fluids used in hydraulic systems together with their operating temperature ranges. There are four basic categories, HFA, HFB, HFC and HFD. There is a sub-division of the HFA and HFD categories according to fluid chemistry.

Table 1

Composition and properties	Symbol ISO-L	Remarks
Oil-in-water emulsions	HFAE	Water content ⩾95 % volume fraction[a] Operating temperature range: +5 °C to +50 °C
Chemical solutions in water	HFAS	Water content ⩾95 % volume fraction[a] Operating temperature range: +5 °C to +50 °C
Water-in-oil emulsions	HFB	Typically contain at least 40 % mass fraction of water Operating temperature range: +5 °C to +50 °C
Water polymer solutions	HFC	Typically contain more than 35 % mass fraction of water in a mixture of glycols and polyglycols Operating temperature range: −20 °C to +50 °C
Synthetic fluids free of water	HFDR	Consisting of phosphate esters Operating temperature range: −20 °C to +70 °C or to +150 °C[b]
Synthetic fluids free of water	HFDU	Consisting of liquids other than phosphate esters Operating temperature range: −20 °C to +70 °C or to +150 °C[b]

[a] A few fluids in this category have viscosities significantly higher than 1 cSt (1 mm^2/s) and may contain ⩾75 % volume fraction of water.

[b] The higher temperature indicates the approximate upper limit for short-term operation. This depends upon whether the application is hydrostatic or hydrodynamic and, for HFDU fluids, the composition of the fluid. Where doubt exists, clarification should be sought from the equipment manufacturer or fluid supplier.

6.1.3 Fluid mixing

The mixing of fire-resistant fluids from different categories shall be avoided. It is also not recommended that fluids of the same category but of different origins be mixed unless the compatibility of the fluids with each other has been clearly established.

Changing the hydraulic fluid in a system from mineral oil to a fire-resistant fluid or from one category of fire-resistant fluid to another, calls for special precautions and reference should be made in these circumstances to Clause 8.

6.2 Characteristics of fluids in different categories

6.2.1 HFAE — Oil-in-water emulsions (thickened and unthickened)

6.2.1.1 General

HFAE fluids are extremely fire resistant due to their very high water content and are available as thickened and unthickened fluids (see 6.2.1.2). The unthickened type is usually supplied as a concentrate which is mixed with water by the user, commonly in the ratio of 2 % to 5 % volume fraction of concentrate with a volume fraction of 98 % to 95 % of water. The optimum concentration shall be decided after tests with the fluid and the diluting water, and discussion with the fluid supplier. When prepared manually, it is usual to add the concentrate gradually, with continued stirring, to the required volume of water. For large volumes, automatic mixers are available. The concentrate typically consists of a mineral oil together with suitable emulsifiers, corrosion inhibitors, pH buffers and coupling agents. Anti-wear additives, anti-foam agents, bactericides and fungicides may be included. For the thickened fluids in this category, the additive package and thickener are up to 25 % of the total volume; these fluids are normally supplied ready mixed, rather than as concentrates.

Emulsions with a particularly small oil droplet size and usually lower mineral oil content are commonly known as micro-emulsions and, depending upon the hardness of the diluting water, may be translucent in appearance.

The finished fluid is usually alkaline, with a pH typically in the region of 9,0 to 9,5.

6.2.1.2 Viscosity

Due to the very high content of water in unthickened fluids, their viscosities are close to that of pure water (approximately 0,8 mm^2/s at 40 °C). Accordingly, hydraulic components designed specifically for use with low viscosity fluids are normally used in hydraulic systems filled with unthickened HFAE fluids. Thickened HFAE fluids have viscosities comparable to mineral oil (e.g. ISO VG 32 and ISO VG 46), allowing more conventional hydraulic components to be used; however, the components are still required to operate reliably with the reduced lubricating properties of these fluids.

6.2.1.3 Lubrication properties

The lubrication properties of HFAE fluids are generally poor. The oil present in the fluid provides basic protection for lubricated contacts, but specially designed hydraulic components are usually required for use with these fluids. The lives of rolling element bearings within components tend to be short.

6.2.1.4 Corrosion protection

In order to ensure adequate corrosion protection, it is important that at all times the recommended proportion of the concentrate in the finished fluid be maintained.

6.2.1.5 Compatibility

a) With seals, gaskets, hoses etc.

   Acrylonitrile-butadiene rubber with high nitrile content (NBR) and fluorinated (FKM) rubbers are the preferred elastomeric sealing materials for HFAE fluids. Other elastomers can be compatible, but their compatibility shall be confirmed by the fluid and seal suppliers. Some polyurethane seals (AU and EU) can be damaged by hydrolysis. Absorbent materials such as leather, paper, and cork should be avoided.

   NOTE See ISO 1629 for rubber nomenclature.

b) With paints and coatings

   HFAE fluids are generally not compatible with conventional paints. Reservoir interiors should either be left unpainted or covered with two-component epoxy coatings. Where corrosion in the non-wetted areas of a reservoir is likely to be a problem, stainless steel can be considered for the reservoir and its cover.

c) With metals

   The majority of metals used in the construction of hydraulic systems designed for use with mineral hydraulic oils are also compatible with HFAE fluids. However cadmium, lead, and magnesium alloys should not be used. Aluminium may be suitable if anodized and zinc-plated components are compatible with some fluids, provided the surfaces are passivated. Where uncertainty exists, the fluid supplier shall be consulted.

6.2.1.6 Working temperature

The reservoir temperature of an HFAE system should not normally exceed 50 °C to avoid excessive loss of water. Lower working temperatures are preferred. The minimum working temperature is 5 °C to obviate the risk of freezing.

6.2.1.7 Fluid maintenance

Dilution of an HFAE concentrate should normally be with potable mains water unless the chemical hardness is particularly high, in which case softened or demineralized water should be used. Ideally, the properties of the finished product should be assessed by the supplier, with the water to be used by the customer for dilution, to ensure that the mixed fluid meets all the technical requirements.

As loss of water from the system is likely to occur over time, the fluid shall be regularly monitored to ensure that the concentration remains within acceptable limits. This is normally assessed by measuring the refractive index of the fluid. It is preferable that water lost through evaporation is replaced using demineralized water to avoid an increase in the concentration of salts in the fluid.

After extended use, cream, free oil, and residues formed from interactions between the hardness salts in the dilution water and the additives in the concentrate, can separate from HFAE fluids. Where significant phase separation occurs and free water can be observed, the cause should be investigated and rectified without delay.

The pH of the fluid shall be regularly monitored and maintained within the fluid supplier's recommended limits.

The fluid should also be monitored regularly for the presence of microbiological contamination (e.g. bacteria, yeasts, and moulds). If left unchecked, high populations of microbes can shorten the service life of the fluid (e.g. by fluid destabilization and additive depletion), cause offensive odours, and present a health hazard to persons who come into contact with it.

6.2.1.8 Filtration

Most filtration media can be used with HFAE fluids, although cellulose and cloth-based materials should be checked for compatibility. Filter rating depends on the application and system requirements. Prior contact with the filter suppliers is advisable if the use of fine filtration is considered, as this may destabilize the fluid.

6.2.1.9 Disposal

The high water content of these fluids often means that disposal is relatively easy. However, it is necessary first to split (“break”) the emulsion into its two main components. A combination of elevated temperatures, pH adjustment, and the addition of proprietary “emulsion breaking” chemicals are the most common techniques to achieve this. Ultrafiltration may also be used to split emulsions into oil-rich and water-rich components. Suppliers of the fluid and of the equipment and chemicals should be consulted for details.

The concentrated oil components can then be incinerated if it is not possible to reuse them. The aqueous phase can normally be discharged to the sewer, diluting if necessary to meet local regulations. Alternatively, the aqueous fluid can be filtered further by nanofiltration or reverse osmosis, to give a fluid either meeting discharge requirements or of sufficiently high quality for re-use.

For most users of small quantities of HFAE fluids, the most economic and straightforward disposal of waste fluid is via registered waste contractors licensed to handle these materials.

6.2.2 HFAS — Chemical solutions in water (thickened and unthickened)

6.2.2.1 General

HFAS fluids are extremely fire-resistant due to their very high water content and are available as thickened and unthickened fluids (see 6.2.2.2). The unthickened type is usually supplied as a concentrate which is mixed with water by the user, commonly in the ratio of 2 % to 5 % volume fraction of concentrate with a volume fraction of 98 % to 95 % of water. The optimum concentration shall be decided after tests with the fluid and the diluting water, and discussion with the fluid supplier. When prepared manually, it is usual to add the concentrate gradually, with continued stirring, to the required volume of water. For large volumes, automatic mixers are available. The concentrate typically consists of a combination of water-soluble corrosion inhibitors, pH buffers, and anti-wear additives; anti-foam agents, bactericides, and fungicides may also be incorporated. For the thickened fluids in this category, the additive package and thickener are up to 25 % of the total volume; these fluids are normally supplied ready mixed, rather than as concentrates.

The mixed fluid is usually alkaline, with a pH typically in the region of 9,0 to 9,5.

6.2.2.2 Viscosity

Due to the very high content of water in unthickened fluids, their viscosities are close to that of pure water (approximately 0,8 mm^2/s at 40 °C). Accordingly, hydraulic components designed specifically for use with low viscosity fluids are normally used in hydraulic systems filled with unthickened HFAS fluids. Thickened HFAS fluids have viscosities comparable to mineral oil (e.g. ISO VG 32 and ISO VG 46), allowing more conventional hydraulic components to be used; however, the components are still required to operate reliably with the reduced lubricating properties of these fluids.

6.2.2.3 Lubrication properties

Although the lubrication properties of HFAS fluids are generally poor, additives can be incorporated to raise the lubrication performance to a level beyond that typically achieved by HFAE fluids. Specially designed hydraulic components are usually required for use with these fluids. The lives of rolling element bearings within components tend to be short.

6.2.2.4 Corrosion protection

In order to ensure adequate corrosion protection, it is important that at all times the recommended proportion of the concentrate in the finished fluid be maintained.

6.2.2.5 Compatibility

a) With seals, gaskets, hoses etc.

Acrylonitrile-butadiene rubber with high nitrile content (NBR) and fluorinated (FKM) rubbers are the preferred elastomeric sealing materials for HFAS fluids. Due to the absence of oil from the formulation, other elastomers such as ethylene propylene diene terpolymer (EPDM) and silicone rubber may be suitable, but their compatibility shall be confirmed by the fluid and seal suppliers. Some polyurethane seals (AU and EU) can be damaged by hydrolysis. Absorbent materials such as leather, paper, and cork should be avoided.

NOTE See ISO 1629 for rubber nomenclature.

b) With paints and coatings

HFAS fluids are generally not compatible with conventional paints. Reservoir interiors should either be left unpainted or covered with two-component epoxy coatings. Where corrosion in the non-wetted areas of a reservoir is likely to be a problem, stainless steel can be considered for the reservoir and its cover.

c) With metals

The majority of metals used in the construction of hydraulic systems designed for use with mineral hydraulic oils are also compatible with HFAS fluids. However, cadmium, lead, and magnesium alloys should not be used. Aluminium can be suitable if anodized and zinc-plated components are compatible with some fluids provided the surfaces are passivated. Where uncertainty exists, the fluid supplier shall be consulted.

6.2.2.6 Working temperature

The reservoir temperature of an HFAS system should not normally exceed 50 °C to avoid excessive loss of water. Lower working temperatures are preferred. The minimum working temperature is 5 °C to obviate the risk of freezing.

6.2.2.7 Fluid maintenance

Dilution of an HFAS concentrate should normally be with potable mains water unless the chemical hardness is particularly high, in which case softened or demineralized water should be used. Ideally, the properties of the finished product should be assessed by the supplier, with the water to be used by the customer for dilution, to ensure that the mixed fluid meets all the technical requirements.

As loss of water from the system is likely to occur over time, the fluid shall be regularly monitored to ensure that the concentration remains within acceptable limits. This is normally assessed by measuring the refractive index of the fluid, although for some fluids, more accurate estimations of the dilution can be made using chemical titration of specific additives, following the fluid supplier's recommended procedure. It is preferable that water lost through evaporation is replaced using demineralized water to avoid an increase in the concentration of salts in the fluid.

After extended use, cream, free oil, and residues formed from interactions between the hardness salts in the dilution water and the additives in the concentrate can separate from HFAS fluids. Where significant phase separation occurs, and free water can be observed, the cause should be investigated without delay.

The pH of the fluid shall be regularly monitored and maintained within the fluid supplier's recommended limits.

The fluid should also be monitored regularly for the presence of microbiological contamination (e.g. bacteria, yeasts, and moulds). If left unchecked, high populations of microbes can shorten the service life of the fluid (e.g. by fluid destabilization and additive depletion), cause offensive odours, and present a health hazard to persons who come into contact with it.

6.2.2.8 Filtration

Most filtration media can be used with HFAS fluids, although cellulose and cloth-based materials should be checked for compatibility. Filter rating depends upon the application and system requirements. Although HFAS fluids are chemical solutions, advice should be sought from the fluid supplier or filter manufacturer if very fine filtration is to be used.

6.2.2.9 Disposal

The most straightforward and economic method for disposal of relatively small quantities of HFAS fluid is to employ a registered waste contractor who is licensed to handle material of this type.

As these fluids are chemical solutions, it can prove difficult to separate the additive components and produce an effluent stream sufficiently free from residual contamination for direct disposal to the foul water drainage system. Many of the fluids are inherently biodegradable, but biocides in the formulation may require that they are diluted with water before they can be disposed of via conventional microbial waste water treatment plants.

6.2.3 HFB — Water-in-oil emulsions (invert emulsions)

6.2.3.1 General

Water-in-oil emulsions are dispersions of water droplets in a continuous phase of mineral oil, with appropriate emulsifiers, stabilizers, and inhibitors. The fire resistance is conferred by the presence of water in the formulation but HFB fluids are not as fire-resistant as HFA fluids due to their high content of mineral oil. These fluids are supplied ready for use, need no dilution, and normally contain a volume fraction of approximately 40 % of water. Changes in water content can reduce emulsion stability and fire resistance.

6.2.3.2 Viscosity

Fluids in category HFB can be supplied to meet a range of viscosity grades as defined in ISO 3448. The most commonly available viscosity grades are ISO VG 68 and ISO VG 100. These fluids display non-Newtonian behaviour, i.e. the measured viscosity varies with the rate of shear. This has an effect on lubrication and it is usual to select a fluid with a higher viscosity than would be chosen for the equivalent application operating with mineral oil.

6.2.3.3 Lubrication properties

The lubrication properties of HFB fluids are generally superior to those of HFA fluids due to the high proportion of mineral oil in their formulations, allowing standard hydraulic components to be used in many installations. However, the presence of an appreciable amount of water in the formulations of HFB fluids often means that reduced pressures and speeds are necessary to maximize component life. Component and fluid suppliers' recommendations shall be sought where there is concern about a proposed application.

6.2.3.4 Corrosion protection

HFB fluids are formulated with appropriate corrosion-preventative additives to provide satisfactory protection for both ferrous and non-ferrous metals commonly employed in the construction of hydraulic systems.

6.2.3.5 Compatibility

a) With seals, gaskets, hoses etc.

   Acrylonitrile-butadiene rubber with high nitrile content (NBR) and fluorinated (FKM) rubbers are the preferred elastomeric sealing materials for HFB fluids. Other elastomers can be compatible, but their compatibility shall be confirmed by the fluid and seal suppliers. Some polyurethane seals (AU and EU) can be damaged by hydrolysis. Absorbent materials such as leather, paper, and cork should be avoided.

   NOTE See ISO 1629 for rubber nomenclature.

b) With paints and coatings

   Most coatings and paints which are compatible with mineral oil are also appropriate for HFB fluids.

c) With metals

   The compatibility of HFB fluids with metals is similar to that of mineral oil. However, cadmium should not be used.

6.2.3.6 Working temperature

The reservoir temperature of a system operating with an HFB fluid should not normally exceed 50 °C to avoid excessive loss of water. The minimum working temperature is 5 °C to avoid the risk of freezing, except where the fluid contains a glycol as part of the formulation and the fluid supplier expects low temperature operation. Although some suppliers claim that these fluids can withstand freeze-thaw cycles, storage above 5 °C is recommended.

Where tank heaters are necessary to maintain a minimum temperature, the energy density at the surface of the heating elements should be no more than 3 W/cm^2 to avoid the risk of splitting the emulsion by localized overheating.

6.2.3.7 Fluid maintenance

As loss of water from the system is likely to occur over time, regular monitoring of the fluid is necessary to ensure that the concentration of water remains within acceptable limits. The water content can be assessed by splitting the emulsion and measuring the amount of water directly. Alternatively, distillation according to

ISO 3733 can be used, although the recorded water content can be greater than the actual water content if the fluid formulation contains water-soluble components such as monoethylene glycol. Viscosity measurements can also be used to estimate water content, although the non-Newtonian properties of HFB fluids means that measurements should be made using a specific technique at a specific temperature. The supplier's recommendation shall be sought if the water content is to be estimated using viscosity measurements.

Where loss of water has occurred, the fluid supplier shall be consulted on the remedial measures that can be taken. Where it is acceptable to replace lost water, demineralized or distilled water should be used, to maintain stability of the fluid. Water should be added at a slow rate into the reservoir of the system, while it is operating, to ensure that layers of water-rich emulsion do not collect at the bottom of the reservoir. The turbulence and mechanical shearing to which the circulating fluid is exposed in the system may be insufficient to break down added water into the very fine droplet size essential for emulsion stability. If water is added, the conditions for addition shall be determined in accordance with the fluid supplier's recommendations to ensure a satisfactory dispersion.

HFB fluids are likely to display some degree of phase separation in service depending upon the application, the duty cycle, and the ingress of contamination. Where the volumes of free oil and water exceed the fluid supplier's recommendations, operation of the system should cease immediately in view of the increased fire hazard and the risk of damage to hydraulic components. Its cause should then be determined and rectified.

6.2.3.8 Filtration

Most filtration media suitable for mineral oils can also be used with HFB fluids, although cellulose and cloth-based materials should be checked for compatibility. The filter rating depends upon the application and system requirements. As some fluids may be destabilized by very fine filtration, where this is to be used the fluid and filter suppliers shall be consulted.

6.2.3.9 Disposal

Although the service life of HFB fluids can vary widely depending upon the application, they are durable when properly maintained. Disposal, when necessary, would normally be via incineration. Alternatively, the emulsion can be split using appropriate chemicals and the oil fraction recovered. The aqueous fraction may be discharged to waste provided local regulations are met.

The most straightforward and economic method for disposal of HFB fluid is to employ a registered waste contractor.

6.2.4 HFC — Water polymer solutions

6.2.4.1 General

Water polymer solutions, commonly known as “water glycol fluids” are solutions of glycols and polymeric glycols in water. These fluids are true solutions and derive their fire resistance from the proportion of water, present at a volume fraction of typically 35 % to 45 % in the formulation. Loss of water by evaporation results in a fluid with a much reduced fire-resistance.

NOTE 1 Fluids formulated as mixtures of water and glycols but having viscosities less than 15 cSt (15 mm^2/s) at 40 °C would be included in category HFAS.

NOTE 2 Since 2004, a new type of water-glycol solution is available. It contains typically 20 % volume fraction water and is claimed to have improved lubrication properties with some reduction in fire-resistance.

6.2.4.2 Viscosity

Fluids in category HFC have very good viscosity-temperature characteristics and can be used at temperatures down to –20 °C. They can also be supplied in viscosity grades ISO VG 15 to ISO VG 100, as defined in ISO 3448.

6.2.4.3 Lubrication properties

The lubrication properties of the combination of water and glycols which form the basis of HFC fluids are generally enhanced with appropriate additives; as a consequence, satisfactory wear protection can be achieved. However, the relatively poor performance with rolling element bearings means that reduced pump pressures and speeds may be necessary to maximize component life.

Designs using plain bearings are available. Component and fluid suppliers' recommendations shall be sought where there is concern about a proposed application.

6.2.4.4 Corrosion protection

HFC fluids are formulated with appropriate corrosion preventative additives to provide satisfactory protection for both ferrous and non-ferrous metals commonly employed in the construction of hydraulic systems.

6.2.4.5 Compatibility

a) With seals, gaskets, hoses, etc.

   Acrylonitrile-butadiene rubber with high nitrile content (NBR) is the preferred elastomeric sealing material for HFC fluids. Other elastomers such as isobutene-isoprene (IIR) rubbers, and ethylene propylene diene terpolymer (EPDM) can be compatible, due to the complete absence of mineral oil from the formulation, but the compatibility of alternative materials, including fluorinated rubbers (FKM) and polyurethane elastomers, shall be confirmed by the fluid and seal suppliers. Absorbent materials such as leather, paper, and cork should be avoided.

   NOTE See ISO 1629 for rubber nomenclature.

b) With paints and coatings

   The majority of conventional paints and coatings used with mineral oils are not compatible with HFC fluids. Where it is necessary to protect surfaces continually wetted by the fluid, two-component epoxy paints are preferred or stainless steel shall be used.

c) With metals

   HFC fluids are compatible with most metals used in the construction of hydraulic systems designed for mineral oil. However, cadmium, zinc, and magnesium alloys should not be used. Aluminium components should be anodized.

6.2.4.6 Working temperature

The working temperature of an HFC system should not generally exceed 50 °C if excessive loss of water is to be avoided. The presence of glycol in the formulation means that operating temperatures significantly below zero are possible provided the viscosity requirements of the system are met.

6.2.4.7 Fluid maintenance

As loss of water from the system is likely to occur over time, regular monitoring of the fluid is necessary to ensure that the concentration of water remains within acceptable limits. Most HFC fluid suppliers provide details of how the concentration of water may be inferred from a measurement of viscosity. Other techniques include measurement by Karl Fischer titration in accordance with ISO 760, and by measuring the volume of released water directly after splitting the fluid with a suitable solvent. The fluid supplier's recommendations for the optimum measurement technique shall be sought.

Where loss of water has occurred, the fluid supplier shall be consulted on the remedial measures that can be taken, if any. Where it is acceptable to replace lost water, demineralized or distilled water should be used to maintain stability of the fluid. Water should be added at a slow rate into the reservoir of the system, while it is operating, to ensure rapid dispersion and to prevent the formation of layers of water-rich solution at the bottom of the reservoir.

The pH of the fluid shall be regularly monitored and maintained within the fluid supplier's recommended limits.

6.2.4.8 Filtration

Most filtration media suitable for mineral oils can also be used with HFC fluids, although cellulose and cloth-based materials should be checked for compatibility. It may be advisable to check with the manufacturer that the adhesives used in the filter cartridges are compatible with these fluids. Filter rating depends upon the application and system requirements.

6.2.4.9 Disposal

Although the service life of HFC fluids can vary widely depending upon the application, they are durable when properly maintained. Disposal, when necessary, would normally be via incineration. Alternative disposal methods shall meet local regulations. HFC fluids shall not be released into water courses.

The most straightforward and economic method for disposal of HFC fluid is to employ a registered waste contractor.

6.2.5 HFDR — Synthetic fluids containing no water and consisting of phosphate esters

6.2.5.1 General

Phosphate esters derive their high fire resistance from their chemical structure. Fluid density at ambient temperature is greater than 900 kg/m^3 for the alkyl derivatives and greater than 1 100 kg/m^3 for the aryl or phenolic-based products.

6.2.5.2 Viscosity

Fluids in category HFDR can be supplied to meet a range of viscosity grades as defined in ISO 3448. Viscosity grades ISO VG 22 to ISO VG 100 are the most commonly available for general industrial applications. Compared with mineral oils, the viscosity-temperature characteristics of phosphate esters are generally poorer and, where cold-start situations are common, it may be advisable to fit heaters into the reservoir. Where such tank heaters are used, the energy density at the surface of the heating elements should not exceed 0,7 W/cm^2 to avoid the risk of damage to the fluid. If the elements are installed in a pumped circuit, where the fluid velocities are much higher, this can be increased to 2 W/cm^2.

6.2.5.3 Lubrication properties

The lubrication properties of HFDR fluids are generally excellent (related phosphorus additive technologies are used as anti-wear agents in other lubricant types). Standard hydraulic components designed for use with mineral oil applications are nearly always suitable for use with phosphate esters provided the appropriate elastomeric seals are fitted. The increased density relative to mineral oils may require slight changes to hydrodynamic bearing design and to the pump inlet arrangement.

6.2.5.4 Corrosion protection

HFDR fluids do not normally contain corrosion preventative additives, as product impurities and the products of hydrolysis can provide some ferrous metal protection.

6.2.5.5 Compatibility

a) With seals, gaskets, hoses, etc.

Fluorinated rubber (FKM) is the preferred elastomeric sealing material for industrial HFDR fluids, but is not suitable for fluids intended for aerospace applications where aliphatic phosphate esters are used. Ethylene propylene diene terpolymer (EPDM) and butyl (IIR) rubbers are also suitable. Absorbent materials such as leather, paper, and cork should be avoided.

NOTE See ISO 1629 for rubber nomenclature.

b) With paints and coatings

The majority of conventional paints and coatings are not compatible with HFDR fluids and normally it is recommended that interior surfaces be left unpainted. Where it is necessary to protect surfaces that are not continually wetted by the fluid, two-component epoxy or vinyl ester paint systems are preferred. Alternatively, stainless steel can be used.

c) With metals

HFDR fluids are compatible with most metals used in the construction of hydraulic systems. Aluminium components should preferably be anodized and the compatibility of copper alloys should be confirmed with the supplier, especially if the application is at elevated temperatures. Aluminium alloy surfaces in rubbing contact should be avoided.

6.2.5.6 Working temperature

The reservoir temperature of a system operating with an HFDR fluid should not normally exceed 70 °C. Lower working temperatures prolong the service life of the fluid. In certain applications, temperatures up to 150 °C can be permitted, but at such temperatures the fluid is subject to a more rapid deterioration and shall be frequently checked. At high temperatures, appropriate seals shall be selected, and advice should be sought from the manufacturer.

6.2.5.7 Fluid maintenance

Phosphate esters are susceptible to hydrolysis and the water content of the fluid should therefore be kept as low as practicable. It is often appropriate to use active water removal techniques such as vacuum dehydration. Degradation of the fluid by hydrolysis and by oxidation leads to the formation of acids; accordingly, the fluid should be routinely monitored for water content (ISO 760 or ISO 12937) and acid number (ISO 6618 or ISO 6619). In some applications the fluid is treated in use with acid sorbent materials to maintain a low acidity. The fluid suppliers should be contacted for more details.

NOTE 1 ISO 12937 is appropriate to users of coulometric titrators but should only be used for aryl phosphates. However, the technique of adding anionic surfactants to phosphate ester samples which are cloudy with water has not been proven and it is possible that it is not suitable.

NOTE 2 ISO 6618 is not suitable for used HFDR fluids which are dark in colour or dyed; ISO 6619 is appropriate for all types of HFDR fluids.

6.2.5.8 Filtration

Most filtration media suitable for mineral oils can be used with HFDR fluids. It may be advisable to check with the manufacturer that the adhesives used in the filter cartridges are compatible with phosphate esters. Filter rating depends upon the application and system requirements; HFDR fluids should be filterable down to the finest ratings normally found in hydraulic applications.

6.2.5.9 Disposal

The life of an HFDR fluid depends upon the application and the maintenance strategy in place. Specialist contractors and some fluid suppliers offer laundering services to restore degraded and contaminated fluid to a condition suitable for further use. For fluid which cannot be recycled, a registered waste contractor should be employed to manage its safe disposal, probably via incineration.

6.2.6 HFDU — Synthetic fluids containing no water and of other composition

6.2.6.1 General

These are fluids of various compositions with differing levels of fire resistance. Although they are fully synthetic in that they are produced by chemical reaction, some of the raw materials may be natural products. The most commonly available types of fluid in this category are polyalkyleneglycols (also called polyol ethers) and polyol esters.

6.2.6.2 Viscosity

Fluids in category HFDU can be supplied to meet a range of viscosity grades as defined in ISO 3448. Most HFDU fluids have higher viscosity indices than mineral oil, i.e. their viscosity change with temperature is smaller.

6.2.6.3 Lubrication properties

The lubrication properties of most HFDU fluids are excellent, so components designed for mineral oil applications are generally suitable without modification.

6.2.6.4 Corrosion protection

HFDU fluids are formulated with appropriate corrosion preventative additives to provide satisfactory protection for both ferrous and non-ferrous metals commonly employed in the construction of hydraulic systems.

6.2.6.5 Compatibility

a) With seals, gaskets, hoses, etc.

   Fluorinated rubber (FKM) is compatible with both the common types of HFDU fluids. The compatibility of elastomers based upon acrylonitrile-butadiene (NBR) rubber, polyurethanes (AU and EU) or butyl (IIR) rubber shall be confirmed by the fluid and seal suppliers. Absorbent materials such as leather, paper, and cork should be avoided.

   NOTE See ISO 1629 for rubber nomenclature.

b) With paints and coatings

   Compatibility with paints and coatings varies with the chemistry of the HFDU fluid. Most are compatible with two-component epoxy paints, but where any doubt exists, the fluid supplier's recommendations shall be sought.

c) With metals

   HFDU fluids are generally compatible with most metals used in the construction of hydraulic systems. In case of doubt, the fluid suppliers' recommendations shall be sought.

6.2.6.6 Working temperature

The temperature of the bulk of the fluid in the reservoir of a system operating with an HFDU fluid should not generally exceed 70 °C. Lower working temperatures prolong the service life of the fluid. Higher operating temperatures can lead to an unacceptably high rate of degradation and, consequently, reduced fluid life. Fluids with high viscosity indices generally operate more reliably at lower temperatures than the equivalent mineral oil ISO viscosity grade.

6.2.6.7 Fluid maintenance

Some HFDU fluids are susceptible to hydrolysis and the water content of the fluid should therefore be kept as low as practicable. For such fluids it may be appropriate to use active water removal techniques, e.g. vacuum dehydration. As with all fluid types, a programme for the regular monitoring of fluid properties ensures the longest possible life and the shortest periods of system downtime.

6.2.6.8 Filtration

Most filtration media suitable for mineral oils can be used with HFDU fluids. It may be advisable to check with the manufacturer that the adhesives used in filter cartridge construction are compatible with the fluid selected. Filter rating depends upon the application and system requirements.

6.2.6.9 Disposal

The service life of an HFDU fluid depends upon the application and the maintenance strategy in place. For fluid which cannot be recycled, a registered waste contractor should be employed to manage its safe disposal, usually by incineration.

7 Installation of hydraulic circuits

7.1 Reservoir

A reservoir of sufficiently large dimensions to allow good air release, fitted with a suitable filter/breather shall be provided. A tight-fitting and well-sealed cover limits water evaporation from fluids of categories HFAE, HFAS, HFB and HFC and also serves to minimize the ingress of contamination. The fluid return pipe shall be located below the minimum permissible fluid level to avoid foaming.

To assist fluid deaeration, the fluid suction line shall be located as far as possible from the return pipe.

7.2 Pipework and hoses

In the design and specification of pipes and hoses, account shall be taken of the higher density of most fire-resistant fluids, and also of the increased viscosity of HFDR fluids at low temperatures.

Consideration shall be given at the design stage to fluid pressure losses in long lengths of pipework, especially where this may affect the selection of a specific type of fire-resistant fluid.

7.3 Pump suction

Flow velocities through suction lines shall not exceed 1 m/s, and pump inlet pressures below atmospheric shall be avoided for fluid categories HFAE, HFAS, HFB, and HFC. Boosted pump inlet conditions are advantageous.

7.4 Strainers and filters

For fluids having either a high density or a high viscosity in the cold state, filters and strainers shall be sized in accordance with the recommendations of the filter supplier. The sizing of filters for HFAE and HFAS fluids shall not be based simply upon fluid viscosity. If calculations for these fluids are based upon viscosity and the filter supplier's recommended maximum pressure drop for clean fluid, they lead to undersized filter assemblies. These result in a relatively short cartridge life and the risk of erosion damage to the filtration media. A filter sizing based upon a 30 cSt (30 mm^2/s) fluid usually leads to an acceptably sized filter.

Fine filtration shall be fitted only in pressure and/or return lines. If it is required to fit a strainer in a pump suction line, it shall be of an appropriate size and rating, to minimize the pressure reduction at the pump inlet port, so reducing the risk of cavitation in the pump.

Adsorbent filters such as activated earth and ion exchange are not generally appropriate for fire-resistant fluids. However, fluids in category HFDR and some fluids in category HFDU may benefit from the control of acid degradation products by these media and the fluid/filter suppliers' recommendations shall be sought if these are to be installed.

7.5 Equipment performance

While the lubrication performance of some fire-resistant fluids is considered to be at least as good as, if not better than, fully formulated mineral oils, many have inferior performance in this respect. In these cases, it may be necessary to down-rate or suitably modify hydraulic circuit components in order that a satisfactory service life is achieved.

A detailed discussion, in conjunction with the manufacturers of the equipment and suppliers of the fluid, is recommended during the design of new hydraulic equipment intended to operate with fire-resistant fluids having reduced lubricity and/or a very low viscosity.

8 Changing the fluid in a hydraulic system

8.1 General

The basic procedure for changing the fluid in a hydraulic system is very similar regardless of the type of fluid previously used in the system and the category of fluid with which it is to be replaced.

Firstly, the hydraulic circuit shall be drained as completely as possible. If necessary, seals, gaskets, etc. shall be changed to materials compatible with the replacement fluid. Filters shall be changed if the existing cartridges are not compatible with the replacement fluid. It may be necessary to dismantle parts of the system in order to remove fluid trapped in pipework.

It may also be necessary to change the sizes of hoses and pipes, particularly on pump suction lines where sub-ambient pressure should be avoided. If the change is from a fluid with good lubrication performance and conventional viscosity to one with poor lubrication performance and/or very low viscosity, the replacement of many of the components (pumps, valves, etc.) with equivalent units designed for use with the replacement fluid may be required.

The system should be filled with a minimum quantity of the replacement fluid, or a special flushing fluid (see also 8.3.1) and run, at minimum pressures, to flush the system and suspend the residues of the original fluid. Where possible, turbulent flow should be used to remove any deposits from the internal surfaces of the pipework. The flushing charge is then immediately drained as completely as possible and the system refilled with new fluid. The system should be monitored frequently after the change to ensure that the level of contamination by the previous fluid is within acceptable limits. If the level of contamination begins to adversely affect the characteristics or performance of the new fluid, it may be necessary to consider a further drain and refill.

8.2 Draining and cleaning the circuit

8.2.1 The following sequence is not mandatory, but most of the steps are likely to be necessary at some stage in the draining of the circuit. However, before attempting this procedure, the equipment builder should be consulted in case written guidance is already available.

8.2.2 Drain the reservoir at the lowest readily available point. This may be a valve or port for draining off collected water or it may be a connection to allow regular replacement of the fluid.

8.2.3 Completely drain the system from the lowest point in the pipework. Drain the reservoir again and remove as much residual fluid as possible — a vacuum cleaner capable of handling liquids and compatible with the original fluid is ideal. If deposits remain on the walls of the reservoir, these should be removed with absorbent, lint-free, wipes. Note that manual cleaning within the confined space of a reservoir is a potentially hazardous activity and shall only be conducted by competent persons.

8.2.4 Disconnect pipes and hoses, where possible, and blow through with low pressure compressed air. The air shall have a dew point below the ambient temperature to avoid blowing water droplets into the hydraulic lines.

8.2.5 Drain accumulators, hydraulic cylinders, pumps and motors, dismantling and cleaning if necessary. Replace components which are not suitable for service with the replacement fluid.

8.2.6 Dismantle and clean all strainers and filters, replacing the filter elements, ensuring that the new cartridges are compatible with, and of the correct specification for, the replacement fluid.

8.2.7 Remove sensitive components, e.g. servo-valves, and overhaul them in a clean environment. Do not use halogenated solvents for this purpose.

8.2.8 Systematically work through the entire system, replacing all incompatible construction materials and inappropriate seals. Where the original fluid was mineral oil, the commonly used acrylonitrile-butadiene (NBR) rubber with high nitrile content is often appropriate for the replacement fluid; however, note that NBR is not suitable for HFDR fluids and that fluorinated (FKM) rubber is not generally suitable for HFC fluids. If there is any doubt of the identity of the original seals or packing, they should be replaced.

8.2.9 Reassemble the system, ensuring that all components are properly installed and that all joints are correctly made. If possible, fit flushing blocks in place of sensitive components such as servo-valves.

8.3 Flushing and draining the circuit

8.3.1 Fill the circuit with the minimum quantity of replacement fluid to safely operate the system and check for major leaks. Some manufacturers may recommend a specific flushing fluid, in which case their advice should be followed. The fluid should be filtered into the system using filling filters with removal ratings appropriate to the components and demands of the circuit and at least as fine as the system filters.

8.3.2 Operate the system with minimum load. Ideally the pressures should initially be reduced, adjusting relief valves if appropriate. All system functions should be operated so that all the pipework and lines are flushed. If possible, reduce the settings on relief valves so that the discharge lines from these valves are flushed. The fluid velocities in pipework should be increased, where possible, to achieve turbulent flow conditions which facilitate the removal of deposits on the internal surfaces of pipes and fittings.

Once most of the residue from the original fluid charge has been dispersed into the flushing charge, the system should be brought up to design pressure and operated normally. It may be necessary to stop and restart the system several times to flush components such as accumulators. The system should be run continuously for a period of time, 4 h being generally sufficient for a very simple circuit. Up to 24 h may be necessary for more complex circuits. Where flushing blocks have been used, refit the components after an appropriate period of flushing. Consult the system manufacturers as necessary.

Monitor the system filters and fit replacement cartridges immediately if any become blocked to avoid filter bypass and loss of protection from damage due to re-circulating particulate contaminants.

